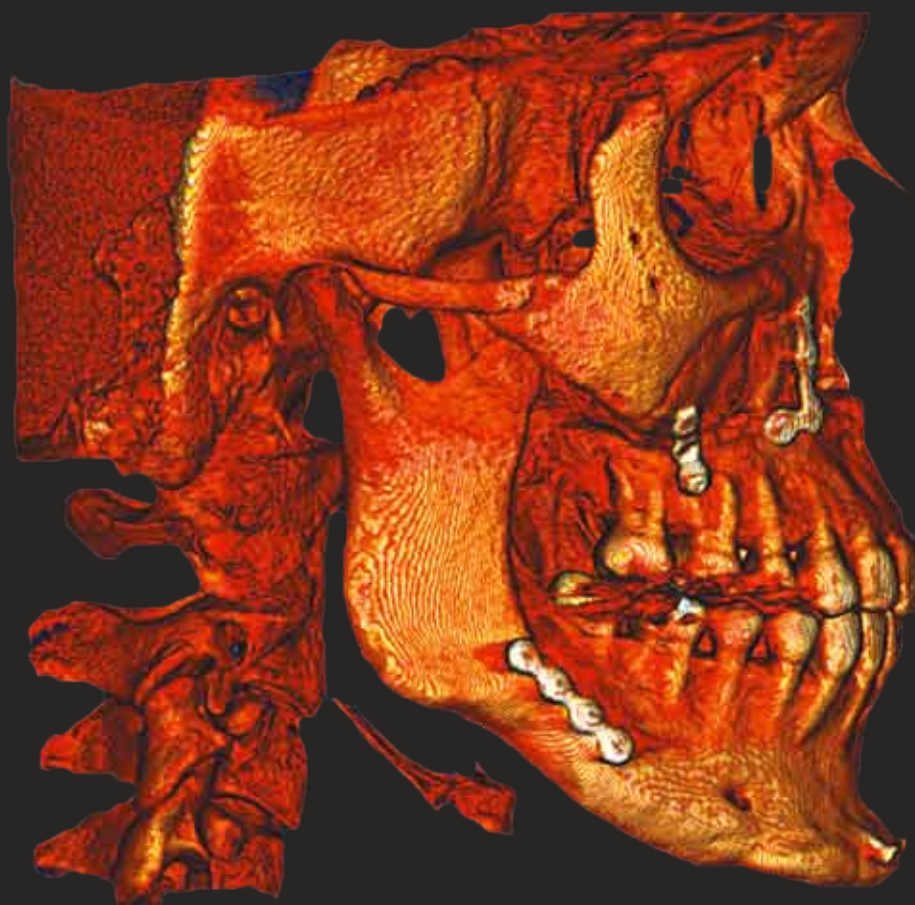


Dental Press Journal of  
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Volume 15, Number 5, September / October 2010



Special Issue

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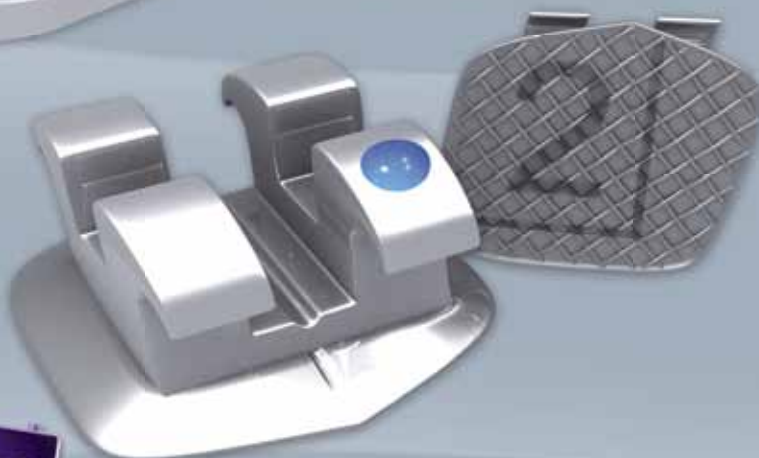


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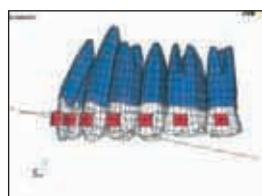
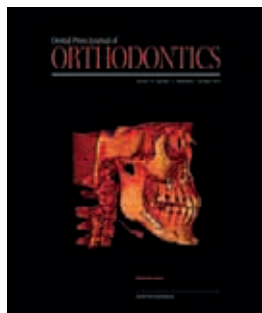
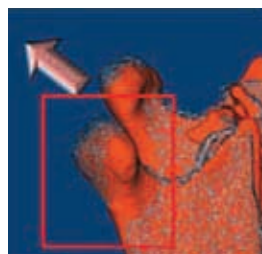
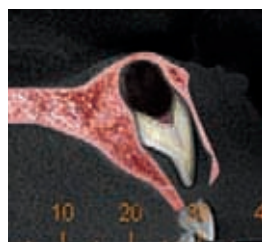


TABLE 1 - Protocols for image acquisition for the i-CAT device.

| Protocol | Scanning time (s) | Voxel size (mm) | Peak voltage (kVp) | mAs   |
|----------|-------------------|-----------------|--------------------|-------|
| 1        | 40                | 0.2             | 120                | 46.72 |
| 2        | 40                | 0.25            | 120                | 46.72 |
| 3        | 20                | 0.3             | 120                | 23.87 |
| 4        | 20                | 0.4             | 120                | 23.87 |



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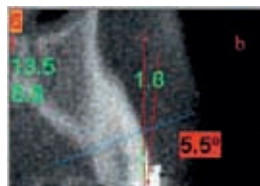
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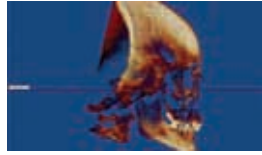
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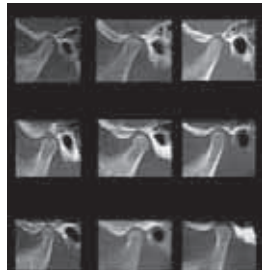
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## The evolution of imaging diagnostics for Orthodontics

In the 1970s, the electronic technologies deployed for space exploration launched a veritable revolution in imaging diagnostics capacity—especially in the field of computer tomography. It is curious to note that before we were able to delve deeper into the human body we had to first travel into space.

This giant leap rapidly spread to encompass several areas, as equipment improved and new applications were developed. For example, contrasts are now used to show the path of blood vessels, and once scanning became fast enough, we acquired the ability to capture a still image of the heart to assess possible coronary stenoses.

A major technological advance was achieved with the development of Cone-Beam Computed Tomography, better known by the English acronym CBCT. This tomograph boasts unique features far superior to a conventional CT scanner. The apparatus is more compact and produces fewer artifacts on metal objects, while its radiation dose is about 15 times milder than that of a conventional CT scanner. These features have made it an outstanding resource in Dentistry, and help to explain its current worldwide use.

The distance traveled by imaging diagnostics technology has been remarkable, and this journey has given us a fresh insight into Orthodontics. We therefore decided to organize a special anniversary edition comprising exclusively articles related to imaging diagnostics. Dr. Telma Martins de Araujo's contribution as associate editor of the journal proved invaluable in making this issue come to fruition. She aimed at a format that would feel as closely as possible like reading a book. As a result, in one single issue, readers can enjoy a multifarious, in-depth view of the role of imaging in Orthodontics.

Enjoy your reading!

Jorge Faber  
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## *Special Editorial - Omar Gabriel*

In August, when professor Omar Gabriel da Silva Filho was hospitalized, I stopped to ponder on the contributions of this great orthodontist, whom I knew not well, although paradoxically, always felt I knew a lot. The first thing that sprung to my mind was the gorgeously compelling speech<sup>1</sup> delivered by writer José Saramago on being awarded the Nobel Prize for Literature in 1998. It was titled "How Characters Became the Masters and the Author Their Apprentice." In it he portrays with subtle poignancy how much a master can learn. A much praised, albeit seldom practiced virtue. And a hallmark of Prof. Omar's life.

I was never Prof. Omar's student, although in many respects I feel as if I have been. Allow me to explain. When I completed my orthodontic training at Rio de Janeiro Federal University (UFRJ), I had but a handful of idols. Among these was Omar, a teacher I had seen only once, and who had charmed me with his down-to-earth, didactic and investigative spirit. At the time, he was one of the few researchers who managed to pass the stringent filters of international journals.

He has always been a stickler for protocols. Today, with over 200 published works, he has established many which are used internationally. Interestingly, this was a forward-looking concern. Evidence-based practice longs to create protocols, and at a time when scientific evidence was still embryonic, his pursuits could be seen as cutting edge even today.

Omar trained many orthodontists, and all those I have talked to over the years were unanimous in their admiration of his inability to say no, and the friendly and respectful way in which he treats students, staff and patients alike. He never speaks ill of other people, and always respects their differences.

I was informed by a friend—Dr. Patricia Freitas Zambonato—about Omar's health condition just before writing these words. She told me it was serious, but stable. The doctors' uncertainty about his diagnosis and prognosis only strengthens our hopes. Some of my friend's sympathetic words about her teacher sounded particularly touching: "Omar is an Angel, who is only capable of doing good," she said.

We are praying for angels to hold his hands.

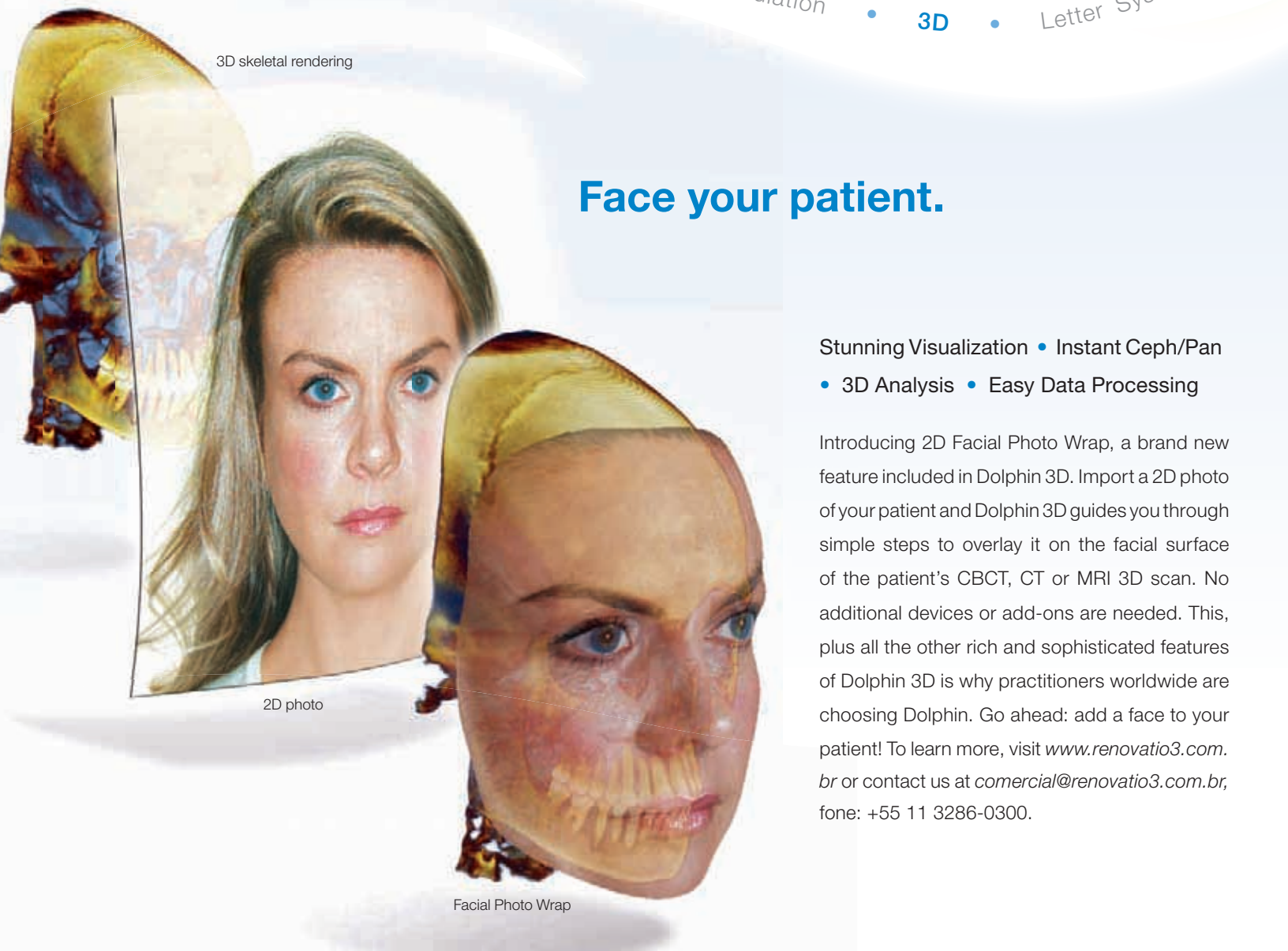
Jorge Faber

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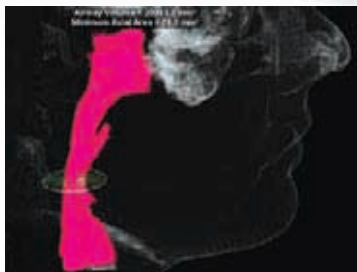
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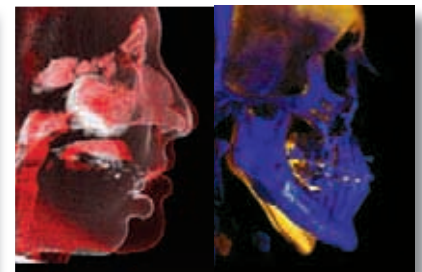
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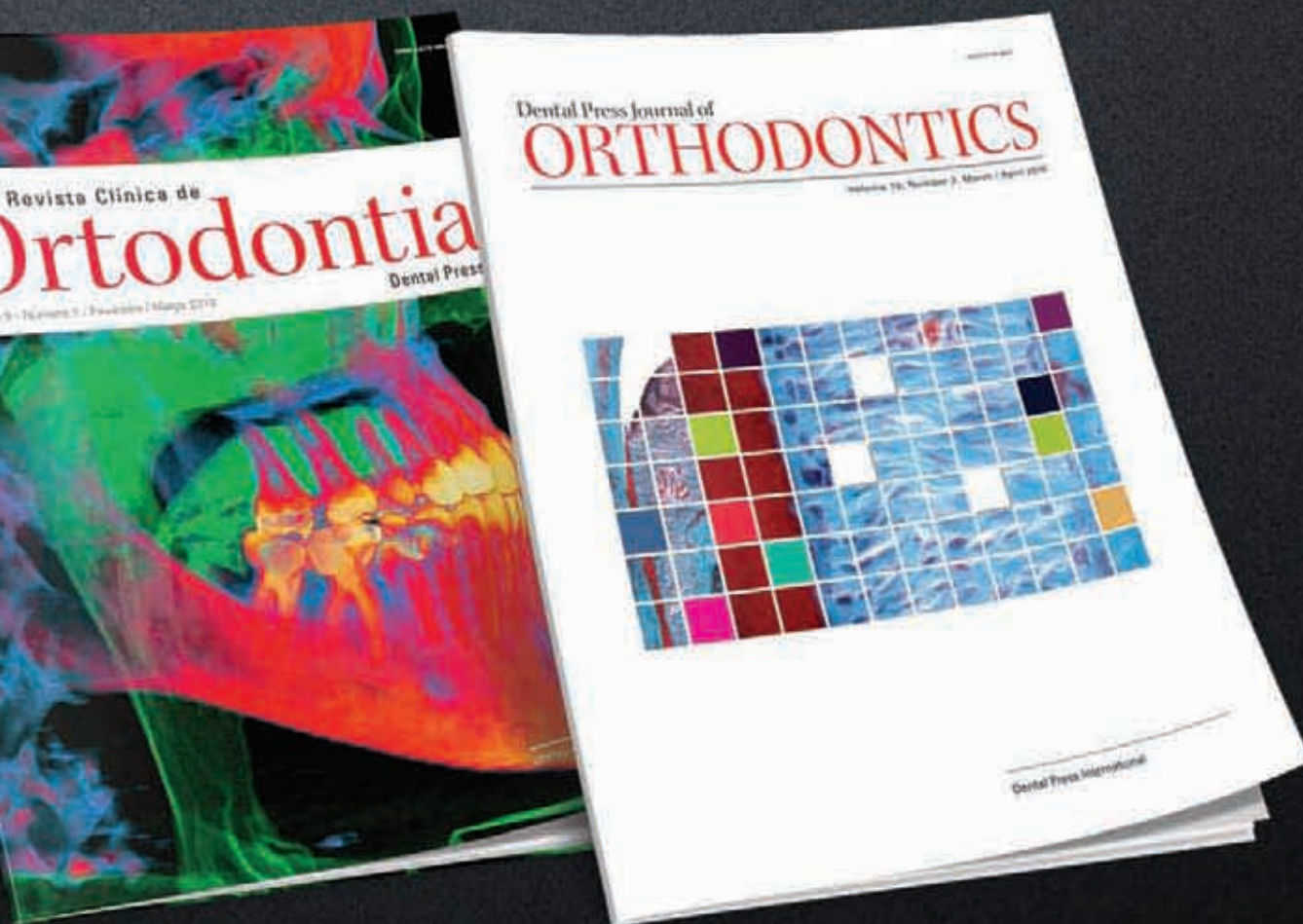
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**Pré-curso - 24º COB (Congresso Odontológico de Bauru)**

Date: November 20, 2010

Location: Teatro Universitário da FOB/USP - Bauru / SP, Brazil

Information: [cob2011@fob.usp.br](mailto:cob2011@fob.usp.br)



**Congresso Internacional de Odontologia do Centenário da APCD**

Date: January 29 - February 1<sup>st</sup>, 2011

Location: Expo Center Norte - São Paulo / SP, Brazil

Information: [www.apcd.org.br/centenario](http://www.apcd.org.br/centenario)  
[secretaria.decofe@apcdcentral.com.br](mailto:secretaria.decofe@apcdcentral.com.br)



**Ortodontia a Bordo**

**1º Meeting Internacional de Ortodontia com Braquetes Autoligados**

Date: March 13-16, 2011

Location: Costa Serena cruise ship (route Búzios, Ilha Bela, Santos, Rio de Janeiro)

Information: (55 021) 2717-2901 / 7841-1927  
[www.ortodontiaabordo.com](http://www.ortodontiaabordo.com)



**AAO 2011 Annual meeting**

Date: May 13-17, 2011

Location: Chicago / USA

Information: [www.aaomembers.org/mtgs/2011-AAO-Annual-Session.cfm](http://www.aaomembers.org/mtgs/2011-AAO-Annual-Session.cfm)



**42º Encontro do Grupo Brasileiro de Professores de Ortodontia e Odontopediatria**

Date: June 9-11, 2011

Location: Tropical Hotel Tambaú - João Pessoa / PB, Brazil

Information: <http://grupo.odo.br/site2010>



**20º Congresso Internacional de Odontologia do Rio de Janeiro – CIORJ**

Date: July 20-23, 2011

Location: Centro de Convenções do Riocentro - Rio de Janeiro / RJ, Brazil

Information: (55 021) 2502-6237 / 2504-0002  
[departamentocongresso@aborj.org.br](mailto:departamentocongresso@aborj.org.br)

## Brazilian Board of Orthodontics and Dentofacial Orthopedics (BBO)

Quality has played an increasingly important role in all professional fields. In healthcare, this concern is directly linked to the quality and quantity of training, expertise and clinical experience in any given field. With this in mind, the Brazilian Association of Orthodontics and Dentofacial Orthopedics (ABOR) decided to create the Brazilian Board of Orthodontics (BBO). This initiative was prompted by the need to establish standards of clinical excellence for the practice of Orthodontics.

The BBO is geared toward encouraging professional self-evaluation and offering a certificate of excellence by means of specific tests to those specialists who demonstrate quality clinical work. The BBO examination consists of two phases:

### PHASE I

Diagnosis and planning of two clinical cases selected by the Board.

### PHASE II

Presentation of ten cases whose results can attest to the clinical excellence of the candidate. All cases must meet specific criteria,

available at [www.bbo.org.br](http://www.bbo.org.br). Furthermore, applicants are expected to discuss their cases in interviews with Board examiners.

The first BBO examination was held in 2004 and the seventh edition took place in March this year in Salvador, Bahia State. The following professionals were approved in Phase I:

- » Carlos Henrique Monteiro B. Carvalho (Belo Horizonte/MG)
- » Dauro Douglas Oliveira (Belo Horizonte/MG)
- » Dione Maria Viana do Vale (Recife/PE)
- » Fernando Antonio Lima Habib (Salvador/BA)
- » Gustavo Mattos Barreto (Aracajú/SE)
- » Kátia Montanha de Andrade (Salvador/BA)
- » Lucianna Gomes de Oliveira (Salvador/BA)
- » Paulo Renato Dias (Assis/SP)
- » Marcelo de Castellucci e Barbosa (Salvador/BA)
- » Marcelo Marigo (Governador Valadares/MG)
- » Rivail Brandão A. B. Filho (Salvador/BA)

The orthodontists depicted in the photo below successfully concluded Phases I and II of the last BBO examination.



Aldino Puppin Filho (ES), Gustavo Kreuzig Bastos (RJ), Mayra Reis Seixas (BA), Márcio Costa Sobral (BA), Fernanda Catharino Menezes Franco (BA), Luiz Fernando Eto (MG) and Márcio Vinicius de Oliveira (MG).

## Master's thesis

In August, Sergei Godeiro Fernandes Rabelo Caldas defended his master's thesis at Paulista State University - Araraquara School of Dentistry. His study was titled "*Evaluation of the force system and long-term stability generated by group B 'T' springs*".



Professors / Drs. Ary dos Santos-Pinto, Lídia Parsekian Martins (advisor), candidate Sergei Rabelo Caldas, Roberto Hideo Shimizu (examiner), Renato Parsekian Martins (co-advisor), Luiz Gonzaga Gandini Júnior (examiner) and Dirceu Barnabé Raveli.

## Doctoral thesis

Also in August, Professor / Dr. Jurandir Barbosa defended his doctoral thesis, titled "*Evaluation of friction produced by conventional and self-ligating brackets - a comparative study*", at St. Leopold Mandic (Campinas). The publisher of this Journal, Prof. Laurindo Furquim, was among the exam board members.



Professors / Drs. Laurindo Furquim (UEM), Carlos Elias (IME-Rio de Janeiro), Maria Cecília Giorgi (SLMandic), Jurandir A. Barbosa, Roberta T. Basting (SLMandic, advisor) and Rodrigo Cecanho (SLMandic).

## 2010 SBO OrtoPremium

The 2010 SBO OrtoPremium International Conference was held on July 7-10 featuring special guest Dr. Charles Burststone, who taught an 8-hour course on orthodontic mechanics.



Organizing committee: Flavio Cesar Carvalho, Mário Pinto, Marco Antonio Schroeder, Flavia Artese, Humberto Iglesias Diniz and Alexandre Trindade Motta.

The event gathered over 400 attendees and 14 speakers of national and international acclaim.

Dr. Maurício Sakima taught a hands-on course on orthodontic mechanics using skeletal anchorage, and the event culminated with an interactive course on the aesthetics of the smile, taught by Dr. Carlos Alexandre Câmara.



Renowned Professor Charles Burststone teaching at the 2010 SBO OrtoPremium Conference.

## 27<sup>th</sup> annual meeting of the SBPqO

Between 9 and 12 September, the town of Águas de Lindoia/SP hosted the 27<sup>th</sup> Meeting of the Brazilian Society for Dental Research (SB-PqO). The Meeting, rated the most important research event in Brazilian dentistry, brought together nearly five thousand researchers from all

over the country. Attendees took part in Interactive Symposia, Immersion Activities, Scientific Offices, Panel Presentation, Hatton Award, Scientific Forum and Presentation of Research Projects (POAC and PIO). The following immersion activities were scheduled: Training on how to write an abstract, Clinical Research Methodology, Postgraduate Meeting and Meeting of editors of scientific journals in the area of Dentistry.



Fabio de Souza, Carina S. Delfino and Rafaella Rocha.



Alexandre Borges and Maria Biazzevic.



Manoel Souza Neto, Altair Cury, Saul Martins de Paiva, Maria Fidela de Lima Navarro and Sigmar de Mello Rode.



Patrícia D. M. Angst, Carlos Moreira and Anelise Montagner.



Elque Prata de Queir and Tainá Bezerra.



Maria Gisette Provenzano and Antônio Guedes Pinto.



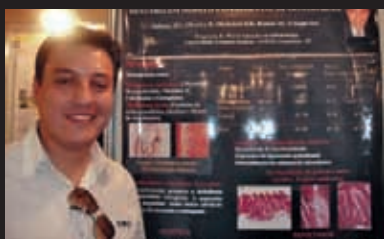
Marcela Vieira.



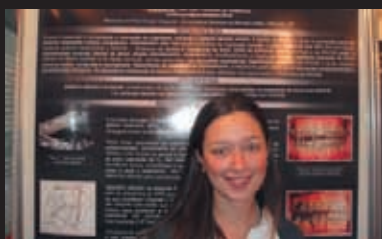
Maria Fidela de Lima Navarro flanked by her son Ricardo and her daughter Paula.



Osmar Cuoghi, Isabela Pordeus, Orlando Airton, Teresa Furquim and Ana Cristina.



Márcio Salazar.



Rachel Furquim.



Felipe Gonçalves.

# Digital impressions and handling of digital models: The future of Dentistry

Waldemar D. Polido\*

## Introduction

New digital impression methods are currently available in the market, and soon the long-awaited dream of sparing patients one of the most unpleasant experiences in dental clinics, the taking of dental impressions, will be replaced by intraoral digital scanning.

Both in orthodontics and restorative area (prosthodontics and restorative dentistry in particular), the use of plaster models is not only essential but routine practice in these clinical specialties. It has long been every dentist's desire to be able to scan plaster models, or even patients' teeth directly in the mouth. Avoiding discomfort, speeding up work, improving communication between colleagues and prosthetic labs, and reducing the physical space needed for storing these models, are some of the alleged benefits of this technology.

Since the introduction of the first digital impression scanner, product development engineers in various companies have developed dental office scanners that are increasingly user-friendly, and produce images and restorations with growing accuracy. The use of these products represents a paradigm shift in the way that dental impressions are taken.

This article addresses the technical aspects

and applications of digital impressions in dentistry, with emphasis on orthodontics.

## How digital impression systems evolved

The major goals of the impression-taking process in restorative dentistry are obtaining a copy (imprint) of one or several prepared teeth, healthy adjacent and antagonist teeth, establishing a proper interocclusal relationship and then converting this information into accurate replicas of the dentition on which indirect restorations can be performed.

In orthodontics and orthognathic surgery, the use of accurate plaster models is an essential prerequisite for establishing suitable diagnosis and treatment planning, as well as for monitoring treatment progress.

The techniques used for impression-taking with elastomers and creating plaster casts have been in widespread use since 1937.<sup>1</sup> Impregnum, a polyether material introduced by the ESPE company in 1965, was the first polyether material specifically produced for use in dentistry.

Many dentists are reluctant to embrace the new technologies because they simply believe elastomeric impression materials and techniques have been in use for so long and work so well that they are irreplaceable. Or else, that 3D digital

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scanning technologies are so recent that they are not yet ready for clinical use. Actually, impression taking using elastomers, for all its inherent problems, has been used in dentistry for 72 years!

Digital impression and scanning systems were introduced in dentistry in the mid 1980s and have evolved to such an extent that some authors predict that in five years most dentists in the U.S. and Europe will be using digital scanners for impression taking.<sup>2</sup>

In Orthodontics digital impression taking has been used successfully for several years with systems like Cadent IOC/OrthoCAD, Dentsply/GAC's OrthoPlex, Stratos/Orametrix SureSmile and EMS RapidForm.

CAD-CAM (Computer Aided Design and Computer Aided Manufacture) systems available today are capable of feeding data through accurate digital scans made from plaster models directly to manufacturing systems that can carve ceramic or resin restorations without the need for a physical copy of the prepared teeth, adjacent teeth and antagonist teeth.

With the development of new high-strength restorative materials with aesthetic properties, such as zirconia, lab techniques have been developed whereby master models obtained through impressions with elastic materials are digitally scanned to create stereolithic models (prototyping) on which restorations are performed. Even with such high-tech improvements, it is clear that these second-generation models are not as accurate as stereolithic models made directly from data obtained from 3D digital scans of the teeth using 3D scanners specially designed for this purpose.

Two types of systems are available on the market today: CAD/CAM systems and dedicated three-dimensional digital impression systems (3D). This article reviews the characteristics of dedicated 3D digital impression systems not only because this is the state-of-the-art today but because it shows great promise for the future,

notably in the areas of restorative dentistry, orthodontics and orthognathic surgery.

### Dedicated Digital Impression Systems

Dedicated digital impression systems eliminate several cumbersome dental office tasks, such as selecting trays, preparing and using materials, disinfecting impressions and sending impressions to the lab. Moreover, lab time is reduced by not having to pour up plaster, place pins and replicas, cut and shape dies or articulate models.

With these systems, final restorations are produced in models created from digitally scanned data instead of plaster models made from physical impressions. Additionally, they enhance patient comfort, improve patient acceptance and understanding of the case. Digital scans can be stored on hard disks indefinitely, while conventional models, which can break or chip, must be physically stored, which requires additional office space.

The iTero digital impression system (Cadent Inc., USA) (Fig 1) entered the market in 2007.



FIGURE 1 - iTero scanner equipment.



FIGURE 2 - iTero scanner.

It uses a parallel confocal imaging system to perform fast digital scans, capturing 100,000 points of laser light and producing perfect focus images of more than 300 focal depths of tooth structures. All of these focal depths are spaced no more than 50 micrometers (50  $\mu\text{m}$ ) apart. Parallel confocal digital scanning captures all elements and materials found in the mouth without the need to apply any materials to the teeth, and it can accurately capture supragingival and subgingival preparations (Figs 2 and 3).

Because it features direct scanning and does not require the use of scanning powder, Cadent's iOC scanner provides orthodontists and their assistants with flexibility in a host of clinical applications. It provides highly accurate orthodontic scanning with real-time viewing in adults and adolescents, in patients with various mouth openings and in full and partial arches. In addition, iOC's software architecture allows data to be exported and used in integration with other orthodontic office management software, such as OrthoCAD (Fig 4).

Another option for digital impression taking is the 3M ESPE Lava Chairside Oral Scanner (COS) system. This system is mounted on a mobile cart with a CPU, touch-screen monitor and a 13 mm thick scanning unit. A camera

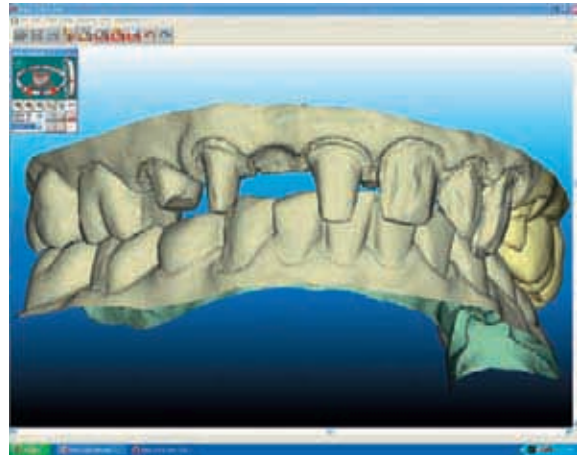


FIGURE 3 - Image showing the digital model for prosthetic dentistry.

fitted on the device comprises 192 LEDs and 22 lens systems.

The method used to capture 3D impressions involves a technology called Active Wavefront Sampling. Lava's "3D in Motion" concept features a revolutionary optical design, image processing algorithms and real-time model reconstruction, which captures 3D data in a video sequence and models data sets in real time. The scanning unit contains a complex optical system that comprises multiple lenses and blue LED cells. The Lava COS system can capture 20 3D data per second, or close to 2400 data sets per arch, for accurate, high-speed scanning.

### Benefits to Clinicians and Labs

The greatest benefit for dental lab technicians and dentists in adopting digital technology lies in eliminating many chemical processes. By virtually eliminating these processes, error accumulation in treatment and in the manufacturing cycle is no longer an issue. Some of these processes are: curing the impression material, curing the plaster and base, curing the investment material in restoration dies, and retraction or shrinkage of conventional feldspathic ceramic materials.

By eliminating conventional impression-taking procedures, clinicians no longer need to



FIGURE 4 - Image showing a digital model for Orthodontics.

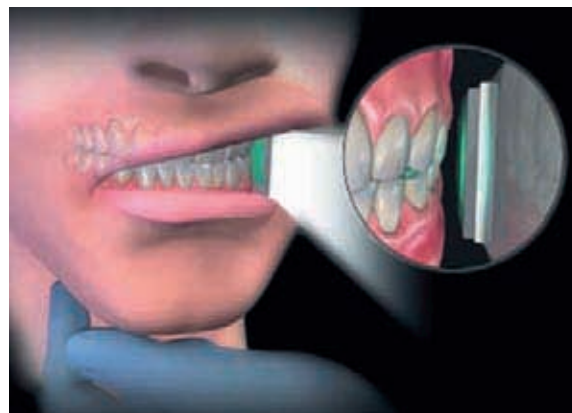


FIGURE 5 - Using the digital scanner to take a checkbite impression.

worry about the possibility of error due to air bubbles breaking the impression materials, displacement and movement of the tray, tray deflection, insufficient impression material, inadequate impression adhesive, or distortion resulting from disinfecting procedures.<sup>3</sup>

Furthermore, and particularly important in orthodontics and orthognathic surgery cases, taking checkbite impressions (centric occlusion) has historically been accomplished through the use of silicone materials or bite wax. When impressions are taken digitally, nothing is placed between maxillary and mandibular teeth. This dramatically reduces the risk of an inadequate interocclusal relationship (Fig 5).

## Discussion

As in implant dentistry and oral and maxillofacial surgery, for example, where digital images obtained by Cone-Beam CT scans are imported into a special software for 3D design and implementation of virtual surgeries, the use of digital models in orthodontics has proven an excellent technique and possibly the future method of choice to handle digital models in this dental specialty.

The integration of scanned models with digital images obtained by Cone-Beam CT, which enable the simulation of orthodontic/surgical

movements in orthognathic surgery cases, for example, substantially facilitates diagnosing and planning of these complex cases.

Rheude et al<sup>5</sup> compared the use of digital models with traditional plaster models in orthodontic diagnosis and treatment planning. They concluded that in most cases digital models can be successfully used as part of the orthodontic records. It is noteworthy that the more the examiners used digital models the more the diagnoses resembled those of conventional models. This indicates a modest learning curve before digital models can be compared to conventional models.

Leifert et al<sup>4</sup> took space measurements in conventional (plaster) models and in digital models (OrthoCad system, Cadent, USA) and concluded that the accuracy of software for space analysis in digital models is just as clinically acceptable and reproducible as in conventional plaster models.

Incorporating digital scanning in daily practice does not require any additional processes or procedures to be learned by either orthodontists or their assistants. Consultations for obtaining orthodontic records remain virtually unchanged in terms of time and goals, with the added benefit that patient satisfaction is significantly enhanced.

Cost-wise, investment may seem sizeable at first. From a commercial point of view, however, digital impressions ensure profitability in the medium term. Similarly to direct digital intraoral radiographs, the possibility of reducing the operational cost of materials and the ability to view the quality of the procedure in real time, reduces the rate of repeat visits and, consequently, chair time. And chair time represents the major cost in any office. Not to mention the priceless value of word-of-mouth marketing derived from patients' favorable comments on digital impression taking versus uncomfortable conventional impression taking with alginate or other materials.

Further added benefits are the ability to save the impressions digitally, reducing costs and freeing up space, which can be exploited in other ways, e.g., by expanding the patient care area.

## Conclusions

By addressing the everyday dental office issues described above, digital impression taking, given its undeniable benefits, will transform digital intraoral scanning into a routine procedure in most dental offices in the coming years. Furthermore, digital impressions tend to reduce repeat visits and retreatment while increasing treatment effectiveness. Patients will benefit from more comfort and a much more pleasant experience in the dentist's chair. Thanks to digital impressions, products fabricated in prosthetic labs will become more consistent and easier to install, requiring reduced chair time.

Since long before the Industrial Revolution men has handcrafted and manufactured millions of different products using analogical processes. In the last 30 years, many of these products have been converted to digital manufacturing—from auto parts to civil construction—given its consistent quality and lower cost. It is therefore no surprise that digital solutions are now being integrated into many dental procedures.

With the popularization of digital systems, and the tremendous growth in two areas of dentistry that can potentially benefit from digital impression taking and digital models (orthodontics and dental implantology) one can confidently predict that in the coming years we will witness a true digital revolution in the dental office. A revolution that will benefit patients in terms of more efficient planning, reduced discomfort and treatment efficiency.

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# Orthodontic traction: possible effects on maxillary canines and adjacent teeth

## Part 2: External cervical resorption due to canine traction

Alberto Consolaro\*

Professionals who resist and restrict the indication of orthodontic traction, especially canine traction, often justify their stance by citing the following reasons:

- 1) Lateral Root Resorption in lateral incisors and premolars.
- 2) External Cervical Resorption of canines due to canine traction.
- 3) Alveolodental ankylosis of the canine(s) involved in the process.
- 4) Calcific metamorphosis of the pulp and aseptic pulp necrosis.

These possible outcomes do not stem primarily and specifically from orthodontic traction. They can be avoided if certain technical precautions are adopted, especially "the four cardinal points for the prevention of problems during orthodontic traction."<sup>2</sup> To understand what these technical precautions are and how they work preventively against the possible consequences of orthodontic traction a biological foundation is required. Providing such biological foundation is the goal of this series of studies on orthodontic traction, focusing particularly on maxillary canines.

The increasing use of imaging tests—such as computed tomography with its various slice planes, and the resulting reconstruction of 3D images, viewable from virtually every angle—allows today's professionals to plan orthodontic traction of maxillary canines with greater accuracy and refinement. This advance in obtaining image slices and 3D images allows surgeons to deal with canines, their follicle, cervical region and adjacent teeth with the aid of detailed planning, which ultimately reduces the risk of unintended outcomes. In other words, technological advances in imaging will make it possible for orthodontic traction to be accomplished more safely and accurately.

### Cervical region of canine and dental follicle

The radiolucent area around the crowns of unerupted teeth is filled by the dental follicle, which is firmly adhered to the surface of the crown by the reduced epithelium of the enamel organ (Figs 1 and 2). This thin and fragile epithelial component is sustained and nourished by a thick layer of connective tissue with variable collagen density—sometimes loosely, sometimes fibrous and even hyalinized.<sup>1</sup> The outer part of the follicle connects

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it seamlessly with the surrounding bone (Fig 1).

By surgically removing the follicle and detaching it from the surrounding bone a tissue fragment is obtained which is organized in the form of a thin film and is therefore known as pericoronal membrane. This tissue fragment represented by the dental follicle, when observed in isolation, has the appearance of a sack, which contained the dental crown, and is thus also called pericoronal pouch. During removal of unerupted teeth, the follicle often remains adhered to the surrounding bone tissue or to the overlying soft tissue of the surgical flap. In surgical procedures, the follicle adheres to the enamel surface only occasionally.

After removing the dental follicle of unerupted teeth, it becomes apparent that the follicle terminates in or attaches itself firmly to the cervical region of the tooth. The reduced epithelium of the enamel remains adhered to the cervical border of the enamel, while its connective portion attaches itself to the cervical root cementum (Figs 1 and 2).

The cemento-enamel junction lies between enamel and cementum. It is therefore reasonable to assert that the dental follicle in the cervical region overlies the line formed by the adjacent relationship between enamel and cementum<sup>1,4,6,8</sup> (Figs 1 and 2).

The cemento-enamel junction exhibits dentin windows or gaps along the cervical circumference of all human teeth, from which dentinal tubules emerge<sup>5,6,8</sup> (Fig 2), exposing inorganic and organic dentinal components, particularly their proteins.

### Surgical exposure and manipulation of the cemento-enamel junction may induce External Cervical Resorption

Some dentin proteins are deposited by odontoblasts during tooth formation and during intrauterine life, without ever having been directly exposed to immune system components. In other words, the immune system cannot recognize some dentin proteins as normal or as belonging to the body because during immunological memory

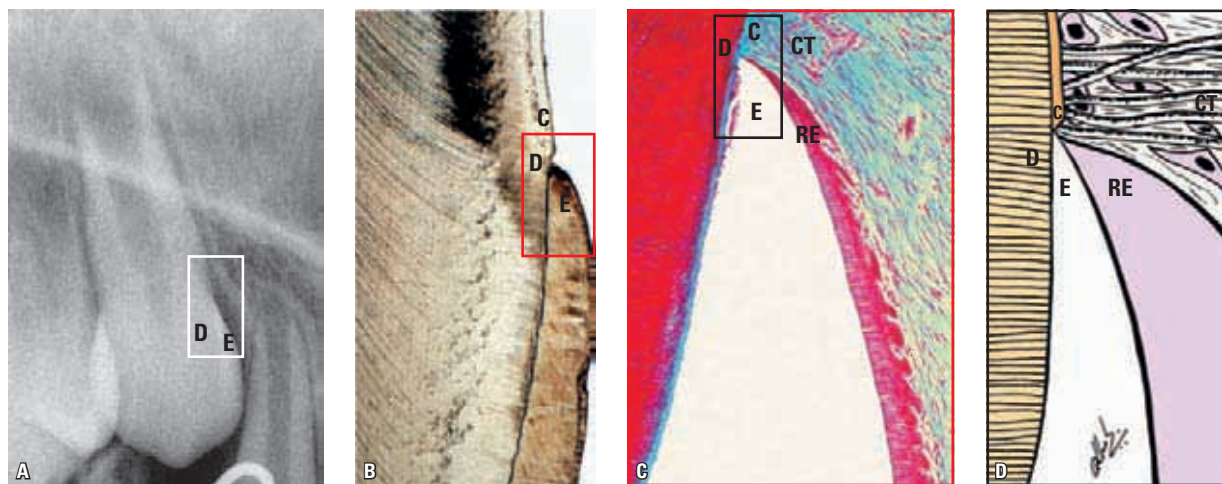


FIGURE 1 - The cervical region is a sensitive tooth structure due to the fragile junction between enamel and cementum (rectangles). In all human permanent and primary teeth, the circle formed by the cemento-enamel junction line comprises exposed gaps or windows of dentin (D), which can only be observed microscopically. In the dental follicle, the reduced epithelium (RE) of the enamel organ adheres to the enamel (E), while its connective tissue (CT) attaches itself to the root cementum (C) via collagen fibers. (B = section obtained by grinding and preserving the enamel; C = section obtained by demineralization, involving loss of the crystallized enamel structure and maintenance of its space).

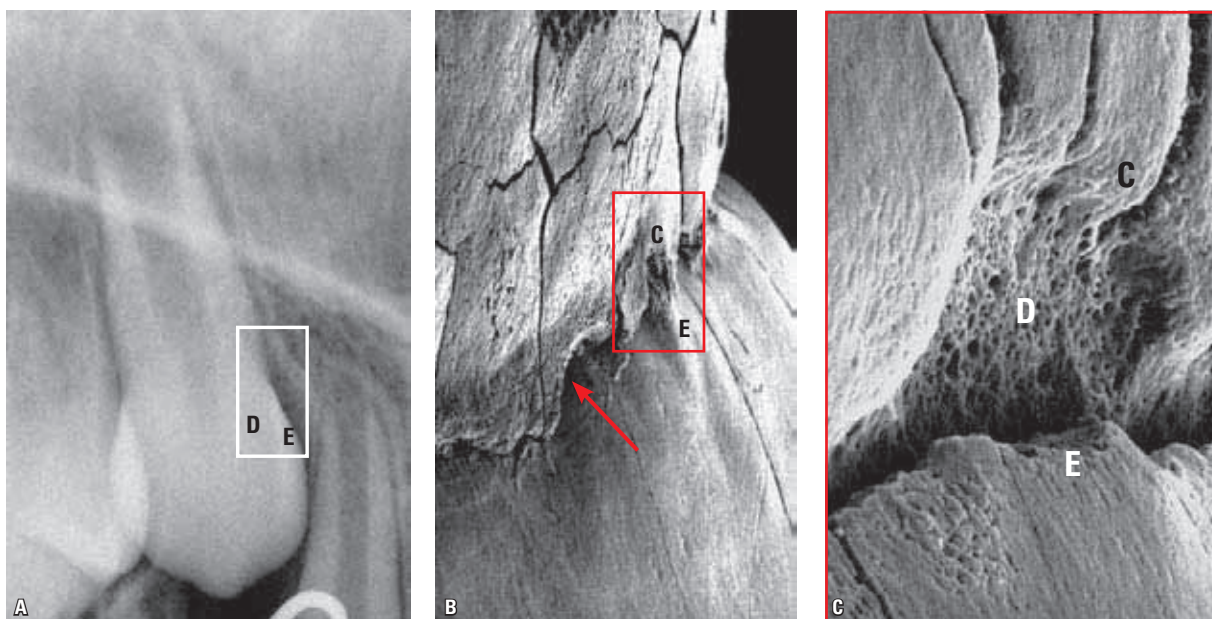


FIGURE 2 - The line formed by the cemento-enamel junction (arrow) around the tooth draws an irregular circle, now characterized by enamel superimposition (E) over the cementum (C), now by the edge-to-edge relationship between cementum and enamel, or else by the formation of dentin windows and its dentinal tubules between the two tissues, as in **C**. All human permanent and deciduous teeth have dentin gaps or windows in their cemento-enamel junction (D), which can only be observed microscopically—especially in 3D using transmission electron microscopy, as in **B** and **C**.

development these proteins were not exhibited, contacted or exposed.

By depositing the dentin the odontoblasts cover it internally thus preventing any contact with other cells and body components. Dentinal proteins are therefore not recognized or cataloged during intrauterine life,<sup>2</sup> unlike what typically occurs with almost all other proteins in the body.

If proteins not cataloged or not contacted by the body during intrauterine life later enter into close contact with the tissues they will be seen as foreign and approached as antigens. Once recognized and located, antigens, or foreign proteins must be eliminated from the body and to this end cells perform phagocytosis and extracellular digestion, and make use of enzymes, toxins, resorption, etc. This occurs with bacteria and some transplants, for example.

In some tissues and organs of the body, as is the case with dentin, some proteins are isolated, not cataloged or recognized by the immune

system, becoming known as sequestered antigens. Other examples are the proteins of the thyroid and sperm. If some time during their life these proteins or sequestered antigens are exposed to connective tissues due to external or internal agents, the cells and other components of the immune system will consider them foreign, or as antigens, and will tend to eliminate them. In the case of dentin, elimination will take place by resorption of the mineralized portion by isolating the foreign protein and dissolving it. In this case, tooth resorption occurs.

During surgical removal of the dental follicle in the cervical region the dentinal windows or gaps present in all human teeth, including deciduous teeth, are inevitably exposed to connective tissue after the flap is folded back onto the tooth. The exposure of these dentin proteins defined as sequestered antigens can induce, over weeks or months, an immunological process of elimination that is medically known as External Cervical Resorption.

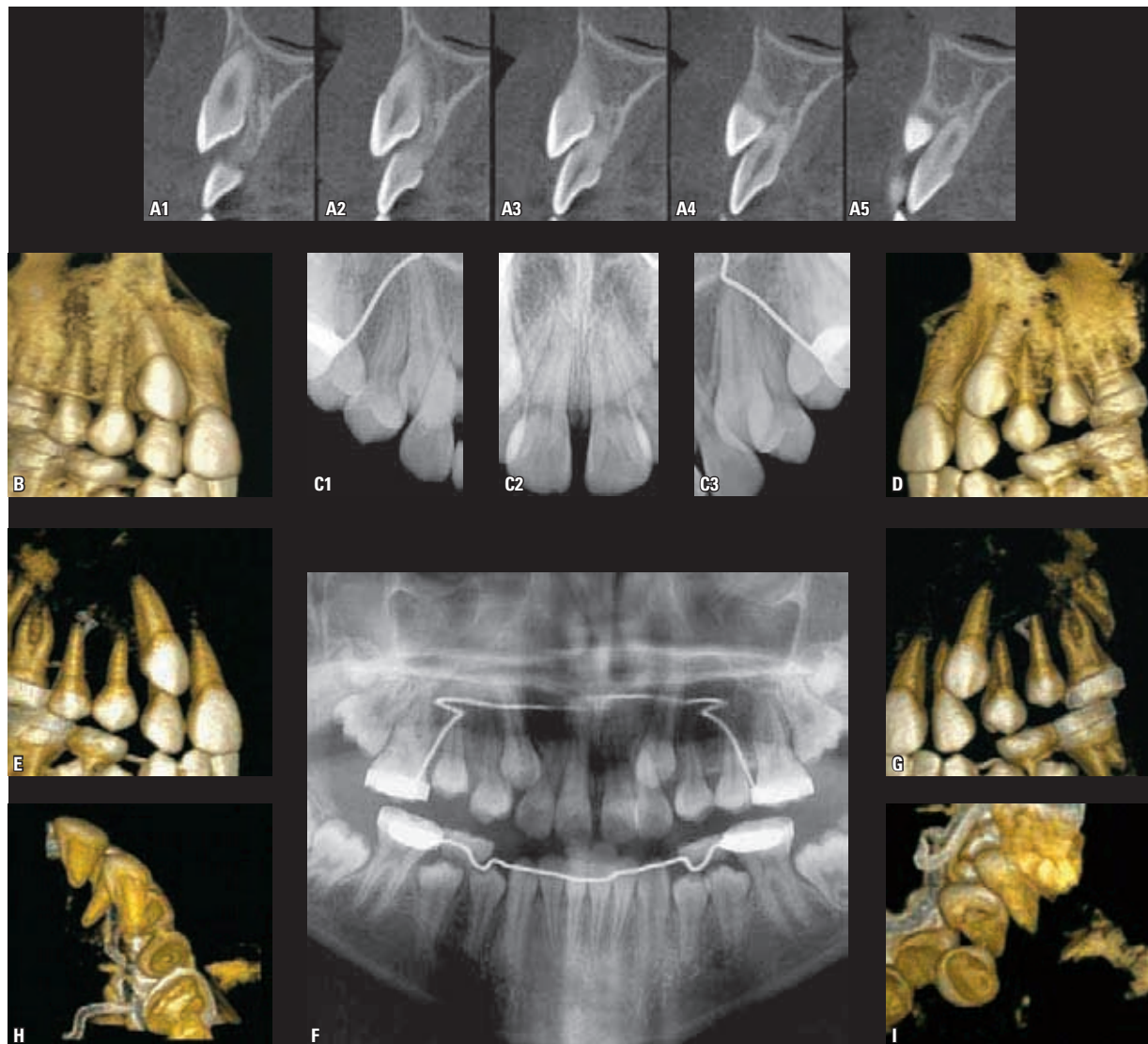


FIGURE 3 - Imaging aspects of unerupted maxillary canines, their position and relationship with adjacent teeth, as well as their spatial individualization providing a view of the cervical region from various observation angles.

During dental trauma as well as after internal tooth bleaching,<sup>4</sup> this type of resorption can also occur because these situations also promote exposure of dentinal gaps to the gingival connective tissue.

#### Procedure for traction of unerupted canines and External Cervical Resorption

If inadequately performed, surgical procedures for placing an orthodontic traction device in

unerupted maxillary canines may involve:

**1. Removal of the entire dental follicle or opening of large windows to expose the enamel and facilitate bonding procedures.** These procedures however can expose the cemento-enamel junction and its dentin windows to connective tissue and immune system components. When the cervical region of unerupted maxillary canines is manipulated, external cervical resorption can be induced after a few

weeks or months. This can happen during orthodontic traction or after the tooth has reached the occlusal plane.

In many cases, detection tends to occur belatedly. External Cervical Resorption is characterized as a slow, painless, insidious process that does not compromise pulp tissues. In more advanced cases, it can lead to gingival inflammation and pulpitis secondary to bacterial contamination.

One **way to prevent this** traction effect of unerupted maxillary canines is to allow at least 2 mm of soft tissue from the dental follicle to remain adhered to the cervical region. It is essential to refrain from manipulating the cemento-enamel junction, and to do so only if strictly necessary.

**2. Applying excessively or extensively acids and other products to facilitate the bonding of devices necessary for attaching the traction wires.** Excessive administration of these products may cause them to seep through to the cervical region where the dental follicle attaches itself to the cemento-enamel junction, affecting the cells and tissues chemically and thereby exposing, and even increasing the number of, dentin gaps and freeing the sequestered antigens into the adjacent connective tissue after closing the surgical wound. This situation may explain some cases of external resorption in maxillary canines subjected to orthodontic traction.

**3. Anchoring or fixing surgical instruments in the cervical region of unerupted maxillary canines.** This anchoring generally aims to achieve luxation or subluxation of the unerupted maxillary canine, as indicated in some procedures where alveolodental ankylosis is suspected. Subsequently, orthodontic traction is applied. The levers, chisels and tips of surgical instruments such as forceps can mechanically damage the follicle and periodontal tissues in the cervical region, and expose, or even increase the exposure of dentin in the cemento-enamel junction, from where External Cervical Resorption originates.

**4. Historically, the first traction protocols for**

**unerupted maxillary canines consisted in binding the dental cervix with wire.** A twisted wire was used and a loop was placed around the tooth in the cervical region of the upper canine with which orthodontic traction was accomplished. The force and displacement of the orthodontic wire in the neck of the tooth exposed the dentin gaps in the cemento-enamel junction, adding to the constant inflammation that resulted from the continuous trauma.

**Installing traction device on the crown and recovering of the surgical cavity: What now? The follicular tissues regenerate and repair themselves!**

Epithelial cells undergo a constant process of proliferation and synthesis, and are therefore appropriately called labile cells.<sup>2</sup> Given this characteristic, the epithelial tissue features great regenerative capacity. When wounds and mucous membranes appear immediately after trauma or surgery, marginal epithelial cells expose all their surface receptors to large amounts of mediators released by the cells themselves, especially EGF (Epidermal or Epithelial Growth Factor), which induces them to proliferate and organize themselves in layers that cover the altered surface.<sup>2</sup>

Typically, the closure of a wound by epithelial proliferation arising out of the surgical margins appears in the shape of an iris or diaphragm, and gradually—within a few hours—decreases the diameter of the area of exposed underlying tissue.<sup>2</sup> Below the epithelium, connective tissue adjacent to the injured area produce granulation tissue which evolves within a few days, giving rise to newly-formed connective tissue that repopulates the region. At a distance, bone can once again form from that same granulation tissue.

When a window is opened into the tissues of the dental follicle in order to set up an orthodontic traction device, by analogy, one can envisage a wound with injured epithelium and exposed connective tissue turned towards the enamel. The reduced epithelium of the enamel organ tends to

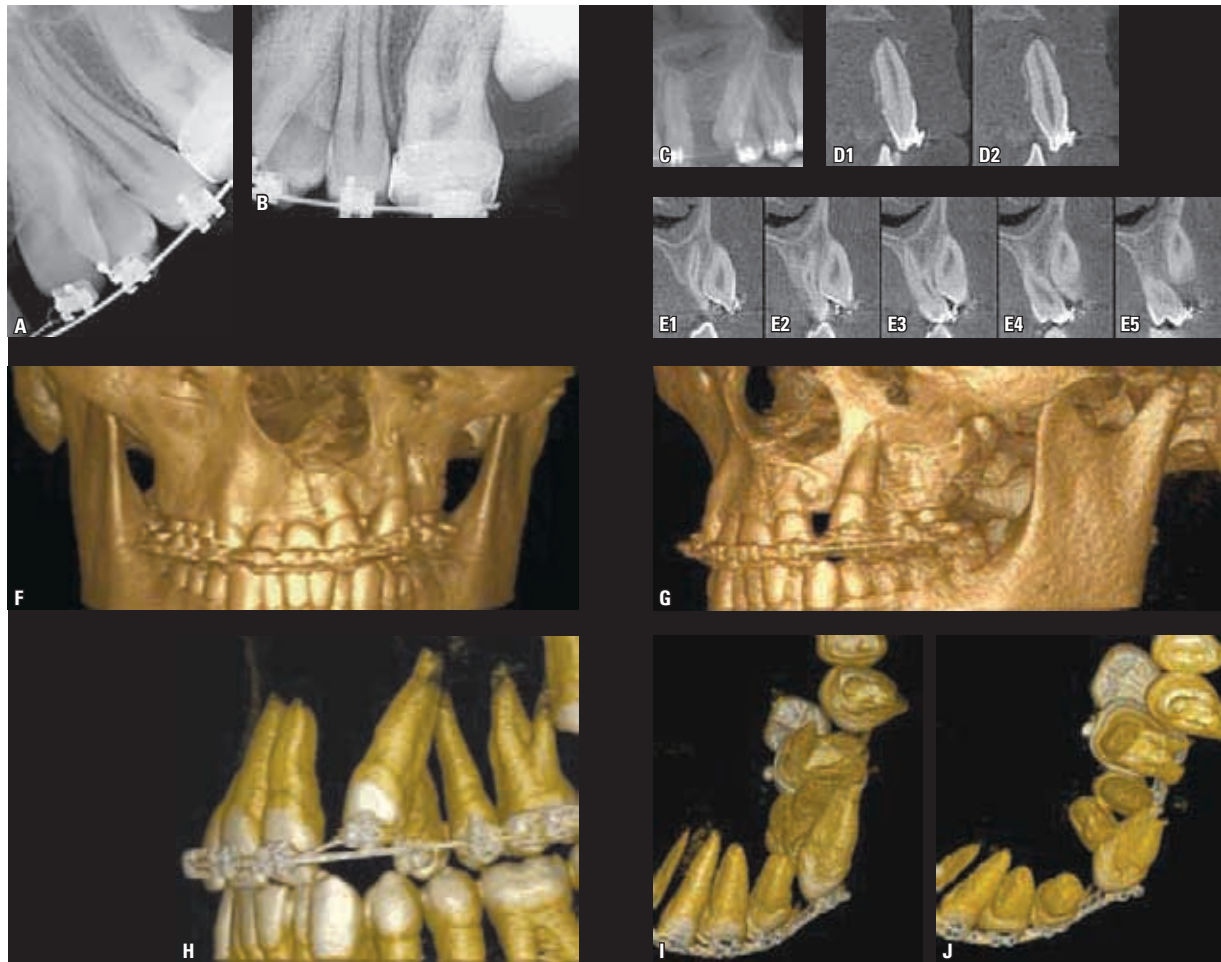


FIGURE 4 - Imaging aspects of unerupted canines undergoing orthodontic traction in cleft patients. It is worthy of note how one can view their position and relationship with adjacent teeth, as well as their spatial individualization from various observation angles.

proliferate rapidly, covering the enamel and traction devices over a period of hours or days. The underlying connective tissue starts forming again from the granulation tissue that grows temporarily in the area. Thus, the enamel is not exposed to the connective tissue until the tooth reaches the oral environment.

#### **Aren't the follicular tissues torn during orthodontic traction?**

During the extrusive tooth movement induced by traction of unerupted maxillary canines there should be no rupture of periodontal or dental follicle fibers, nor any tearing of their vessels

and nerves. If this happens, such dental trauma is named surgical or orthodontically induced avulsion—often mistakenly called rapid traction or extrusion. Biologically, this can be defined as dental injury, which may result in conditions such as alveolodental ankylosis and replacement resorption.

Induced tooth movement consists of forces that are slowly applied and dissipated, consistent with normal biological tissue. Connective and epithelial tissues are constantly remodeling, which gives them remarkable ability to adapt to new functional demands.

As a canine moves towards occlusion due to traction, tissues adjacent to the dental follicle and

bone tissues remodel and adapt naturally to the presence of the crown and traction devices without rupturing or offering any physical resistance. No tissue laceration occurs due to the displacement of a traction device along with a tooth. Vessels and nerves do not rupture and the tissues are not "torn". Right angles, walls and corners of metal traction devices will not cause any trauma to adjacent follicle tissues. Should tissue laceration occur, extrusion is not being caused by an orthodontic tooth movement per se, but rather by rapid tooth displacement, of a surgical or traumatic nature.

### **The junctional epithelium also forms during orthodontic traction**

Given the proximity between follicle and oral mucosa, the reduced epithelium of the enamel organ will fuse together with the oral mucosa. In the central region of this extensive area of epithelial fusion necrosis will occur due to lack of nourishment because the source of such nourishment, the connective tissue, is now distant. The incisal tip of the canine will appear at this site. The two epithelia now fused around the crown will give rise to the primary junctional epithelium to prevent the internal environment—represented by the connective tissue—from being exposed to a highly contaminated oral environment. This process also occurs in teeth that erupt in the oral environment with the aid of orthodontic treatment.

### **CT and 3D images as resources for diagnosing and assessing External Cervical Resorption**

Compared with CT images reconstructed in 3D, radiographs provide a visual perception of images at a more advanced stage in the process of loss of mineral components in bone tissue and teeth (Figs 3 and 4). For example, in an acute dentoalveolar abscess, radiographic images have virtually lost their key features since it is generally accepted that in order to generate images, bone resorption in a particular location should be at least 10 days old.

In assessing the damage caused by root re-

sorption in maxillary lateral incisors due to the proximity of unerupted canines, it seems appropriate to highlight some of the evidence. Associated root resorption was found in the periapical radiographs of 3,000 patients between 10 and 15 years of age. Moreover, 12.5% of their lateral incisors were located near canines that had remained unerupted for longer than normal.<sup>7</sup> The same cases were evaluated using tomographic slices and reconstructions, and disclosed 25% impairment. Computed Tomography (CT) is the best method to accurately assess the damage caused by canine traction to the roots of upper lateral incisors.

By extrapolation, CT and 3D images can promote a much earlier diagnosis of External Cervical Resorption in teeth subjected to orthodontic traction. In practice, before starting the procedures and 6 months to 1 year after a given tooth has been allocated in the dental arch, CT and 3D images can reveal early cases of cervical resorption.

Early diagnosis of external cervical resorption determines what sort of treatment should be administered: By raising a gingival flap one can have access to areas of resorption and fill them with functional, biological and aesthetically pleasing materials, with excellent prognosis. The use of CT scans and 3D images before starting orthodontic traction might help in planning such traction, in addition to averting the pre-existence of processes like external cervical resorption, alveolodental ankylosis and replacement resorption of the teeth subjected to traction (Figs 3 and 4).

In cases of alveolodental ankylosis, radiographic images only appear when the bone is in contact with more than 20% of the root surface. Prior to this percentage, if the unerupted tooth, e.g., an upper canine, fails to migrate to their position even in the presence of sufficient space and despite orthodontic traction, a diagnosis of alveolodental ankylosis can be confirmed, even without radiographic images. The routine use

of CT scans and 3D images may allow a diagnosis of alveolodental ankylosis to be reached at a much earlier stage, when the root surface is still relatively preserved.

### Final considerations

One of the possible consequences of maxillary unerupted canine traction is external cervical resorption. In planning and implementing the orthodontic traction of unerupted maxillary canines, one is advised to:

- a) Consider the fragile structure of the cemento-enamel junction with its dentin "gaps" present in all teeth, including deciduous.
- b) Avoid unnecessary surgical instrumental manipulation of the cervical region.

c) Do not spill or leak chemicals such as acids, for example, used for bonding orthodontic traction devices.

When performing orthodontic traction of unerupted maxillary canines, a few hours and days after surgery, the epithelial, fibrous connective and bone tissues regenerate and repair themselves, in that order. Normal relationship is thus restored with epithelial covering of the enamel and metal devices, reconstruction of fibrous connective tissue and new peripheral bone formation. As the tooth moves in the occlusal direction, pericoronal tissues are not lacerated or torn. Normal tissue remodeling fulfills functional demands and gradually adapts to this dental extrusion movement.

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## An interview with

## Lucia Helena Soares Cevidanes

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- PhD in Oral Biology, University of North Carolina at Chapel Hill, 2003.
- Assistant Professor, Department of Orthodontics, University of North Carolina at Chapel Hill.
- Diplomate, American Board of Orthodontics.
- Reviewer of the American Journal of Orthodontics and Dentofacial Orthopedics, Angle Orthodontist, Journal of Dental Research, European Journal of Oral Sciences, World Journal of Orthodontics, Orthodontics and Craniofacial Research, International Journal of Oral Maxillofacial Surgery, and Dentomaxillofacial Radiology.
- Thomas M. Graber Award of Special Merit by the American Association of Orthodontists, 2004.
- B. F. and Helen Dewel Award for best clinical article published in 2005 in the American Journal of Orthodontics and Dentofacial Orthopedics.
- Teaching Award by the American Association of Orthodontics Foundation in 2008 and 2009.



It gives me great pleasure to conduct an interview with Professor Lucia Cevidanes, an example of humbleness, courage and determination. Born in Caratinga, Minas Gerais, she attended dentistry at the Federal University of Goiás and earned a Masters Degree in Orthodontics at UMESp, where she was faculty member for four years. After setting up a private practice in Santo André/SP, she decided to pursue her dream of earning a PhD abroad, which she accomplished at one of the most prestigious research centers in Orthodontics and Orthognathic Surgery worldwide. Building on a clinical sample she had tenaciously put together in Brazil, she entered the world of diagnostic imaging to undertake an award-winning research project. Ultimately, her outstanding contributions led her to a position as Faculty Member of the Department of Orthodontics at UNC, where she develops some of the most stimulating research projects in today's literature. Coordinating a research team comprised of American, European and Brazilian collaborators in experiments that make use of three-dimensional diagnosis, Prof. Cevidanes spends her time on a wide range of activities, such as lectures in different countries, clinical and theoretical teaching activities at Graduate and Masters courses in Orthodontics, participation in an interdisciplinary group devoted to the treatment of craniofacial anomalies while still maintaining a clinical orthodontic practice at the institution. Married to Larry, who is also a professor at UNC in the field of psychology, she has two daughters, Teresa and Angelina, who she enjoys taking for a stroll down Franklin Street, in Chapel Hill, on week-ends. They also travel on vacation to visit friends in Connecticut or family on their farm in Minas Gerais State, Brazil.

*Alexandre Trindade Motta*

**What is your outlook on the dissemination of Cone-Beam Computed Tomography (CBCT) among clinicians and what knowledge and equipment are necessary before it can be used routinely in diagnosing, planning and evaluating orthodontic, orthopedic and surgical treatment?** Ary dos Santos-Pinto

Several hurdles must be overcome before CBCT is used routinely in clinical orthodontics:

a) Laying down guidelines to determine which cases benefit from additional clinical information to justify its higher cost and increased radiation dose to patients. The Board of Trustees of the American Association of Orthodontists (AAO) and American Academy of Oral and Maxillofacial Radiology (AAOMR) has appointed a council committed to having these guidelines ready by the end of 2010. It includes the following orthodontists: Dr. Carla Evans (Univ. of Chicago), Dr. Martin Palomo (Case Western University), Dr. Kirt Simmons (Arkansas Children's Hospital) and Dr. Lucia Cevdanes. Radiologists in the group are led by Dr. William Scarfe (Univ. of Louisville), Dr. Mansur Ahmad (Univ. of Minnesota) and Dr. John Ludlow (Univ. of North Carolina). The guidelines are "to be reviewed every three years as scientific evidence builds up in the literature".<sup>1</sup>

b) Validation and development of three-dimensional analysis software. Current versions of commercial software are still fraught with limitations and require monthly updates. Moreover, the accuracy of the tools employed in these programs has not yet been scientifically validated.

c) Absence of standard population data to support diagnostic analysis. Issues related to identifying anatomical landmarks in traditional cephalometric analysis have been regarded as a major source of errors in determining the key craniofacial measurements. In 3D, this problem is further compounded by the fact that many anatomical landmarks are poorly defined in one of the three planes of space. For example, the gonial point is located on a curve, which makes determining its location in the vertical plane an error-prone process.

**Given the increasing use of 3D CBCT images, a recurring question emerges: should we use them in all cases or only in selected cases?**

Alexandre Motta

In my opinion, these images should be used in selected cases. For example, Class I malocclusion cases without tooth impaction do not justify the use of Cone-Beam tomography.

**For which clinical procedures or clinical cases would you consider it essential to request computed tomography in orthodontic practice?** Liliana Maltagliati

The guidelines to determine which cases can benefit from CBCT clinical information will be laid down by the joint efforts of the AAO and AAOMR. Not only which cases can benefit from CT, but also on which occasions or how often this radiographic follow-up procedure is indicated. Comparisons using population standards and two-dimensional (2D) cephalometric representations fail to address many issues pertaining to diagnosis and mechanisms of treatment response and growth. Planning treatment for the following orthodontic problems, in particular, can be potentially enhanced by 3D diagnostic information: Skeletal anchorage with mini-plates (Fig 1), dental impaction or eruption failure, patients with maxillomandibular discrepancy in any of the three planes of space (transversal - asymmetries; vertical - open/deep bite; anteroposterior - skeletal Class II and III), and temporomandibular disorders (TMDs).

**As regards image acquisition, do you believe different devices such as the NewTom and i-CAT can provide comparable quality images, or would the differences compromise the serial, longitudinal superimposition? Could differences in image acquisition with patients lying or sitting affect these assessments, especially those of the airways for the purpose of diagnosing nasal, nasopharyngeal and oropharyngeal obstructions?** Ary dos Santos-Pinto

Depending on the software used for viewing, image voxel size needs to be standardized so that images acquired with different equipment, such as the NewTom and i-CAT, are comparable. If proper care is not exercised when performing CBCT in centric occlusion, differences in image acquisition with patients lying or sitting could affect, in particular, not just the assessment of the airways and facial soft tissues but mandibular posture as well. Currently, all our images are acquired using a thin wax bite in centric occlusion. Additionally, images acquired using the NewTom display more noise, especially in the image periphery, often compromising the quality of 3D surface models (Fig 2).

**After years studying imaging, initially with magnetic resonance, investigating the effects of functional appliances on TMJ, and then later with computed tomography, how important do you really think these diagnostic imaging methods are for treating TMDs?** Liliana Maltagliati

In my view, imaging diagnostics and TMD treatment are two areas where considerable research is still needed. TMD treatment is still narrowly focused on alternatives to minimize patient discomfort and pain. Despite many theories conducted beyond the field of Orthodontics and Oral Rehabilitation, the etiology of TMD involves facial myalgias and neuralgias for which CBCT imaging diagnostics would not be indicated. A clinical diagnosis using the parameters defined by the Diagnostic Criteria for TMD (RDC/TMD criteria)<sup>2</sup> is indicated before patients are referred for Cone-Beam CT (Fig 3).<sup>3</sup>

**Would surface bone remodeling (resorption and apposition) pose a limitation to 3D image superimposition?** Daniela Garib

Not at all. However, the techniques of 3D image superimposition to assess surface bone remodeling (resorption and apposition) must not make

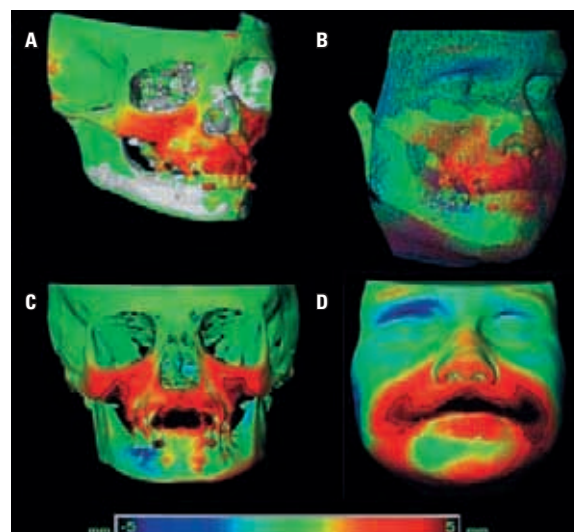


FIGURE 1 - Superimpositions on the anterior cranial fossa to assess relative growth and response to orthopedic treatment with skeletal anchorage in the maxilla and mandible. Anterior displacement of the midface (in red).

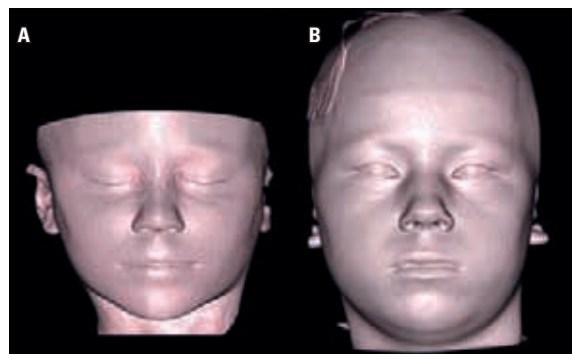


FIGURE 2 - Visualization of soft tissues in the faces of two patients with NewTom (A) and i-CAT (B) scans. Note that both scans show acceptable quality image with control of surface artifacts, very common in Cone-Beam technique. Also note the increased definition of the surface scan produced with the i-CAT scanner.

use of adjacent structures as reference but rather regional superimposition (Fig 4). The study of bone remodeling in the mandible, for example, must use stable structures during mandibular growth, as in Bjork's 2D studies. In cases of mandibular surgery, this is complicated because the mandible is changed by surgery, so any "best fit" technique has a bias toward evaluating postoperative remodeling.

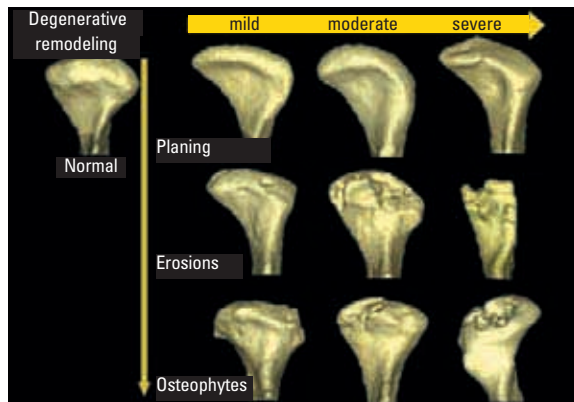


FIGURE 3 - Degenerative remodeling of the mandibular condyle in patients with TMD.

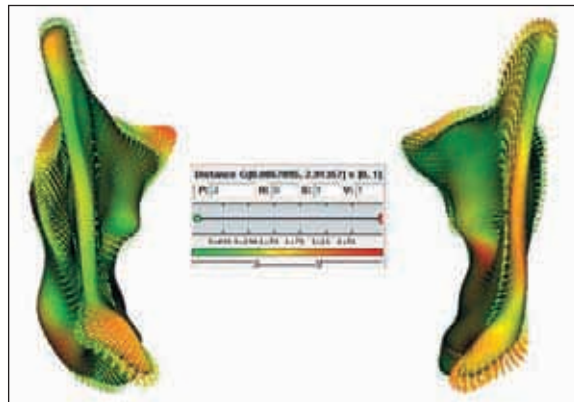


FIGURE 4 - New methods of 3D superimposition on the mandible, showing bone remodeling vectors in a patient with idiopathic condylar resorption.

**Can an examination of study models in orthodontics be performed directly on the images of the dental arches, thus eliminating the need to take impressions of the dental arches?** Ary dos Santos-Pinto

The best reference on orthodontic study models performed directly on images of the dental arches is the work published by Dr. Gwenn Swennen.<sup>4</sup> As explained in detail in her article, it requires more than one scan, and a well calibrated device in order to correct artifacts in the region of the brackets and restorations.

**What are the main differences between commercial and free three-dimensional analysis software?** Alexandre Motta

Commercial software provides clinicians with a more user-friendly interface. The major issue is price. Besides, as remarked in my reply to the first question above, despite the marketing appeal of impressive diagnostic images the accuracy of most commercial software tools has yet to be validated scientifically. The ongoing development of public domain software is supported by the National Institute of Health in the United States, but with research, not commercial purposes. Their focus is on improving the quality of image analysis and not just developing user-friendly software for use in routine clinical practice. Thus, this software can run better on Linux than on Windows or Mac, as their computer graphics programs are developed for the Linux operating system.

**How do you envisage the transition of 3D superimposition techniques from the research universe to clinical practice?** Daniela Garib

Firstly, the barriers I mentioned in my first answer regarding the routine use of CBCT in orthodontic practice need to be surmounted. 3D superimposition methods currently used in research must undergo considerable development before they are employed in clinical routine, thanks in large measure to a platform recently developed by the National Institute of Health in the United States, which incorporates several features from different imaging modalities, including CBCT, spiral scanning, magnetic resonance and ultrasound, as well as several analysis procedures for building 3D models, superimposition, visualization and quantification aimed at diagnosing and assessing treatment results.

**As the use of CT in clinical research intensifies, we anticipate an increased potential for errors that can compromise outcome, especially**

**in "before and after" studies, given the difficulty in reproducing cross sections in successive examinations. What precautions would you recommend to help researchers avoid errors in methodology?** Liliana Maltagliati

I agree that this is a serious risk we will be facing, mainly due to a lack of knowledge and proper training in 3D analysis. Clinicians have a hard time understanding analyses that are not based on anatomical landmarks because they are mathematically more complex. In November 2009, a group of American professors led by Dr. Martin Palomo and Mark Hans, from Case Western University, held their second meeting, where they discussed the standardization of image superimposition techniques, and these discussions will continue throughout November 2010.

**In light of your academic experience around the world as a researcher and lecturer, what major trends and future prospects do you see for the application of 3D technology in orthodontics?** Alexandre Motta

The use of 3D images for diagnosis, treatment planning, surgical simulation, evaluation of orthodontic treatment and biomechanical results has aroused great interest and led to the development of research worldwide.

**As a Brazilian orthodontist who plays a brilliant role as a researcher in one of the most prestigious research centers in the country that saw the birth of orthodontics, what are your views on Brazilian orthodontics today?** Daniela Garib

Orthodontics in Brazil has been developing and keeping up to date and dynamic largely owing to the efforts of excellent researchers. I have also had the pleasure and privilege of keeping in touch and collaborating with teachers and students from several Brazilian institutions in the development of some major research projects.

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# Analysis of initial movement of maxillary molars submitted to extraoral forces: a 3D study

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## Abstract

**Objective:** To analyze maxillary molar displacement by applying three different angulations to the outer bow of cervical-pull headgear, using the finite element method (FEM).

**Methods:** Maxilla, teeth set up in Class II malocclusion and equipment were modeled through variational formulation and their values represented in X, Y, Z coordinates. Simulations were performed using a PC computer and ANSYS software version 8.1. Each outer bow model reproduced force lines that ran above (ACR) (1), below (BCR) (2) and through the center of resistance (CR) (3) of the maxillary permanent molars of each Class II model. Evaluation was limited to the initial movement of molars submitted to an extraoral force of 4 Newtons. **Results:** The initial distal movement of the molars, using as reference the mesial surface of the tube, was higher in the crown of the BCR model ( $0.47 \times 10^{-6}$ ) as well as in the root of the ACR ( $0.32 \times 10^{-6}$ ) model, causing the crown to tip distally and mesially, respectively. On the CR model, the points on the crown ( $0.15 \times 10^{-6}$ ) and root ( $0.12 \times 10^{-6}$ ) moved distally in a balanced manner, which resulted in bodily movement. In occlusal view, the crowns on all models showed a tendency towards initial distal rotation, but on the CR model this movement was very small. In the vertical direction (Z), all models displayed extrusive movement (BCR  $0.18 \times 10^{-6}$ ; CR  $0.62 \times 10^{-6}$ ; ACR  $0.72 \times 10^{-6}$ ). **Conclusions:** Computer simulations of cervical-pull headgear use disclosed the presence of extrusive and distal movement, distal crown and root tipping, or bodily movement.

**Keywords:** Headgear. Finite Element Method. Tooth movement.

\* Access [www.dentalpress.com.br/journal](http://www.dentalpress.com.br/journal) to read the full article.

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### Editor's summary

This study employed the digital finite element method to compare the effects of cervical headgear—with variations in force vector direction, on the movement of maxillary first permanent molars. By changing the length and/or inclination of the outer bow of the headgear, or by applying different force vectors, impact on the dental and skeletal structures can be altered. Maxillary models were reproduced with teeth mounted in Class II malocclusion and an extraoral appliance (cervical traction headgear) with the outer bow modified at three different heights, determining force lines above, below and along the center of resistance of the first molars (Fig 1). In computer simulations, the program ANSYS (version 8.1, Ansys Inc. Canonsburg, PA, USA) was utilized, which relies on the finite element method for quantification of forces, moments and stresses. Molar distalization activations were simulated to determine quantitatively the parameters involved in orthodontic biomechanics.

The initial distal movement of the maxillary first molars ( $U_x$ ) on the model where the resultant of forces passed below the center of resistance (BCR) caused greater distal tipping in the crown than in the root, producing a tip-back movement.

On the model where the resultant passed through the center of resistance (CR), distal bodily movement occurred, causing displacement of the distal root as far as the middle third. On the model where the resultant of forces passed above the center of resistance (ACR), displacement was greater in the distal root, producing a forward tip. In occlusal view, all models showed a trend towards initial distal rotation of the crown. In the CR model however this movement was very limited. Results for vertical direction ( $U_z$ ) revealed that all models exhibited extrusion, which was higher on the ACR model. The extrusion noted in the three models can be explained by the origin of the force application point, which is low, i.e., in the patients' neck. Care should be exercised in cases where it is necessary to raise the outer bow in order to achieve an external line of action as close as possible to the effect desired for the molar, since outer bow elevation increases the extrusive component.

It was shown that the use of cervical headgear causes extrusive and distal movement. Force line orientation is important to control the type of maxillary molar movement, which can be translational, tip-back or tip-forward when distal movement is produced by an extraoral appliance.

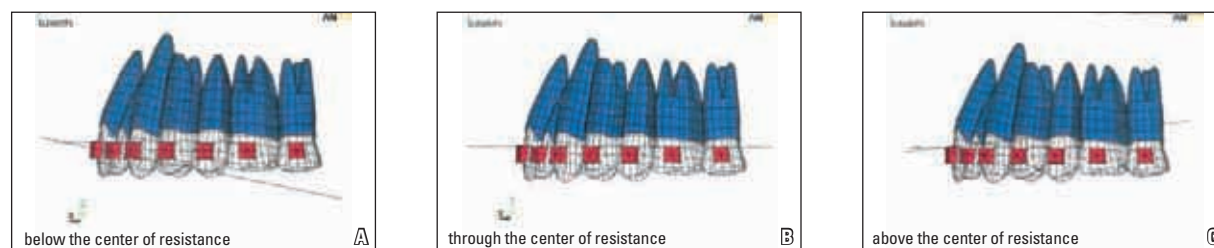


FIGURE 1 - Reproduction of the three models of cervical headgear with different outer bow inclinations in relation to X, Y and Z coordinates, using the Ansys 8.1 program: **A**) BCR (below the center of resistance); **B**) CR (through the center of resistance) and **C**) ACR (above the center of resistance).

## Questions to the authors

### 1) What motivated you to pursue this investigation?

Despite its aesthetic limitations and the need for compliance, headgear (HG) is a conventional and still widely used appliance that enables different force lines to be applied. HG use requires a basic knowledge of biomechanics since the effects on the dental and skeletal structures can be altered depending on the force vectors you apply. Some studies have shown that a major limitation of this method is the difficulty in isolating molar movement without allowing growth in the bone bases to interfere with the analysis. For this reason, we set out to analyze the initial distal movement of maxillary first molars caused by three different headgear outer bow inclination using computer simulations and the finite element method.

### 2) How important is the finite element method for research in orthodontics?

Studies on applied mechanics using finite elements have been successful. With this method you can assess biomechanical components such as displacement, strain, pressure, stress and induced forces on various structures used in orthodontics. The accuracy of the results yielded by the finite element method depends on how the study model is processed, so you should be aware of their limitations.

### 3) Do the authors suggest future research using the same methodology?

Yes, mainly studies that compare the adverse effects of tooth movement by extraoral and intraoral appliances. Almost all the mechanics used for orthodontic movement can be simulated, although assessment with finite elements only allows us to interpret the initial responses to applied mechanics.

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## 2D / 3D Cone-Beam CT images or conventional radiography: Which is more reliable?

Carolina Perez Couceiro\*\*, Oswaldo de Vasconcellos Vilella\*\*\*

### Abstract

**Objective:** To compare the reliability of two different methods used for viewing and identifying cephalometric landmarks, i.e., (a) using conventional cephalometric radiographs, and (b) using 2D and 3D images generated by Cone-Beam Computed Tomography. **Methods:** The material consisted of lateral view 2D and 3D images obtained by Cone-Beam Computed Tomography printed on photo paper, and lateral cephalometric radiographs, taken in the same radiology clinic and on the same day, of two patients selected from the archives of the Specialization Program in Orthodontics, at the School of Dentistry, Fluminense Federal University (UFF). Ten students from the Specialization Program in Orthodontics at UFF identified landmarks on transparent acetate paper and measurements were made of the following cephalometric variables: ANB, FMIA, IMPA, FMA, interincisal angle, 1-NA (mm) and 1-NB (mm). Arithmetic means were then calculated, standard deviations and coefficients of variance of each variable for both patients. **Results and Conclusions:** The values of the measurements taken from 3D images showed less dispersion, suggesting greater reliability when identifying some cephalometric landmarks. However, since the printed 3D images used in this study did not allow us to view intracranial landmarks, the development of specific software is required before this type of examination can be used in routine orthodontic practice.

**Keywords:** Cone-Beam Computed Tomography. Radiography. Orthodontics.

### Editor's summary

Cone-Beam Computed Tomography (CBCT) offers the advantage of enabling image reconstruction from a lateral radiograph in conventional orthodontic cephalometry. This investigation aimed to compare how reliably cephalometric landmarks can be identified when viewed on conventional radiographs (Fig 1), and when viewed on two different

CBCT images, i.e., conventional 2D reconstruction and maximum intensity projection (MIP), depicted in Figures 2 and 3, by analyzing the dispersion of the values obtained from measurements performed on each image. CBCT-generated images were printed on photographic paper and cephalometric tracings were manually performed by 10 examiners at two different times.

\* Access [www.dentalpress.com.br/journal](http://www.dentalpress.com.br/journal) to read the full article.

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Coefficient of variance was applied with the purpose of assessing the dispersion of cephalometric values. Values from the measurements performed on the 3D CBCT images showed less dispersion in seven situations. This result was repeated—considering the data of patients 1 and 2, for the FMA angle only. This finding seems to suggest that three-dimensional images are more reliable for identifying some cephalometric landmarks which are difficult to detect in 2D images, such as porion (Po), orbitale (Or), subspinale

(A), supramentale (B) and nasion (N). Likewise, the inferior mandibular border seemed easier to identify. Nevertheless, 3D images do not seem to be as reliable when identifying the intersection of the long axes of maxillary and mandibular central incisors. It is interesting to note also that printed 3D images, as used in this study, did not allow the viewing of intracranial points, often essential for cephalometric analysis. No difference was pointed out between conventional images and 2D Cone-Beam CT reconstruction.



FIGURE 1 - Lateral cephalometric radiograph.



FIGURE 2 - 2D image obtained with Cone-Beam Computed Tomography, in lateral view.



FIGURE 3 - 3D image obtained with the Cone-Beam Computed Tomography, in lateral view.

## Questions to the authors

### 1) Did the examiners report any difficulties in marking the points on the 3D image?

No, the cephalometric landmarks were easily identified on the 3D image and the lines and angles were easily traced and measured, respectively. Not many differences were found compared to cephalometric tracings commonly performed by examiners on a conventional cephalometric image.

### 2) Did the examiners notice any differences in structure identification between conventional cephalometric images and 2D CBCT reconstruction?

The investigators reported greater difficulty in

identifying cephalometric landmarks and in performing cephalometric tracings on the 2D CBCT-generated reconstruction.

### 3) Do the authors find it feasible to use 2D CBCT-generated reconstruction in cephalometry?

Yes. Not only in 2D but in 3D as well, provided that cephalometric analyses are adapted to three-dimensional images.

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# Evaluation of referential dosages obtained by Cone-Beam Computed Tomography examinations acquired with different voxel sizes

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## Abstract

**Objectives:** The aim of this study was to evaluate the dose-area product (DAP) and the entrance skin dose (ESD), using protocols with different voxel sizes, obtained with i-CAT Cone-Beam Computed Tomography (CBCT), to determine the best parameters based on radioprotection principles. **Methods:** A pencil-type ionization chamber was used to measure the ESD and a PTW device was used to measure the DAP. Four protocols were tested: (1) 40s, 0.2 mm voxel and 46.72 mAs; (2) 40s, 0.25 mm voxel and 46.72 mAs; (3) 20s, 0.3 mm voxel and 23.87 mAs; (4) 20s, 0.4 mm voxel and 23.87 mAs. The kilovoltage remained constant (120 kVp). **Results:** A significant statistical difference ( $p < 0.001$ ) was found among the four protocols for both methods of radiation dosage evaluation (DAP and ESD). For DAP evaluation, protocols 2 and 3 presented a statistically significant difference, and it was not possible to detect which of the protocols for ESD evaluation promoted this result. **Conclusions:** DAP and ESD are evaluation methods for radiation dose for Cone-Beam Computed Tomography, and more studies are necessary to explain such result. The voxel size alone does not affect the radiation dose in CBCT (i-CAT) examinations. The radiation dose for CBCT (i-CAT) examinations is directly related to the exposure time and milliamperes.

**Keywords:** Cone-Beam Computed Tomography. Radiation. Voxel.

## Editor's summary

The voxel size, the smallest unit of a Cone-Beam Computed Tomography (CBCT) image, is related to the definition of tomographic image.

The question raised by the authors of this study is whether voxel size can affect radiation dose during CT scanning. Measurement of dose-area product (DAP) and entrance skin dose (ESD) when

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TABLE 1 - Protocols for image acquisition for the i-CAT device.

| Protocol | Scanning time (s) | Voxel size (mm) | Peak voltage (kVp) | mAs   |
|----------|-------------------|-----------------|--------------------|-------|
| 1        | 40                | 0.2             | 120                | 46.72 |
| 2        | 40                | 0.25            | 120                | 46.72 |
| 3        | 20                | 0.3             | 120                | 23.87 |
| 4        | 20                | 0.4             | 120                | 23.87 |

TABLE 2 - Mean values of radiation doses (ESD and DAP) for the four protocols.

| Protocol | Entrance Skin Dose - ESD (mGy) | Dose Area Product-DAP (mGy m <sup>2</sup> ) |
|----------|--------------------------------|---------------------------------------------|
| 1        | 3.77                           | 44.92                                       |
| 2        | 3.78                           | 45.30                                       |
| 3        | 2.00                           | 24.43                                       |
| 4        | 2.00                           | 24.98                                       |
|          | (p = 0.00083)                  | (p = 0.000145)                              |

obtaining CBCT images with an i-CAT (Imaging Sciences International, Hatfield, PA, USA) was performed according to the protocols specified in Table 1. In all protocols, the field of view (collimation) of the scan was equivalent to 6 cm. The tests were repeated four times for each protocol.

The median DAP and ESD values found for the four protocols are shown in Table 2. A significant difference ( $p < 0.001$ ) was found among the four protocols for the two radiation dose assessment methods. The size of the voxel by itself did not influence the exposed radiation dose. When the exposure factors (TE, kVp and mAs) are maintained, simply changing the voxel size does not influence the radiation dose significantly. However, the protocols correlate the use of smaller voxels with greater milliamperage exposure times, which invariably increases the exposure dose.

## Questions to the authors

### 1) Which of the image acquisition protocols you tested is the most cost-effective? Why?

Not only this but other studies have shown that the protocol using a 0.3 mm voxel offers a combination of good resolution and reduced radiation dose. It is therefore the most cost-effective.

### 2) Does the size of the field of view (FOV) used in Cone-Beam CT examinations influence the radiation dose?

Yes. Especially when it comes to kerma area product (KAP), which increases the probability of stochastic effects. However, in our study, no influence was observed because we used the same FOV in all incidences and measurements. But, for example, in CBCT scans with a reduced FOV or restricted to measurement levels by sextants, the dose received is significantly reduced, implying very specific indications.

### 3) Do studies of radiation dose with Cone-Beam CT pose any difficulties or limitations?

Yes, researchers are still seeking a dosimetric quantity and/or a methodology that allows CBCT exposures to be assessed in order to estimate stochastic effects and compare exposures with other technologies. This is only made possible thanks to the volumetric acquisition and advanced technology of CBCT equipment.

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# Linear measurements of human permanent dental development stages using Cone-Beam Computed Tomography: A preliminary study

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## Abstract

**Objective:** To determine the linear measurements of human permanent dentition development stages using Cone-Beam Computed Tomography. **Methods:** This study was based on databases of private radiology clinics involving 18 patients (13 male and 5 female, with age ranging from 3 to 20 years). Cone-Beam Computed Tomography (CBCT) images were acquired with i-CAT system and measured with a specific function of the i-CAT software. Two hundred and thirty-eight teeth were analyzed in different development stages in the coronal and sagittal planes. The method was based on delimitation and measurement of the distance between anatomical landmarks corresponding to the development of the dental crowns and roots. These measurements allowed the development of a quantitative model to evaluate the initial and final development stages for all dental groups. **Results and Conclusions:** The measurements acquired from different dental groups are in agreement with estimates of investigations previously published. CBCT images of different development stages may contribute to diagnosis, planning and outcome of treatment in various dental specialties. The dimensions of dental crowns and roots may have important clinical and research applications, constituting a noninvasive technique which contributes to in vivo studies. However, further studies are recommended to minimize methodological variables.

**Keywords:** Tooth development. Incomplete root formation. Apexogenesis. Cone-Beam Computed Tomography. Computed tomography.

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## INTRODUCTION

Knowledge of the development stages of permanent teeth is essential for clinical practice in several dental specialties, since it may have influence on diagnosis, treatment planning and treatment outcome.

Several studies have evaluated calcification and development of human teeth using various methodologies.<sup>16,19,20,21,24,26,27,28,34,35,38-41,44,46,47,49</sup> Radiographic images, although representing two-dimensional aspects of three-dimensional structures, were the most widely used resource to determine the calcification and development stages of human permanent teeth.<sup>20,34,35,39,49</sup> A classical study by Nolla<sup>35</sup> evaluated the stages of development of human permanent teeth using radiographic records selected from the files on the basis of length, which were graded on a scale from 0 to 10 based on development.

Technological advances offer imaging modalities which have brought important contributions to dental radiology, such as viable diagnostic tools, namely digital radiography, densitometry methods, Cone-Beam Computed Tomography (CBCT), magnetic resonance imaging, ultrasound and nuclear techniques,<sup>8</sup> providing detailed high-resolution images of oral structures and permitting early detection of alterations in maxillofacial structures.

Since the introduction of computed tomography,<sup>2,17,37</sup> it has been observed that its clinical application has exerted a significant impact on health care.<sup>1,4,7,10-15,19,22,25,29-31,42,43,45,48</sup> Recently, clinical dentistry and research have benefitted from CBCT application,<sup>3,6,8,18,32,42</sup> which has permitted visualization of three-dimensional images, with additional handling strategies.<sup>6</sup> The higher potential for clinical application and the accuracy compared with periapical radiographs have contributed to treatment planning, diagnosis, therapy and prognosis of different diseases.<sup>1,4,6,7,10-15,19,25,26,29-31,42,43,45</sup>

Another remarkable feature of this technology is the CBCT measurement tool, which enables the determination of linear distances and volume of anatomic structures,<sup>4,22,45</sup> presurgical planning of maxillofacial lesions,<sup>7</sup> root length and marginal bone level

during orthodontic treatment,<sup>30,43</sup> reconstruction techniques,<sup>1,29</sup> bone level changes following regenerative periodontal therapy,<sup>15</sup> periodontal defect,<sup>19</sup> periapical lesions,<sup>11,12</sup> and root resorptions.<sup>13</sup>

However, based on the potential of high-resolution image acquisition and the availability of new emerging three-dimensional imaging modalities, it seems appropriate to study the linear measurements of human permanent dentition during development, particularly in the first 20 years of age. Thus, the aim of this study was to determine the linear measurements of human permanent teeth at different development stages using Cone-Beam Computed Tomography.

## MATERIAL AND METHODS

### Image Selection

This study was structured using databases of private radiology clinics (CIRO, Goiânia, GO, Brazil; RIO, Brasília, DF, Brazil; CROIF, Cuiabá, MT, Brazil) involving 18 patients (n=238 teeth), 13 male, 5 female, with age ranging from 3 to 20 years. The patients were referred to the dental radiology service for different diagnostic purposes. The sample had no history of dental caries, orthodontic treatment or disturbance of dental development.

The study design was approved by the Local Ethics Research Committee (UFG, Proc. #169/2008).

### Imaging Methods

CBCT images were acquired with i-CAT Cone-Beam 3D imaging system (Imaging Sciences International, Hatfield, PA, USA). Volumes were reconstructed with 0.2 mm isometric voxel. The tube voltage was 120 kVp and the tube current 3.8 mA. Exposure time was 40 seconds. Images were examined with the scanner's proprietary software (Xoran version 3.1.62; Xoran Technologies, Ann Arbor, MI, USA) in a PC workstation running Microsoft Windows XP professional SP-2 (Microsoft Corp, Redmond, WA, USA), with Intel(R) Core(TM) 2 Duo-6300 1.86 Ghz processor (Intel Corporation, USA), NVIDIA GeForce 6200 turbo cache graphics card

(NVIDIA Corporation, USA) and Monitor EIZO - Flexscan S2000, resolution 1600x1200 pixels (EIZO NANO Corporation Hakusan, Japan).

### Imaging Measurements

The method used to study the development of the permanent teeth with CBCT was based on delimiting and measuring the distance between anatomical landmarks according to the development of the dental crowns and roots. All the measurements on the CBCT images were acquired by two dental radiology specialists using a proprietary measurement tool supplied with the CBCT scanner (Xoran 3.1.62; Xoran Technologies, Ann Arbor, MI, USA). A specific function of the i-CAT software that offers values in millimeters was used to measure teeth images. The measurements were made both in the sagittal and coronal planes (the reference used was the largest measurement extension given by the software). The reference distances used were as follows:

- » AB - maximum width between the incisal edge or cusp tip and cemento-enamel junction;
- » BC - maximum width between the cemento-enamel junction and the most apical point of the root;
- » AC - maximum width between the incisal edge or cusp tip and the most apical point of the root;
- » CD - maximum width of the apical foramen;
- » A'B' - maximum width between the incisal edge or cusp tip and the end of dental crown, used in teeth that no root formation was detected;
- » B'C' - maximum width of the apical foramen, used in teeth where no root formation was detected.

The calibrated examiners measured all 238 teeth at different development stages using the CBCT images and assessed the dimensions in the directions described above. When a consensus was not reached a third observer made the final decision. Due to peculiarities of distinct dental groups, especially for multirooted teeth, measurements

were made specifically for each root. The B'C' reference for teeth with more than one root used the mean distance between roots.

Using these measurements a quantitative model with five scores was suggested for all dental groups (with the exception of the third molar): 0 = absence of dental crypt; 1 = presence of dental crypt; 2 = dental crown partially formed; 3 = dental crown completely formed; 4 = beginning of root formation – open apex; 5 = end of root formation – closed apex) (Fig 1).

### RESULTS

Linear measurements (mm) of the dental development stages are shown in Tables 1 to 16. Table 17 presents the mean values (mm) of dental development stages on CBCT scans. Figures 2 to 21 show the images of dental development stages.

### DISCUSSION

The formation stages of deciduous and permanent teeth are basically the same, differing only in time periods. The dental lamina of deciduous dentition begins between the sixth and eighth week of embryonic development. Permanent teeth begin their development between the twentieth week of intra-uterine life and the tenth month after birth; permanent molars, between the twentieth week of intra-uterine life (first molar) and the fifth year of life (third molar).<sup>33</sup> Dental development starts during the intra-uterine life and lasts approximately until the second decade of life.

The values found by delimiting and measuring the distances between anatomical landmarks corresponding to human teeth development stages are described in Tables 1 to 16. These results allowed the establishment of a model to quantify the initial and final stages of tooth development for each dental group, based on mean values (Table 17). Figures 2 to 21 illustrate dimensions of dental development stages for maxillary and mandibular central and lateral incisors, canine, premolars and molars in the coronal and sagittal planes.

TABLE 1 - Linear measurements (mm) of dental development stages of maxillary anterior teeth (Coronal view).

| Age<br>(years) | Maxillary Central Incisor |       |       |       |      | Maxillary Lateral Incisor |      |      |       |       | Maxillary Canine |      |       |       |       |       |      |      |
|----------------|---------------------------|-------|-------|-------|------|---------------------------|------|------|-------|-------|------------------|------|-------|-------|-------|-------|------|------|
|                | A'B'                      | AB    | BC    | AC    | CD   | B'C'                      | A'B' | AB   | BC    | AC    | CD               | B'C' | A'B'  | AB    | BC    | AC    | CD   | B'C' |
| 3              | 8.50                      |       |       |       |      | 4.70                      | 5.24 |      |       |       |                  | 3.90 | 7.30  |       |       |       |      | 6.36 |
| 4              | 11.03                     |       |       |       |      | 5.47                      | 9.31 |      |       |       |                  | 4.20 | 10.22 |       |       |       |      | 6.84 |
| 5              | 11.50                     |       |       |       |      | 4.50                      | 7.85 |      |       |       |                  | 3.61 | 9.77  |       |       |       |      | 5.77 |
| 6              |                           | 9.30  | 8.61  | 17.57 | 4.24 |                           |      | 7.87 | 5.60  | 13.10 | 3.61             |      |       | 9.02  | 3.06  | 11.88 | 4.80 |      |
| 7              |                           | 10.90 | 8.64  | 18.84 | 3.22 |                           |      | 8.63 | 5.20  | 13.72 | 3.81             |      |       | 10.70 | 2.81  | 12.78 | 5.46 |      |
| 8              |                           | 11.19 | 14.02 | 24.79 | 2.81 |                           |      | 8.55 | 9.77  | 18.00 | 2.81             |      |       | 11.38 | 4.37  | 15.42 | 5.69 |      |
| 9              |                           | 8.66  | 12.34 | 19.85 | 0.00 |                           |      | 7.28 | 11.79 | 18.43 | 0.00             |      |       | 8.35  | 11.22 | 19.00 | 2.01 |      |
| 10             |                           | 9.85  | 16.12 | 25.08 | 0.00 |                           |      | 7.53 | 14.84 | 21.65 | 0.00             |      |       | 9.93  | 10.32 | 19.67 | 2.81 |      |
| 11             |                           | 8.74  | 12.76 | 21.01 | 0.00 |                           |      | 7.84 | 13.97 | 21.01 | 0.00             |      |       | 9.04  | 17.03 | 25.02 | 0.00 |      |
| 12             |                           | 11.06 | 13.49 | 24.00 | 0.00 |                           |      | 8.40 | 14.23 | 21.93 | 0.00             |      |       | 10.44 | 15.69 | 25.40 | 2.09 |      |
| 13             |                           | 9.18  | 14.49 | 22.83 | 0.00 |                           |      | 7.47 | 15.56 | 22.17 | 0.00             |      |       | 9.07  | 18.05 | 26.46 | 0.00 |      |
| 14             |                           | 9.63  | 12.53 | 21.78 | 0.00 |                           |      | 7.22 | 15.45 | 22.17 | 0.00             |      |       | 7.62  | 18.58 | 25.55 | 0.00 |      |
| 15             |                           | 10.33 | 14.36 | 24.01 | 0.00 |                           |      | 7.47 | 13.34 | 20.50 | 0.00             |      |       | 8.48  | 18.75 | 26.61 | 0.00 |      |
| 16             |                           | 8.83  | 14.05 | 21.78 | 0.00 |                           |      | 7.50 | 13.68 | 20.53 | 0.00             |      |       | 8.35  | 19.50 | 27.34 | 0.00 |      |
| 17             |                           | 9.33  | 12.17 | 20.80 | 0.00 |                           |      | 7.95 | 13.10 | 20.54 | 0.00             |      |       | 8.92  | 15.18 | 23.41 | 0.00 |      |
| 18             |                           | 9.57  | 15.23 | 23.77 | 0.00 |                           |      | 7.80 | 14.56 | 21.40 | 0.00             |      |       | 9.51  | 19.94 | 28.22 | 0.00 |      |
| 19             |                           | 10.31 | 16.32 | 25.80 | 0.00 |                           |      | 8.06 | 15.09 | 22.15 | 0.00             |      |       | 7.97  | 18.87 | 26.06 | 0.00 |      |
| 20             |                           | 9.11  | 15.18 | 23.07 | 0.00 |                           |      | 7.73 | 13.19 | 20.00 | 0.00             |      |       | 8.77  | 19.26 | 26.60 | 0.00 |      |

TABLE 2 - Linear measurements (mm) of dental development stages of maxillary anterior teeth (Sagittal view).

| Age<br>(years) | Maxillary Central Incisor |       |       |       |      | Maxillary Lateral Incisor |       |       |       |       | Maxillary Canine |      |       |       |       |       |      |      |
|----------------|---------------------------|-------|-------|-------|------|---------------------------|-------|-------|-------|-------|------------------|------|-------|-------|-------|-------|------|------|
|                | A'B'                      | AB    | BC    | AC    | CD   | B'C'                      | A'B'  | AB    | BC    | AC    | CD               | B'C' | A'B'  | AB    | BC    | AC    | CD   | B'C' |
| 3              | 9.60                      |       |       |       |      | 5.79                      | 6.30  |       |       |       |                  | 4.30 | 7.13  |       |       |       |      | 5.41 |
| 4              | 11.40                     |       |       |       |      | 6.04                      | 10.06 |       |       |       |                  | 5.53 | 9.92  |       |       |       |      | 6.74 |
| 5              | 13.23                     |       |       |       |      | 5.52                      | 10.15 |       |       |       |                  | 5.53 | 10.24 |       |       |       |      | 6.18 |
| 6              |                           | 12.41 | 7.70  | 19.57 | 4.49 |                           |       | 10.04 | 2.67  | 12.50 | 5.83             |      |       | 10.63 | 1.71  | 12.20 | 7.62 |      |
| 7              |                           | 13.62 | 9.06  | 22.07 | 3.58 |                           |       | 12.01 | 4.12  | 15.95 | 5.66             |      |       | 10.44 | 3.06  | 13.22 | 7.30 |      |
| 8              |                           | 12.43 | 13.33 | 24.80 | 3.23 |                           |       | 11.23 | 9.04  | 19.50 | 5.02             |      |       | 13.00 | 2.91  | 15.81 | 8.77 |      |
| 9              |                           | 10.85 | 11.01 | 20.87 | 0.00 |                           |       | 10.72 | 10.88 | 20.24 | 0.00             |      |       | 10.10 | 10.12 | 19.68 | 3.80 |      |
| 10             |                           | 12.04 | 15.58 | 26.44 | 0.00 |                           |       | 10.47 | 14.49 | 23.87 | 1.28             |      |       | 11.77 | 8.80  | 20.24 | 5.02 |      |
| 11             |                           | 12.04 | 12.38 | 23.24 | 0.00 |                           |       | 10.83 | 13.00 | 22.75 | 0.00             |      |       | 11.51 | 17.77 | 27.90 | 0.00 |      |
| 12             |                           | 12.28 | 15.15 | 26.27 | 0.00 |                           |       | 11.61 | 15.70 | 26.17 | 0.00             |      |       | 13.01 | 14.30 | 26.76 | 3.79 |      |
| 13             |                           | 11.12 | 14.81 | 25.05 | 0.00 |                           |       | 9.65  | 14.85 | 23.39 | 0.00             |      |       | 11.61 | 17.05 | 27.51 | 0.00 |      |
| 14             |                           | 11.09 | 14.48 | 24.96 | 0.00 |                           |       | 10.07 | 14.37 | 23.74 | 0.00             |      |       | 10.05 | 16.75 | 26.01 | 0.00 |      |
| 15             |                           | 11.29 | 13.18 | 23.68 | 0.00 |                           |       | 9.48  | 12.88 | 21.46 | 0.00             |      |       | 9.95  | 18.09 | 26.97 | 0.00 |      |
| 16             |                           | 11.65 | 13.59 | 24.56 | 0.00 |                           |       | 9.67  | 14.78 | 23.35 | 0.00             |      |       | 11.29 | 19.25 | 29.50 | 0.00 |      |
| 17             |                           | 11.26 | 10.00 | 20.32 | 0.00 |                           |       | 10.01 | 11.17 | 19.78 | 0.00             |      |       | 10.59 | 15.25 | 24.53 | 0.00 |      |
| 18             |                           | 12.79 | 13.10 | 25.44 | 0.00 |                           |       | 11.20 | 13.21 | 23.34 | 0.00             |      |       | 12.61 | 16.39 | 28.24 | 0.00 |      |
| 19             |                           | 11.93 | 15.09 | 26.42 | 0.00 |                           |       | 9.81  | 15.33 | 24.01 | 0.00             |      |       | 9.65  | 18.41 | 27.46 | 0.00 |      |
| 20             |                           | 13.06 | 14.75 | 26.58 | 0.00 |                           |       | 10.79 | 16.24 | 25.37 | 0.00             |      |       | 11.41 | 18.09 | 28.04 | 0.00 |      |

TABLE 3 - Linear measurements (mm) of dental development stages of maxillary premolars teeth (Coronal view).

| Age<br>(years) | Maxillary First Premolar |      |       |       |      |      |              |      |       |       |      |      | Maxillary Second Premolar |                   |       |       |      |      |              |      |                   |       |      |      |  |  |
|----------------|--------------------------|------|-------|-------|------|------|--------------|------|-------|-------|------|------|---------------------------|-------------------|-------|-------|------|------|--------------|------|-------------------|-------|------|------|--|--|
|                | Buccal Root              |      |       |       |      |      | Palatal Root |      |       |       |      |      | Buccal Root               |                   |       |       |      |      | Palatal Root |      |                   |       |      |      |  |  |
|                | A'B'                     | AB   | BC    | AC    | CD   | B'C' | A'B'         | AB   | BC    | AC    | CD   | B'C' | A'B'                      | AB                | BC    | AC    | CD   | B'C' | A'B'         | AB   | BC                | AC    | CD   | B'C' |  |  |
| 3              | 4.30                     |      |       |       |      | 4.88 | 3.31         |      |       |       |      | 4.88 |                           | PRESENCE OF CRYPT |       |       |      |      |              |      | PRESENCE OF CRYPT |       |      |      |  |  |
| 4              | 6.85                     |      |       |       |      | 4.24 | 5.47         |      |       |       |      | 4.24 | 4.24                      |                   |       |       |      | 4.58 | 3.66         |      |                   |       |      | 4.58 |  |  |
| 5              | 6.85                     |      |       |       |      | 5.11 | 5.77         |      |       |       |      | 5.11 | 3.66                      |                   |       |       |      | 3.66 | 2.77         |      |                   |       |      | 2.77 |  |  |
| 6              |                          | 7.98 | 1.81  | 9.62  | 4.20 |      |              | 7.40 | 1.40  | 8.74  | 4.20 |      |                           | 7.56              | 1.40  | 8.82  | 4.18 |      |              | 7.38 | 1.22              | 8.51  | 4.18 |      |  |  |
| 7              |                          | 8.54 | 2.43  | 10.72 | 4.44 |      |              | 8.59 |       |       | 4.44 |      |                           | 7.78              | 1.02  | 8.74  | 4.60 |      |              | 7.81 | 1.02              | 8.75  | 4.60 |      |  |  |
| 8              |                          | 8.40 | 6.07  | 14.00 | 3.26 |      |              | 7.07 | 4.68  | 11.42 | 3.26 |      |                           | 7.52              | 3.81  | 11.02 | 4.02 |      |              | 7.33 | 3.41              | 10.44 | 4.02 |      |  |  |
| 9              |                          | 7.97 | 8.12  | 15.63 | 2.21 |      |              | 6.84 | 7.69  | 14.21 | 2.01 |      |                           | 7.78              | 6.80  | 14.44 | 3.21 |      |              | 7.40 | 6.80              | 14.04 | 3.61 |      |  |  |
| 10             |                          | 7.86 | 11.69 | 19.01 | 1.41 |      |              | 6.85 | 11.61 | 18.25 | 1.41 |      |                           | 7.53              | 11.29 | 18.42 | 2.01 |      |              | 6.90 | 10.65             | 17.46 | 2.40 |      |  |  |
| 11             |                          | 8.73 | 12.91 | 20.80 | 1.22 |      |              | 7.67 | 13.10 | 20.22 | 0.00 |      |                           | 7.84              | 13.12 | 20.42 | 1.79 |      |              | 7.53 | 12.70             | 19.81 | 1.22 |      |  |  |
| 12             |                          | 8.85 | 12.81 | 20.60 | 1.26 |      |              | 7.81 | 12.37 | 19.64 | 0.82 |      |                           | 7.52              | 11.51 | 18.27 | 0.63 |      |              | 7.97 | 11.71             | 19.22 | 0.63 |      |  |  |
| 13             |                          | 7.15 | 14.76 | 21.40 | 0.00 |      |              | 7.15 | 12.73 | 19.40 | 0.00 |      |                           | 6.77              | 15.89 | 22.01 | 0.00 |      |              | 6.32 | 15.85             | 21.61 | 0.00 |      |  |  |
| 14             |                          | 6.96 | 14.16 | 20.45 | 0.00 |      |              | 6.84 | 14.32 | 20.63 | 0.00 |      |                           | 6.77              | 15.16 | 21.40 | 0.00 |      |              | 6.32 | 14.80             | 20.60 | 0.00 |      |  |  |
| 15             |                          | 7.66 | 15.67 | 22.43 | 0.00 |      |              | 7.38 | 14.96 | 22.01 | 0.00 |      |                           | 7.40              | 14.12 | 21.01 | 0.00 |      |              | 7.15 | 14.12             | 20.80 | 0.00 |      |  |  |
| 16             |                          | 7.72 | 14.63 | 21.80 | 0.00 |      |              | 7.18 | 14.56 | 21.26 | 0.00 |      |                           | 7.72              | 16.36 | 23.43 | 0.00 |      |              | 6.99 | 16.06             | 22.51 | 0.00 |      |  |  |
| 17             |                          | 7.35 | 12.33 | 18.81 | 0.00 |      |              | 7.16 | 11.07 | 17.61 | 0.00 |      |                           | 6.49              | 11.47 | 17.51 | 0.00 |      |              | 6.41 | 11.04             | 16.71 | 0.00 |      |  |  |
| 18             |                          | 8.03 | 14.12 | 21.40 | 0.00 |      |              | 7.38 | 13.14 | 20.52 | 0.00 |      |                           | 7.78              | 15.07 | 22.42 | 0.00 |      |              | 7.17 | 15.25             | 21.86 | 0.00 |      |  |  |
| 19             |                          | 7.47 | 14.37 | 21.20 | 0.00 |      |              | 7.15 | 14.01 | 20.60 | 0.00 |      |                           | 7.15              | 15.82 | 22.40 | 0.00 |      |              | 7.40 | 16.51             | 23.21 | 0.00 |      |  |  |
| 20             |                          | 8.17 | 17.42 | 24.61 | 0.00 |      |              | 7.02 | 16.02 | 22.09 | 0.00 |      |                           | 8.16              | 16.41 | 24.00 | 0.00 |      |              | 7.34 | 16.60             | 23.40 | 0.00 |      |  |  |

TABLE 4 - Linear measurements (mm) of dental development stages of maxillary premolars teeth (Sagittal view).

| Age<br>(years) | Maxillary First Premolar |      |       |       |      |      |              |      |       |       |      |      | Maxillary Second Premolar |                   |       |       |      |      |                   |      |       |       |      |      |  |  |
|----------------|--------------------------|------|-------|-------|------|------|--------------|------|-------|-------|------|------|---------------------------|-------------------|-------|-------|------|------|-------------------|------|-------|-------|------|------|--|--|
|                | Buccal Root              |      |       |       |      |      | Palatal Root |      |       |       |      |      | Buccal Root               |                   |       |       |      |      | Palatal Root      |      |       |       |      |      |  |  |
|                | A'B'                     | AB   | BC    | AC    | CD   | B'C' | A'B'         | AB   | BC    | AC    | CD   | B'C' | A'B'                      | AB                | BC    | AC    | CD   | B'C' | A'B'              | AB   | BC    | AC    | CD   | B'C' |  |  |
| 3              | 4.51                     |      |       |       |      | 5.98 | 2.28         |      |       |       |      | 5.98 |                           | PRESENCE OF CRYPT |       |       |      |      | PRESENCE OF CRYPT |      |       |       |      |      |  |  |
| 4              | 6.85                     |      |       |       |      | 7.97 | 6.33         |      |       |       |      | 7.97 | 4.54                      |                   |       |       |      | 6.61 | 3.35              |      |       |       |      | 6.61 |  |  |
| 5              | 6.58                     |      |       |       |      | 7.60 | 5.47         |      |       |       |      | 7.60 | 3.79                      |                   |       |       |      | 2.47 | 3.01              |      |       |       |      | 2.47 |  |  |
| 6              |                          | 8.20 | 1.22  | 9.34  | 7.40 |      |              | 7.27 | 1.34  | 8.41  | 7.40 |      |                           | 6.84              | 1.22  | 7.96  | 8.02 |      |                   | 7.27 | 1.08  | 8.02  | 8.02 |      |  |  |
| 7              |                          | 9.14 | 2.15  | 11.03 | 7.96 |      |              | 8.40 |       |       | 7.96 |      |                           | 6.99              | 2.15  | 8.84  | 9.02 |      |                   | 7.35 | 1.41  | 8.60  | 9.02 |      |  |  |
| 8              |                          | 9.22 | 4.22  | 13.05 | 8.26 |      |              | 7.73 | 4.56  | 12.00 | 8.26 |      |                           | 9.22              | 2.34  | 11.02 | 9.00 |      |                   | 7.62 | 2.34  | 9.65  | 9.00 |      |  |  |
| 9              |                          | 7.97 | 7.89  | 15.45 | 5.43 |      |              | 7.40 | 7.77  | 15.07 | 5.43 |      |                           | 7.59              | 6.65  | 13.89 | 6.48 |      |                   | 7.82 | 6.55  | 14.02 | 6.48 |      |  |  |
| 10             |                          | 8.75 | 12.15 | 20.39 | 3.54 |      |              | 6.91 | 10.45 | 17.20 | 3.54 |      |                           | 8.66              | 9.31  | 17.66 | 4.00 |      |                   | 7.03 | 9.73  | 16.63 | 4.00 |      |  |  |
| 11             |                          | 8.98 | 11.94 | 20.60 | 0.80 |      |              | 7.82 | 12.48 | 20.22 | 0.00 |      |                           | 8.29              | 12.03 | 19.90 | 2.41 |      |                   | 7.73 | 12.24 | 19.63 | 2.41 |      |  |  |
| 12             |                          | 9.41 | 11.51 | 20.60 | 0.82 |      |              | 7.62 | 11.81 | 19.25 | 0.80 |      |                           | 8.52              | 10.44 | 18.38 | 2.01 |      |                   | 8.41 | 10.88 | 18.41 | 2.01 |      |  |  |
| 13             |                          | 8.80 | 12.66 | 21.27 | 0.00 |      |              | 7.07 | 13.21 | 19.90 | 0.00 |      |                           | 7.57              | 14.95 | 22.06 | 0.00 |      |                   | 6.68 | 15.37 | 21.54 | 0.00 |      |  |  |
| 14             |                          | 7.73 | 12.83 | 20.22 | 0.00 |      |              | 7.22 | 12.86 | 19.80 | 0.00 |      |                           | 7.86              | 13.30 | 20.76 | 0.00 |      |                   | 6.94 | 14.04 | 20.39 | 0.00 |      |  |  |
| 15             |                          | 8.16 | 14.14 | 21.80 | 0.00 |      |              | 7.50 | 13.75 | 21.02 | 0.00 |      |                           | 7.25              | 14.26 | 20.91 | 0.00 |      |                   | 7.47 | 14.21 | 20.82 | 0.00 |      |  |  |
| 16             |                          | 8.26 | 14.31 | 22.35 | 0.00 |      |              | 7.53 | 14.41 | 21.66 | 0.00 |      |                           | 7.86              | 14.60 | 21.84 | 0.00 |      |                   | 7.33 | 14.87 | 21.50 | 0.00 |      |  |  |
| 17             |                          | 7.52 | 10.31 | 17.26 | 0.00 |      |              | 7.16 | 10.61 | 17.32 | 0.00 |      |                           | 7.29              | 10.68 | 17.64 | 0.00 |      |                   | 7.11 | 10.85 | 17.11 | 0.00 |      |  |  |
| 18             |                          | 9.42 | 12.42 | 21.56 | 0.00 |      |              | 7.67 | 12.28 | 19.89 | 0.00 |      |                           | 8.46              | 15.05 | 22.95 | 0.00 |      |                   | 7.67 | 14.99 | 22.04 | 0.00 |      |  |  |
| 19             |                          | 8.10 | 13.19 | 20.62 | 0.00 |      |              | 7.23 | 14.20 | 21.01 | 0.00 |      |                           | 7.53              | 16.54 | 23.57 | 0.00 |      |                   | 7.03 | 17.28 | 23.50 | 0.00 |      |  |  |
| 20             |                          | 9.43 | 15.76 | 24.45 | 0.00 |      |              | 7.67 | 13.94 | 21.54 | 0.00 |      |                           | 8.63              | 17.15 | 24.96 | 0.00 |      |                   | 7.84 | 16.83 | 24.39 | 0.00 |      |  |  |

TABLE 5 - Linear measurements (mm) of dental development stages of maxillary first molar tooth (Coronal view).

| Age<br>(years) | Maxillary First Molar |      |       |       |      |                    |      |      |       |       |              |      |       |      |       |       |      |      |
|----------------|-----------------------|------|-------|-------|------|--------------------|------|------|-------|-------|--------------|------|-------|------|-------|-------|------|------|
|                | Mesio Buccal Root     |      |       |       |      | Distal Buccal Root |      |      |       |       | Palatal Root |      |       |      |       |       |      |      |
|                | A'B'                  | AB   | BC    | AC    | CD   | B'C'               | A'B' | AB   | BC    | AC    | CD           | B'C' | A'B'  | AB   | BC    | AC    | CD   | B'C' |
| 3              | 7.50                  |      |       |       |      | 7.22               | 7.50 |      |       |       |              | 7.22 | 10.06 |      |       |       |      | 7.85 |
| 4              |                       | 7.59 | 2.72  | 10.26 | 6.64 |                    |      | 7.52 | 2.28  | 9.72  | 6.64         |      |       | 9.02 | 1.90  | 10.92 | 6.64 |      |
| 5              |                       | 7.71 | 3.06  | 10.57 | 6.63 |                    |      | 7.35 | 3.06  | 10.24 | 6.63         |      |       | 8.88 | 2.85  | 11.44 | 6.63 |      |
| 6              |                       | 6.85 | 8.91  | 15.61 | 2.20 |                    |      | 8.77 | 8.66  | 16.80 | 2.01         |      |       | 6.79 | 8.68  | 15.01 | 3.35 |      |
| 7              |                       | 7.86 | 9.85  | 17.80 | 1.08 |                    |      | 7.96 | 9.42  | 17.23 | 1.00         |      |       | 8.29 | 11.18 | 18.42 | 3.01 |      |
| 8              |                       | 6.94 | 11.74 | 18.40 | 1.61 |                    |      | 7.53 | 11.64 | 18.84 | 1.41         |      |       | 8.44 | 10.96 | 18.82 | 3.22 |      |
| 9              |                       | 6.84 | 12.36 | 18.80 | 0.00 |                    |      | 7.03 | 11.91 | 18.83 | 0.00         |      |       | 8.22 | 13.49 | 20.82 | 0.00 |      |
| 10             |                       | 6.36 | 14.74 | 20.81 | 0.00 |                    |      | 7.64 | 13.80 | 21.42 | 0.00         |      |       | 8.35 | 15.77 | 23.27 | 0.00 |      |
| 11             |                       | 6.60 | 14.31 | 20.32 | 0.00 |                    |      | 7.57 | 12.06 | 19.40 | 0.00         |      |       | 8.22 | 14.95 | 22.03 | 0.00 |      |
| 12             |                       | 7.81 | 13.18 | 20.60 | 0.00 |                    |      | 8.01 | 13.10 | 20.94 | 0.00         |      |       | 8.30 | 16.02 | 23.50 | 0.00 |      |
| 13             |                       | 6.36 | 12.99 | 19.02 | 0.00 |                    |      | 6.48 | 12.53 | 18.82 | 0.00         |      |       | 7.23 | 14.60 | 21.26 | 0.00 |      |
| 14             |                       | 6.26 | 12.03 | 18.03 | 0.00 |                    |      | 6.68 | 11.44 | 18.00 | 0.00         |      |       | 7.47 | 13.22 | 20.00 | 0.00 |      |
| 15             |                       | 6.99 | 14.04 | 20.62 | 0.00 |                    |      | 7.81 | 12.21 | 20.02 | 0.00         |      |       | 7.47 | 13.82 | 20.42 | 0.00 |      |
| 16             |                       | 6.79 | 13.85 | 20.22 | 0.00 |                    |      | 7.24 | 13.64 | 20.80 | 0.00         |      |       | 7.98 | 16.07 | 22.86 | 0.00 |      |
| 17             |                       | 6.32 | 11.47 | 17.05 | 0.00 |                    |      | 6.91 | 9.58  | 16.25 | 0.00         |      |       | 7.60 | 11.96 | 18.54 | 0.00 |      |
| 18             |                       | 7.03 | 14.04 | 20.62 | 0.00 |                    |      | 7.30 | 12.56 | 19.63 | 0.00         |      |       | 7.54 | 13.74 | 20.22 | 0.00 |      |
| 19             |                       | 7.28 | 14.84 | 21.46 | 0.00 |                    |      | 7.81 | 12.96 | 21.46 | 0.00         |      |       | 8.36 | 14.51 | 22.01 | 0.00 |      |
| 20             |                       | 7.67 | 14.29 | 21.14 | 0.00 |                    |      | 8.40 | 12.96 | 21.00 | 0.00         |      |       | 8.36 | 17.09 | 24.27 | 0.00 |      |

TABLE 6 - Linear measurements (mm) of dental development stages of maxillary first molar tooth (Sagittal view).

| Age<br>(years) | Maxillary First Molar |      |       |       |       |                    |      |      |       |       |              |       |      |      |       |       |       |       |
|----------------|-----------------------|------|-------|-------|-------|--------------------|------|------|-------|-------|--------------|-------|------|------|-------|-------|-------|-------|
|                | Mesio Buccal Root     |      |       |       |       | Distal Buccal Root |      |      |       |       | Palatal Root |       |      |      |       |       |       |       |
|                | A'B'                  | AB   | BC    | AC    | CD    | B'C'               | A'B' | AB   | BC    | AC    | CD           | B'C'  | A'B' | AB   | BC    | AC    | CD    | B'C'  |
| 3              | 6.63                  |      |       |       |       | 11.16              | 6.60 |      |       |       |              | 11.16 | 7.74 |      |       |       |       | 11.16 |
| 4              |                       | 9.60 | 1.90  | 11.24 | 10.01 |                    |      | 7.50 |       |       | 10.01        |       |      | 8.30 | 2.72  | 10.90 | 10.01 |       |
| 5              |                       | 7.79 | 2.10  | 9.83  | 10.80 |                    |      | 7.71 | 2.12  | 9.72  | 10.80        |       |      | 8.36 | 2.18  | 10.19 | 10.80 |       |
| 6              |                       | 6.71 | 9.23  | 15.81 | 2.00  |                    |      | 7.34 | 9.93  | 16.41 | 1.65         |       |      | 8.54 | 9.70  | 17.84 | 2.72  |       |
| 7              |                       | 7.92 | 9.63  | 17.41 | 4.42  |                    |      | 7.62 | 9.34  | 16.84 | 3.49         |       |      | 8.35 | 10.40 | 18.58 | 2.67  |       |
| 8              |                       | 7.96 | 10.41 | 18.01 | 4.08  |                    |      | 7.47 | 10.80 | 17.56 | 2.34         |       |      | 6.84 | 11.00 | 17.69 | 2.61  |       |
| 9              |                       | 7.21 | 12.08 | 18.83 | 0.00  |                    |      | 7.23 | 11.74 | 18.43 | 0.00         |       |      | 7.42 | 13.92 | 21.00 | 0.00  |       |
| 10             |                       | 7.42 | 14.08 | 21.31 | 0.00  |                    |      | 7.80 | 12.48 | 20.25 | 0.00         |       |      | 8.14 | 13.88 | 21.95 | 0.00  |       |
| 11             |                       | 7.10 | 12.23 | 18.91 | 0.00  |                    |      | 7.73 | 12.36 | 19.81 | 0.00         |       |      | 8.06 | 13.08 | 20.91 | 0.00  |       |
| 12             |                       | 7.96 | 13.35 | 20.72 | 0.00  |                    |      | 7.42 | 13.65 | 20.22 | 0.00         |       |      | 8.93 | 15.07 | 23.62 | 0.00  |       |
| 13             |                       | 6.71 | 12.66 | 19.20 | 0.00  |                    |      | 6.48 | 12.04 | 18.40 | 0.00         |       |      | 7.43 | 13.67 | 20.46 | 0.00  |       |
| 14             |                       | 6.85 | 12.13 | 18.71 | 0.00  |                    |      | 6.71 | 10.95 | 17.41 | 0.00         |       |      | 7.79 | 11.57 | 19.10 | 0.00  |       |
| 15             |                       | 7.28 | 13.25 | 20.22 | 0.00  |                    |      | 7.38 | 12.06 | 19.40 | 0.00         |       |      | 8.03 | 12.61 | 20.42 | 0.00  |       |
| 16             |                       | 7.30 | 13.22 | 20.24 | 0.00  |                    |      | 6.87 | 14.31 | 21.02 | 0.00         |       |      | 7.52 | 15.03 | 22.37 | 0.00  |       |
| 17             |                       | 7.29 | 10.85 | 17.25 | 0.00  |                    |      | 7.04 | 9.71  | 16.25 | 0.00         |       |      | 7.76 | 11.03 | 18.54 | 0.00  |       |
| 18             |                       | 8.86 | 12.03 | 20.52 | 0.00  |                    |      | 8.24 | 11.30 | 19.28 | 0.00         |       |      | 7.07 | 13.81 | 20.63 | 0.00  |       |
| 19             |                       | 7.81 | 13.45 | 20.82 | 0.00  |                    |      | 7.28 | 14.12 | 21.00 | 0.00         |       |      | 8.22 | 14.81 | 22.69 | 0.00  |       |
| 20             |                       | 8.93 | 12.18 | 20.41 | 0.00  |                    |      | 7.86 | 14.14 | 21.60 | 0.00         |       |      | 9.14 | 15.42 | 23.99 | 0.00  |       |

TABLE 7 - Linear measurements (mm) of dental development stages of maxillary second molar tooth (Coronal view).

| Age<br>(years) | Maxillary Second Molar |      |       |       |      |                    |      |      |       |       |      |      |      |                  |       |       |      |      |
|----------------|------------------------|------|-------|-------|------|--------------------|------|------|-------|-------|------|------|------|------------------|-------|-------|------|------|
|                | Mesio buccal Root      |      |       |       |      | Distal buccal Root |      |      |       |       |      |      |      | Palatal Root     |       |       |      |      |
|                | A'B'                   | AB   | BC    | AC    | CD   | B'C'               | A'B' | AB   | BC    | AC    | CD   | B'C' | A'B' | AB               | BC    | AC    | CD   | B'C' |
| 3              | ABSENCE OF CRYPT       |      |       |       |      | ABSENCE OF CRYPT   |      |      |       |       |      |      |      | ABSENCE OF CRYPT |       |       |      |      |
| 4              | 5.11                   |      |       |       |      | 7.00               | 3.01 |      |       |       |      | 7.00 | 4.84 |                  |       |       |      | 7.00 |
| 5              | 4.26                   |      |       |       |      | 3.31               |      |      |       |       |      |      |      | 4.26             |       |       |      |      |
| 6              |                        | 7.57 |       |       | 6.85 |                    |      | 7.22 |       |       | 6.85 |      |      | 7.98             |       |       | 6.85 |      |
| 7              |                        | 8.66 |       |       | 7.07 |                    |      | 8.04 |       |       | 7.07 |      |      | 8.79             |       |       | 7.07 |      |
| 8              |                        | 7.09 | 2.43  | 9.26  | 7.10 |                    |      | 6.81 | 1.65  | 8.40  | 7.10 |      |      | 7.42             | 3.03  | 10.06 | 7.10 |      |
| 9              |                        | 7.47 | 6.21  | 13.21 | 4.40 |                    |      | 7.22 | 4.90  | 12.01 | 4.40 |      |      | 7.84             | 5.10  | 12.50 | 3.80 |      |
| 10             |                        | 6.91 | 8.22  | 14.67 | 2.04 |                    |      | 6.65 | 6.60  | 13.21 | 2.47 |      |      | 7.53             | 8.29  | 15.01 | 3.49 |      |
| 11             |                        | 7.25 | 9.41  | 16.21 | 1.02 |                    |      | 7.60 | 6.71  | 14.14 | 1.00 |      |      | 7.72             | 9.63  | 16.51 | 3.21 |      |
| 12             |                        | 7.47 | 10.31 | 17.34 | 2.21 |                    |      | 6.99 | 7.86  | 14.62 | 2.04 |      |      | 8.20             | 9.49  | 17.04 | 2.61 |      |
| 13             |                        | 6.46 | 11.61 | 17.60 | 0.00 |                    |      | 6.45 | 11.30 | 17.29 | 0.00 |      |      | 7.28             | 13.03 | 19.25 | 0.00 |      |
| 14             |                        | 6.14 | 12.32 | 17.82 | 0.00 |                    |      | 6.36 | 11.69 | 17.64 | 0.00 |      |      | 7.07             | 14.99 | 21.00 | 0.00 |      |
| 15             |                        | 7.23 | 11.76 | 18.29 | 0.00 |                    |      | 7.44 | 10.25 | 17.60 | 0.00 |      |      | 7.40             | 13.27 | 20.22 | 0.00 |      |
| 16             |                        | 7.28 | 14.52 | 20.72 | 0.00 |                    |      | 7.03 | 13.42 | 20.45 | 0.00 |      |      | 7.84             | 16.02 | 22.87 | 0.00 |      |
| 17             |                        | 6.43 | 13.46 | 19.07 | 0.00 |                    |      | 6.33 | 12.21 | 18.29 | 0.00 |      |      | 6.91             | 11.94 | 18.17 | 0.00 |      |
| 18             |                        | 7.78 | 13.98 | 20.72 | 0.00 |                    |      | 7.60 | 11.64 | 19.22 | 0.00 |      |      | 8.14             | 14.95 | 22.00 | 0.00 |      |
| 19             |                        | 7.21 | 13.26 | 19.80 | 0.00 |                    |      | 7.21 | 13.06 | 20.12 | 0.00 |      |      | 7.43             | 14.71 | 21.95 | 0.00 |      |
| 20             |                        | 7.86 | 14.02 | 21.25 | 0.00 |                    |      | 7.57 | 12.61 | 19.67 | 0.00 |      |      | 8.41             | 17.85 | 24.80 | 0.00 |      |

TABLE 8 - Linear measurements (mm) of dental development stages of maxillary second molar tooth (Sagittal view).

| Age<br>(years) | Maxillary Second Molar |      |       |       |       |      |                    |      |       |       |       |      |                  |      |       |       |       |      |
|----------------|------------------------|------|-------|-------|-------|------|--------------------|------|-------|-------|-------|------|------------------|------|-------|-------|-------|------|
|                | Mesio Buccal Root      |      |       |       |       |      | Distal Buccal Root |      |       |       |       |      | Palatal Root     |      |       |       |       |      |
|                | A'B'                   | AB   | BC    | AC    | CD    | B'C' | A'B'               | AB   | BC    | AC    | CD    | B'C' | A'B'             | AB   | BC    | AC    | CD    | B'C' |
| 3              | ABSENCE OF CRYPT       |      |       |       |       |      | ABSENCE OF CRYPT   |      |       |       |       |      | ABSENCE OF CRYPT |      |       |       |       |      |
| 4              | 5.32                   |      |       |       |       | 7.81 | 3.06               |      |       |       |       | 7.81 | 5.18             |      |       |       |       | 7.81 |
| 5              | 4.54                   |      |       |       |       |      | 3.00               |      |       |       |       |      | 4.74             |      |       |       |       |      |
| 6              |                        | 7.80 |       |       | 10.19 |      |                    | 7.02 |       |       | 10.19 |      |                  | 9.06 |       |       | 10.19 |      |
| 7              |                        | 8.42 |       |       | 9.87  |      |                    | 8.40 |       |       | 9.87  |      |                  | 9.22 |       |       | 9.87  |      |
| 8              |                        | 8.23 | 1.26  | 9.18  | 12.01 |      |                    | 7.15 | 1.71  | 8.55  | 12.01 |      |                  | 7.88 | 1.22  | 8.92  | 12.01 |      |
| 9              |                        | 7.78 | 5.88  | 13.01 | 8.24  |      |                    | 7.28 | 5.53  | 12.43 | 8.24  |      |                  | 7.28 | 5.41  | 12.50 | 8.24  |      |
| 10             |                        | 7.34 | 7.57  | 14.41 | 2.81  |      |                    | 7.28 | 6.23  | 13.27 | 2.83  |      |                  | 7.77 | 6.03  | 13.64 | 4.08  |      |
| 11             |                        | 8.49 | 9.01  | 16.43 | 2.01  |      |                    | 7.50 | 7.00  | 14.82 | 1.08  |      |                  | 7.66 | 8.55  | 16.16 | 1.97  |      |
| 12             |                        | 8.03 | 8.66  | 16.28 | 2.72  |      |                    | 7.78 | 6.85  | 14.56 | 3.68  |      |                  | 8.16 | 9.43  | 17.50 | 2.24  |      |
| 13             |                        | 6.99 | 11.60 | 18.19 | 0.00  |      |                    | 6.58 | 10.25 | 16.71 | 0.00  |      |                  | 7.47 | 12.50 | 19.60 | 0.00  |      |
| 14             |                        | 6.21 | 11.61 | 17.41 | 0.00  |      |                    | 6.48 | 10.82 | 17.27 | 0.00  |      |                  | 7.97 | 13.62 | 21.26 | 0.00  |      |
| 15             |                        | 7.67 | 11.64 | 18.49 | 0.00  |      |                    | 7.62 | 10.01 | 17.20 | 0.00  |      |                  | 8.41 | 12.13 | 19.68 | 0.00  |      |
| 16             |                        | 7.62 | 12.81 | 20.24 | 0.00  |      |                    | 7.03 | 14.01 | 20.94 | 0.00  |      |                  | 8.12 | 14.41 | 22.42 | 0.00  |      |
| 17             |                        | 6.80 | 11.95 | 18.04 | 0.00  |      |                    | 6.88 | 10.85 | 17.01 | 0.00  |      |                  | 8.31 | 12.12 | 19.06 | 0.00  |      |
| 18             |                        | 9.67 | 11.68 | 21.20 | 0.00  |      |                    | 7.33 | 12.50 | 19.60 | 0.00  |      |                  | 8.51 | 13.22 | 21.42 | 0.00  |      |
| 19             |                        | 7.47 | 13.06 | 20.01 | 0.00  |      |                    | 6.60 | 13.60 | 19.40 | 0.00  |      |                  | 7.86 | 13.80 | 21.49 | 0.00  |      |
| 20             |                        | 8.54 | 13.16 | 20.85 | 0.00  |      |                    | 7.54 | 12.46 | 19.33 | 0.00  |      |                  | 7.78 | 15.93 | 23.43 | 0.00  |      |

TABLE 9 - Linear measurements (mm) of dental development stages of mandibular anterior teeth (Coronal view).

| Age<br>(years) | Mandibular Central Incisor |      |       |       |      | Mandibular Lateral Incisor |       |      |       |       | Mandibular Canine |      |      |      |       |       |      |      |
|----------------|----------------------------|------|-------|-------|------|----------------------------|-------|------|-------|-------|-------------------|------|------|------|-------|-------|------|------|
|                | A'B'                       | AB   | BC    | AC    | CD   | B'C'                       | A'B'  | AB   | BC    | AC    | CD                | B'C' | A'B' | AB   | BC    | AC    | CD   | B'C' |
| 3              | 8.45                       |      |       |       |      | 3.35                       | 7.50  |      |       |       |                   | 3.35 | 7.31 |      |       |       |      | 4.80 |
| 4              | 9.97                       |      |       |       |      | 3.31                       | 10.36 |      |       |       |                   | 3.91 | 9.90 |      |       |       |      | 5.71 |
| 5              | 10.90                      |      |       |       |      | 3.00                       | 10.65 |      |       |       |                   | 3.61 | 9.30 |      |       |       |      | 5.32 |
| 6              |                            | 8.19 | 8.72  | 16.81 | 2.18 |                            |       | 8.16 | 7.26  | 15.07 | 2.77              |      |      | 9.02 | 2.42  | 11.21 | 6.00 |      |
| 7              |                            | 8.63 | 12.64 | 21.02 | 0.00 |                            |       | 7.87 | 13.65 | 21.15 | 0.00              |      |      | 8.88 | 9.43  | 18.05 | 3.21 |      |
| 8              |                            | 9.37 | 13.06 | 22.60 | 0.00 |                            |       | 9.18 | 14.51 | 23.40 | 0.60              |      |      | 9.95 | 8.09  | 17.66 | 3.61 |      |
| 9              |                            | 9.12 | 14.52 | 23.51 | 0.00 |                            |       | 8.73 | 15.57 | 24.01 | 1.50              |      |      | 9.10 | 12.25 | 21.12 | 3.50 |      |
| 10             |                            | 8.10 | 15.85 | 23.76 | 0.00 |                            |       | 9.10 | 16.02 | 24.81 | 1.03              |      |      | 8.46 | 13.06 | 21.05 | 3.25 |      |
| 11             |                            | 8.59 | 12.53 | 20.80 | 0.00 |                            |       | 8.60 | 15.26 | 23.43 | 0.00              |      |      | 9.49 | 17.47 | 26.44 | 1.60 |      |
| 12             |                            | 8.88 | 13.66 | 22.20 | 0.00 |                            |       | 8.74 | 15.00 | 23.52 | 0.00              |      |      | 8.92 | 15.93 | 24.39 | 0.00 |      |
| 13             |                            | 6.71 | 12.68 | 19.01 | 0.00 |                            |       | 6.84 | 14.47 | 20.82 | 0.00              |      |      | 7.53 | 14.26 | 21.05 | 0.00 |      |
| 14             |                            | 7.92 | 13.67 | 21.40 | 0.00 |                            |       | 7.42 | 15.42 | 22.41 | 0.00              |      |      | 8.54 | 14.85 | 23.03 | 0.00 |      |
| 15             |                            | 8.74 | 9.81  | 18.31 | 0.00 |                            |       | 8.91 | 10.72 | 19.40 | 0.00              |      |      | 8.79 | 13.39 | 21.65 | 0.00 |      |
| 16             |                            | 8.59 | 12.68 | 21.00 | 0.00 |                            |       | 8.83 | 14.40 | 22.61 | 0.00              |      |      | 9.62 | 16.16 | 25.41 | 0.00 |      |
| 17             |                            | 8.20 | 13.50 | 21.40 | 0.00 |                            |       | 8.94 | 15.47 | 23.90 | 0.00              |      |      | 9.67 | 20.52 | 28.81 | 0.00 |      |
| 18             |                            | 7.23 | 14.60 | 21.61 | 0.00 |                            |       | 7.53 | 15.06 | 22.01 | 0.00              |      |      | 7.86 | 18.68 | 25.89 | 0.00 |      |
| 19             |                            | 7.28 | 14.14 | 21.00 | 0.00 |                            |       | 7.78 | 14.71 | 22.20 | 0.00              |      |      | 7.66 | 18.95 | 26.00 | 0.00 |      |
| 20             |                            | 7.57 | 14.34 | 21.60 | 0.00 |                            |       | 7.73 | 12.66 | 20.20 | 0.00              |      |      | 9.23 | 19.67 | 28.43 | 0.00 |      |

TABLE 10 - Linear measurements (mm) of dental development stages of mandibular anterior teeth (Sagittal view).

| Age<br>(years) | Mandibular Central Incisor |       |       |      |    | Mandibular Lateral Incisor |       |       |       |       | Mandibular Canine |      |       |       |       |       |      |      |
|----------------|----------------------------|-------|-------|------|----|----------------------------|-------|-------|-------|-------|-------------------|------|-------|-------|-------|-------|------|------|
|                | A'B'                       | AB    | BC    | AC   | CD | B'C'                       | A'B'  | AB    | BC    | AC    | CD                | B'C' | A'B'  | AB    | BC    | AC    | CD   | B'C' |
| 3              | 8.40                       |       |       |      |    | 4.85                       | 8.19  |       |       |       |                   | 4.85 | 7.11  |       |       |       |      | 4.80 |
| 4              | 10.90                      |       |       |      |    | 5.53                       | 10.55 |       |       |       |                   | 6.63 | 9.53  |       |       |       |      | 6.41 |
| 5              | 11.89                      |       |       |      |    | 5.43                       | 11.16 |       |       |       |                   | 5.18 | 9.31  |       |       |       |      | 5.11 |
| 6              | 10.44                      | 8.24  | 18.09 | 5.13 |    |                            |       | 10.26 | 5.41  | 15.49 | 6.36              |      | 11.80 |       |       |       |      | 8.54 |
| 7              | 10.14                      | 12.03 | 21.41 | 0.00 |    |                            |       | 10.63 | 11.88 | 21.65 | 2.34              |      |       | 11.74 | 6.91  | 18.27 | 6.02 |      |
| 8              | 11.07                      | 12.52 | 22.62 | 0.00 |    |                            |       | 11.32 | 13.15 | 23.84 | 2.60              |      |       | 11.76 | 6.03  | 17.46 | 7.42 |      |
| 9              | 10.59                      | 14.98 | 24.50 | 0.00 |    |                            |       | 11.00 | 13.73 | 23.80 | 1.75              |      |       | 12.18 | 10.69 | 22.09 | 6.50 |      |
| 10             | 10.36                      | 15.10 | 24.50 | 0.00 |    |                            |       | 10.64 | 13.61 | 23.36 | 1.82              |      |       | 12.10 | 10.44 | 21.82 | 6.17 |      |
| 11             | 10.45                      | 14.14 | 23.53 | 0.00 |    |                            |       | 10.72 | 15.03 | 24.56 | 0.00              |      |       | 13.05 | 14.45 | 26.08 | 2.83 |      |
| 12             | 10.34                      | 13.07 | 22.82 | 0.00 |    |                            |       | 10.66 | 14.52 | 24.05 | 0.00              |      |       | 11.79 | 13.59 | 24.09 | 0.00 |      |
| 13             | 9.43                       | 10.58 | 19.46 | 0.00 |    |                            |       | 8.60  | 13.24 | 21.02 | 0.00              |      |       | 9.77  | 14.23 | 22.60 | 0.00 |      |
| 14             | 9.46                       | 12.97 | 21.40 | 0.00 |    |                            |       | 9.75  | 14.48 | 23.27 | 0.00              |      |       | 11.61 | 15.21 | 25.55 | 0.00 |      |
| 15             | 10.00                      | 10.88 | 20.06 | 0.00 |    |                            |       | 10.80 | 12.26 | 22.01 | 0.00              |      |       | 11.84 | 13.09 | 24.11 | 0.00 |      |
| 16             | 9.80                       | 13.72 | 22.29 | 0.00 |    |                            |       | 10.33 | 15.12 | 23.94 | 0.00              |      |       | 12.28 | 15.29 | 26.65 | 0.00 |      |
| 17             | 9.85                       | 13.61 | 22.67 | 0.00 |    |                            |       | 11.29 | 12.70 | 22.99 | 0.00              |      |       | 13.44 | 17.27 | 29.47 | 0.00 |      |
| 18             | 9.57                       | 14.45 | 23.19 | 0.00 |    |                            |       | 9.40  | 15.98 | 24.56 | 0.00              |      |       | 11.85 | 15.58 | 26.19 | 0.00 |      |
| 19             | 8.99                       | 13.58 | 21.60 | 0.00 |    |                            |       | 9.49  | 14.81 | 23.22 | 0.00              |      |       | 9.95  | 16.83 | 25.81 | 0.00 |      |
| 20             | 8.55                       | 13.74 | 21.47 | 0.00 |    |                            |       | 9.51  | 13.91 | 22.49 | 0.00              |      |       | 11.22 | 18.72 | 28.60 | 0.00 |      |

TABLE 11 - Linear measurements (mm) of dental development stages of mandibular premolars teeth (Coronal view).

| Age<br>(years) | Mandibular First Premolar |      |       |       |      | Mandibular Second Premolar |      |      |                   |       |      |      |
|----------------|---------------------------|------|-------|-------|------|----------------------------|------|------|-------------------|-------|------|------|
|                | A'B'                      | AB   | BC    | AC    | CD   | B'C'                       | A'B' | AB   | BC                | AC    | CD   | B'C' |
| 3              | 4.88                      |      |       |       |      | 5.18                       |      |      | PRESENCE OF CRYPT |       |      |      |
| 4              | 6.31                      |      |       |       |      | 5.43                       | 4.58 |      |                   |       |      | 4.51 |
| 5              | 5.69                      |      |       |       |      | 5.43                       |      |      | PRESENCE OF CRYPT |       |      |      |
| 6              | 8.25                      |      |       |       |      | 5.41                       | 8.19 |      |                   |       |      | 5.53 |
| 7              |                           | 8.17 | 5.20  | 13.15 | 3.88 |                            |      | 7.40 | 2.34              | 9.62  | 3.38 |      |
| 8              |                           | 8.66 | 5.06  | 13.35 | 3.62 |                            |      | 8.36 | 3.98              | 11.74 | 5.00 |      |
| 9              |                           | 8.07 | 7.91  | 15.25 | 2.06 |                            |      | 7.75 | 4.37              | 11.63 | 4.01 |      |
| 10             |                           | 8.38 | 7.11  | 15.05 | 3.26 |                            |      | 8.07 | 3.88              | 11.57 | 3.51 |      |
| 11             |                           | 8.61 | 14.20 | 22.04 | 2.21 |                            |      | 7.84 | 15.03             | 22.20 | 2.72 |      |
| 12             |                           | 9.30 | 13.42 | 21.90 | 0.60 |                            |      | 8.08 | 13.07             | 20.70 | 0.90 |      |
| 13             |                           | 7.25 | 14.36 | 20.40 | 0.00 |                            |      | 6.39 | 15.10             | 20.82 | 0.00 |      |
| 14             |                           | 6.80 | 15.97 | 21.81 | 0.00 |                            |      | 6.39 | 16.51             | 22.22 | 0.00 |      |
| 15             |                           | 8.35 | 12.76 | 20.65 | 0.00 |                            |      | 8.05 | 13.42             | 21.00 | 0.00 |      |
| 16             |                           | 8.14 | 15.09 | 22.31 | 0.00 |                            |      | 7.97 | 15.73             | 23.01 | 0.00 |      |
| 17             |                           | 8.54 | 18.29 | 25.83 | 0.00 |                            |      | 7.66 | 18.44             | 25.10 | 0.00 |      |
| 18             |                           | 7.84 | 15.92 | 23.01 | 0.00 |                            |      | 7.43 | 16.48             | 23.00 | 0.00 |      |
| 19             |                           | 7.54 | 15.97 | 22.61 | 0.00 |                            |      | 7.21 | 16.64             | 23.04 | 0.00 |      |
| 20             |                           | 8.10 | 17.23 | 24.27 | 0.00 |                            |      | 7.40 | 16.48             | 23.21 | 0.00 |      |

TABLE 12 - Linear measurements (mm) of dental development stages of mandibular premolars teeth (Sagittal view).

| Age<br>(years) | Mandibular First Premolar |       |       |       |      | Mandibular Second Premolar |      |      |                   |       |      |      |
|----------------|---------------------------|-------|-------|-------|------|----------------------------|------|------|-------------------|-------|------|------|
|                | A'B'                      | AB    | BC    | AC    | CD   | B'C'                       | A'B' | AB   | BC                | AC    | CD   | B'C' |
| 3              | 4.37                      |       |       |       |      | 4.81                       |      |      | PRESENCE OF CRYPT |       |      |      |
| 4              | 6.93                      |       |       |       |      | 5.73                       | 4.69 |      |                   |       |      | 5.60 |
| 5              | 5.41                      |       |       |       |      | 4.81                       |      |      | PRESENCE OF CRYPT |       |      |      |
| 6              | 8.47                      |       |       |       |      | 8.11                       | 7.82 |      |                   |       |      | 8.53 |
| 7              |                           | 9.28  | 3.42  | 12.63 | 5.46 |                            |      | 7.07 | 2.67              | 9.31  | 6.01 |      |
| 8              |                           | 9.39  | 4.00  | 13.16 | 6.91 |                            |      | 8.84 | 3.22              | 11.73 | 5.44 |      |
| 9              |                           | 9.30  | 6.50  | 15.26 | 6.50 |                            |      | 8.40 | 3.04              | 10.91 | 6.58 |      |
| 10             |                           | 8.94  | 6.79  | 15.10 | 6.29 |                            |      | 7.50 | 3.78              | 10.96 | 6.96 |      |
| 11             |                           | 9.21  | 13.61 | 21.67 | 1.79 |                            |      | 9.30 | 12.41             | 21.11 | 4.08 |      |
| 12             |                           | 9.14  | 13.28 | 22.00 | 1.20 |                            |      | 9.26 | 11.94             | 20.16 | 0.90 |      |
| 13             |                           | 8.33  | 13.93 | 21.00 | 0.00 |                            |      | 7.62 | 13.97             | 20.60 | 0.00 |      |
| 14             |                           | 8.44  | 15.05 | 22.60 | 0.00 |                            |      | 6.58 | 16.75             | 22.80 | 0.00 |      |
| 15             |                           | 8.94  | 12.29 | 20.42 | 0.00 |                            |      | 9.11 | 12.96             | 21.42 | 0.00 |      |
| 16             |                           | 9.11  | 14.76 | 22.91 | 0.00 |                            |      | 8.80 | 15.69             | 23.24 | 0.00 |      |
| 17             |                           | 10.63 | 17.46 | 27.22 | 0.00 |                            |      | 9.12 | 16.49             | 24.85 | 0.00 |      |
| 18             |                           | 8.99  | 14.95 | 23.00 | 0.00 |                            |      | 8.43 | 15.92             | 23.40 | 0.00 |      |
| 19             |                           | 7.69  | 15.78 | 22.43 | 0.00 |                            |      | 7.53 | 16.12             | 23.02 | 0.00 |      |
| 20             |                           | 9.22  | 16.83 | 25.02 | 0.00 |                            |      | 7.96 | 16.88             | 23.90 | 0.00 |      |

TABLE 13 - Linear measurements (mm) of dental development stages of mandibular first molar tooth (Coronal view).

| Age (years) | Mandibular First Molar               |      |       |       |      |                                       |      |      |       |       |                           |      |      |      |       |                            |      |      |      |      |       |       |      |      |
|-------------|--------------------------------------|------|-------|-------|------|---------------------------------------|------|------|-------|-------|---------------------------|------|------|------|-------|----------------------------|------|------|------|------|-------|-------|------|------|
|             | Mesial Root - Mesiobuccal Root Canal |      |       |       |      | Mesial Root - Mesiolingual Root Canal |      |      |       |       | Distal Root - Buccal Side |      |      |      |       | Distal Root - Lingual Side |      |      |      |      |       |       |      |      |
|             | A'B'                                 | AB   | BC    | AC    | CD   | B'C'                                  | A'B' | AB   | BC    | AC    | CD                        | B'C' | A'B' | AB   | BC    | AC                         | CD   | B'C' | A'B' | AB   | BC    | AC    | CD   | B'C' |
| 3           | 8.11                                 |      |       |       |      | 8.24                                  | 7.26 |      |       |       |                           | 8.24 | 8.08 |      |       |                            |      | 8.24 | 6.98 |      |       |       |      | 8.24 |
| 4           |                                      | 7.85 | 2.01  | 9.60  | 7.52 |                                       |      | 8.08 | 2.42  | 10.26 | 7.52                      |      |      | 7.20 | 1.82  | 9.00                       | 7.52 |      |      | 7.06 | 1.82  | 8.88  | 7.52 |      |
| 5           |                                      | 8.11 | 3.13  | 11.12 | 8.83 |                                       |      | 7.51 | 3.42  | 10.87 | 8.83                      |      |      | 8.90 | 2.42  | 11.14                      | 8.83 |      |      | 8.08 | 3.00  | 10.75 | 8.83 |      |
| 6           |                                      | 7.79 | 8.40  | 16.00 | 3.01 |                                       |      | 8.00 | 8.72  | 16.54 | 2.70                      |      |      | 8.45 | 7.35  | 16.24                      | 3.31 |      |      | 7.79 | 9.04  | 16.77 | 3.35 |      |
| 7           |                                      | 7.92 | 10.49 | 18.20 | 1.41 |                                       |      | 7.80 | 11.41 | 19.10 | 1.52                      |      |      | 8.49 | 9.48  | 17.96                      | 2.21 |      |      | 7.57 | 10.32 | 17.89 | 1.90 |      |
| 8           |                                      | 8.71 | 10.79 | 19.21 | 2.15 |                                       |      | 7.57 | 12.04 | 19.21 | 1.34                      |      |      | 8.62 | 9.95  | 18.53                      | 2.79 |      |      | 8.25 | 10.75 | 18.87 | 1.34 |      |
| 9           |                                      | 7.20 | 14.86 | 21.26 | 0.79 |                                       |      | 7.22 | 15.65 | 22.32 | 1.06                      |      |      | 7.76 | 13.75 | 21.32                      | 0.79 |      |      | 6.91 | 14.01 | 20.77 | 1.03 |      |
| 10          |                                      | 7.67 | 14.87 | 21.40 | 1.60 |                                       |      | 7.04 | 14.94 | 21.15 | 0.71                      |      |      | 7.67 | 13.76 | 21.10                      | 1.52 |      |      | 6.80 | 14.39 | 20.75 | 0.75 |      |
| 11          |                                      | 6.65 | 16.48 | 22.61 | 0.00 |                                       |      | 7.09 | 16.50 | 23.20 | 0.00                      |      |      | 7.67 | 14.27 | 21.61                      | 0.00 |      |      | 7.21 | 14.89 | 22.03 | 0.00 |      |
| 12          |                                      | 7.21 | 15.89 | 22.52 | 0.00 |                                       |      | 7.71 | 15.89 | 23.13 | 0.00                      |      |      | 8.66 | 13.88 | 22.49                      | 0.00 |      |      | 7.59 | 14.78 | 22.24 | 0.00 |      |
| 13          |                                      | 6.55 | 12.37 | 18.47 | 0.00 |                                       |      | 6.68 | 12.71 | 19.10 | 0.00                      |      |      | 7.69 | 11.80 | 18.91                      | 0.00 |      |      | 6.99 | 12.48 | 19.20 | 0.00 |      |
| 14          |                                      | 6.32 | 14.74 | 20.60 | 0.00 |                                       |      | 6.71 | 15.90 | 22.20 | 0.00                      |      |      | 7.35 | 13.81 | 20.74                      | 0.00 |      |      | 6.75 | 15.01 | 21.61 | 0.00 |      |
| 15          |                                      | 6.99 | 12.76 | 19.25 | 0.00 |                                       |      | 7.64 | 12.52 | 19.90 | 0.00                      |      |      | 7.67 | 11.21 | 18.76                      | 0.00 |      |      | 6.32 | 12.76 | 17.63 | 0.00 |      |
| 16          |                                      | 7.15 | 15.75 | 21.95 | 0.00 |                                       |      | 7.03 | 16.26 | 22.57 | 0.00                      |      |      | 7.86 | 13.62 | 21.38                      | 0.00 |      |      | 7.40 | 14.60 | 21.61 | 0.00 |      |
| 17          |                                      | 6.32 | 17.26 | 23.02 | 0.00 |                                       |      | 6.79 | 16.08 | 22.44 | 0.00                      |      |      | 6.16 | 15.61 | 21.62                      | 0.00 |      |      | 6.99 | 15.02 | 21.81 | 0.00 |      |
| 18          |                                      | 6.91 | 14.25 | 20.65 | 0.00 |                                       |      | 6.96 | 14.85 | 21.42 | 0.00                      |      |      | 7.62 | 12.63 | 20.02                      | 0.00 |      |      | 6.87 | 13.06 | 19.80 | 0.00 |      |
| 19          |                                      | 7.28 | 14.14 | 20.81 | 0.00 |                                       |      | 6.90 | 15.37 | 21.63 | 0.00                      |      |      | 6.71 | 14.81 | 21.26                      | 0.00 |      |      | 6.90 | 15.34 | 21.63 | 0.00 |      |
| 20          |                                      | 6.71 | 13.74 | 19.97 | 0.00 |                                       |      | 6.48 | 16.60 | 20.74 | 0.00                      |      |      | 7.66 | 13.81 | 20.55                      | 0.00 |      |      | 6.98 | 13.41 | 19.77 | 0.00 |      |

TABLE 14 - Linear measurements (mm) of dental development stages of mandibular first molar tooth (Sagittal view).

| Age (years) | Mandibular First Molar               |      |       |       |      |                                       |      |      |       |       |                           |      |      |      |       |                            |      |      |      |      |       |       |      |      |
|-------------|--------------------------------------|------|-------|-------|------|---------------------------------------|------|------|-------|-------|---------------------------|------|------|------|-------|----------------------------|------|------|------|------|-------|-------|------|------|
|             | Mesial Root - Mesiobuccal Root Canal |      |       |       |      | Mesial Root - Mesiolingual Root Canal |      |      |       |       | Distal Root - Buccal Side |      |      |      |       | Distal Root - Lingual Side |      |      |      |      |       |       |      |      |
|             | A'B'                                 | AB   | BC    | AC    | CD   | B'C'                                  | A'B' | AB   | BC    | AC    | CD                        | B'C' | A'B' | AB   | BC    | AC                         | CD   | B'C' | A'B' | AB   | BC    | AC    | CD   | B'C' |
| 3           | 7.52                                 |      |       |       |      | 9.18                                  | 7.22 |      |       |       |                           | 9.18 | 7.92 |      |       |                            |      | 9.18 | 6.91 |      |       |       |      | 9.18 |
| 4           |                                      | 8.05 | 1.50  | 9.42  | 7.50 |                                       |      | 7.65 | 2.72  | 10.27 | 7.50                      |      |      | 8.32 | 2.77  | 10.63                      | 7.50 |      |      | 6.30 | 2.34  | 8.24  | 7.50 |      |
| 5           |                                      | 7.92 | 2.77  | 10.41 | 7.55 |                                       |      | 7.00 | 2.72  | 9.64  | 7.55                      |      |      | 7.79 | 2.77  | 10.31                      | 7.20 |      |      | 7.52 | 2.95  | 10.22 | 7.20 |      |
| 6           |                                      | 8.75 | 9.92  | 18.20 | 2.77 |                                       |      | 7.35 | 9.18  | 16.20 | 2.47                      |      |      | 8.54 | 8.11  | 16.38                      | 2.16 |      |      | 7.00 | 8.54  | 15.07 | 2.01 |      |
| 7           |                                      | 8.48 | 10.10 | 18.05 | 4.24 |                                       |      | 7.44 | 11.76 | 18.81 | 4.24                      |      |      | 8.49 | 9.42  | 17.67                      | 4.04 |      |      | 7.40 | 10.77 | 17.81 | 4.04 |      |
| 8           |                                      | 9.21 | 10.58 | 19.34 | 2.15 |                                       |      | 6.44 | 13.38 | 18.67 | 2.15                      |      |      | 8.60 | 10.31 | 18.64                      | 2.79 |      |      | 7.47 | 11.65 | 18.40 | 2.79 |      |
| 9           |                                      | 7.94 | 15.00 | 21.77 | 1.25 |                                       |      | 7.04 | 14.25 | 20.74 | 1.50                      |      |      | 7.83 | 14.30 | 21.37                      | 2.02 |      |      | 7.00 | 15.21 | 21.67 | 2.02 |      |
| 10          |                                      | 8.31 | 12.50 | 19.51 | 1.75 |                                       |      | 6.86 | 12.13 | 18.58 | 1.75                      |      |      | 8.25 | 13.48 | 21.26                      | 2.55 |      |      | 6.62 | 15.04 | 20.93 | 2.55 |      |
| 11          |                                      | 8.49 | 14.56 | 22.61 | 0.00 |                                       |      | 8.16 | 15.78 | 23.02 | 0.00                      |      |      | 7.62 | 14.95 | 22.04                      | 0.00 |      |      | 6.25 | 16.27 | 21.98 | 0.00 |      |
| 12          |                                      | 9.40 | 14.71 | 22.93 | 0.00 |                                       |      | 7.59 | 16.61 | 23.22 | 0.00                      |      |      | 8.66 | 15.18 | 22.96                      | 0.00 |      |      | 7.94 | 16.16 | 23.56 | 0.00 |      |
| 13          |                                      | 7.52 | 12.61 | 19.00 | 0.00 |                                       |      | 6.65 | 13.96 | 19.75 | 0.00                      |      |      | 7.62 | 11.64 | 18.51                      | 0.00 |      |      | 6.48 | 13.11 | 18.98 | 0.00 |      |
| 14          |                                      | 7.33 | 14.54 | 21.03 | 0.00 |                                       |      | 6.65 | 15.83 | 21.25 | 0.00                      |      |      | 7.47 | 13.50 | 20.42                      | 0.00 |      |      | 6.00 | 15.12 | 20.68 | 0.00 |      |
| 15          |                                      | 8.60 | 10.92 | 19.03 | 0.00 |                                       |      | 6.99 | 12.81 | 19.27 | 0.00                      |      |      | 7.62 | 12.43 | 19.61                      | 0.00 |      |      | 6.60 | 13.89 | 20.19 | 0.00 |      |
| 16          |                                      | 8.35 | 15.14 | 22.66 | 0.00 |                                       |      | 7.53 | 16.51 | 23.02 | 0.00                      |      |      | 8.00 | 14.18 | 21.51                      | 0.00 |      |      | 7.53 | 15.12 | 22.03 | 0.00 |      |
| 17          |                                      | 6.91 | 16.76 | 22.53 | 0.00 |                                       |      | 7.02 | 16.24 | 23.03 | 0.00                      |      |      | 6.85 | 14.93 | 21.34                      | 0.00 |      |      | 6.91 | 15.16 | 21.40 | 0.00 |      |
| 18          |                                      | 7.73 | 13.61 | 20.60 | 0.00 |                                       |      | 6.75 | 15.56 | 21.30 | 0.00                      |      |      | 7.53 | 13.67 | 20.82                      | 0.00 |      |      | 6.01 | 15.57 | 20.94 | 0.00 |      |
| 19          |                                      | 7.62 | 15.30 | 22.00 | 0.00 |                                       |      | 5.66 | 17.46 | 22.42 | 0.00                      |      |      | 7.84 | 13.78 | 21.00                      | 0.00 |      |      | 6.83 | 15.31 | 21.54 | 0.00 |      |
| 20          |                                      | 7.62 | 13.85 | 20.24 | 0.00 |                                       |      | 6.91 | 14.79 | 20.56 | 0.00                      |      |      | 7.17 | 13.82 | 20.20                      | 0.00 |      |      | 6.08 | 14.70 | 20.39 | 0.00 |      |

TABLE 15 - Linear measurements (mm) of dental development stages of mandibular second molar tooth (Coronal view).

| Age<br>(years) | Mandibular Second Molar               |      |       |       |      |                                        |      |      |       |       |                           |       |      |      |       |                            |      |       |      |      |       |       |      |      |       |
|----------------|---------------------------------------|------|-------|-------|------|----------------------------------------|------|------|-------|-------|---------------------------|-------|------|------|-------|----------------------------|------|-------|------|------|-------|-------|------|------|-------|
|                | Mesial Root - Mesio Buccal Root Canal |      |       |       |      | Mesial Root - Mesio Lingual Root Canal |      |      |       |       | Distal Root - Buccal Side |       |      |      |       | Distal Root - Lingual Side |      |       |      |      |       |       |      |      |       |
|                | A'B'                                  | AB   | BC    | AC    | CD   | B'C'                                   | A'B' | AB   | BC    | AC    | CD                        | B'C'  | A'B' | AB   | BC    | AC                         | CD   | B'C'  | A'B' | AB   | BC    | AC    | CD   | B'C' |       |
| 3              | PRESENCE OF CRYPT                     |      |       |       |      | PRESENCE OF CRYPT                      |      |      |       |       | PRESENCE OF CRYPT         |       |      |      |       | PRESENCE OF CRYPT          |      |       |      |      |       |       |      |      |       |
| 4              | 4.80                                  |      |       |       |      | 8.45                                   | 4.51 |      |       |       |                           | 8.45  | 4.58 |      |       |                            |      | 8.45  | 4.08 |      |       |       |      |      | 8.45  |
| 5              | 3.31                                  |      |       |       |      |                                        | 3.31 |      |       |       |                           |       | 2.42 |      |       |                            |      |       | 4.20 |      |       |       |      |      |       |
| 6              | 8.53                                  |      |       |       |      | 10.36                                  | 7.30 |      |       |       |                           | 10.36 | 8.47 |      |       |                            |      | 10.36 | 7.13 |      |       |       |      |      | 10.36 |
| 7              |                                       | 8.24 | 1.84  | 9.65  | 7.59 |                                        |      | 7.05 | 1.98  | 8.68  | 7.59                      |       |      | 7.66 | 1.61  | 9.13                       | 7.59 |       |      | 6.88 | 1.60  | 8.24  | 7.59 |      |       |
| 8              |                                       | 8.10 | 5.10  | 12.86 | 2.61 |                                        |      | 7.86 | 5.50  | 12.80 | 3.41                      |       |      | 8.14 | 4.22  | 11.98                      | 3.31 |       |      | 7.25 | 3.80  | 10.82 | 3.50 |      |       |
| 9              |                                       | 8.14 | 6.64  | 14.27 | 2.55 |                                        |      | 7.04 | 6.32  | 13.06 | 3.01                      |       |      | 7.62 | 5.88  | 13.44                      | 3.16 |       |      | 7.27 | 5.02  | 12.10 | 3.02 |      |       |
| 10             |                                       | 8.14 | 6.41  | 14.04 | 2.61 |                                        |      | 7.02 | 6.41  | 13.12 | 2.55                      |       |      | 7.52 | 5.40  | 12.89                      | 3.35 |       |      | 7.38 | 5.64  | 12.91 | 3.16 |      |       |
| 11             |                                       | 7.98 | 11.22 | 18.42 | 2.28 |                                        |      | 6.96 | 11.85 | 18.20 | 2.68                      |       |      | 7.73 | 10.00 | 17.64                      | 2.60 |       |      | 6.94 | 10.01 | 16.83 | 2.83 |      |       |
| 12             |                                       | 7.87 | 12.26 | 19.02 | 1.27 |                                        |      | 7.42 | 12.43 | 19.05 | 1.50                      |       |      | 8.37 | 9.64  | 17.74                      | 1.80 |       |      | 7.13 | 10.52 | 17.44 | 1.80 |      |       |
| 13             |                                       | 7.53 | 12.29 | 18.78 | 0.00 |                                        |      | 6.99 | 12.46 | 18.73 | 0.00                      |       |      | 7.42 | 11.25 | 18.05                      | 0.00 |       |      | 7.03 | 11.45 | 18.01 | 0.00 |      |       |
| 14             |                                       | 6.83 | 14.67 | 20.22 | 0.00 |                                        |      | 6.51 | 12.71 | 18.09 | 0.00                      |       |      | 7.21 | 13.00 | 19.74                      | 0.00 |       |      | 6.99 | 13.72 | 20.40 | 0.00 |      |       |
| 15             |                                       | 8.29 | 11.98 | 18.98 | 0.00 |                                        |      | 8.43 | 10.28 | 18.66 | 0.00                      |       |      | 7.69 | 12.09 | 18.47                      | 0.00 |       |      | 8.03 | 10.25 | 18.16 | 0.00 |      |       |
| 16             |                                       | 7.60 | 16.64 | 22.53 | 0.00 |                                        |      | 7.89 | 13.60 | 21.45 | 0.00                      |       |      | 7.87 | 16.32 | 22.47                      | 0.00 |       |      | 6.75 | 14.40 | 21.05 | 0.00 |      |       |
| 17             |                                       | 7.67 | 16.20 | 22.88 | 0.00 |                                        |      | 7.96 | 15.52 | 22.59 | 0.00                      |       |      | 7.09 | 16.12 | 22.61                      | 0.00 |       |      | 7.78 | 15.13 | 22.40 | 0.00 |      |       |
| 18             |                                       | 7.80 | 14.46 | 21.21 | 0.00 |                                        |      | 7.10 | 14.82 | 21.22 | 0.00                      |       |      | 7.86 | 12.66 | 20.22                      | 0.00 |       |      | 8.22 | 11.80 | 19.80 | 0.00 |      |       |
| 19             |                                       | 7.35 | 13.45 | 20.00 | 0.00 |                                        |      | 7.17 | 13.89 | 20.20 | 0.00                      |       |      | 7.50 | 12.24 | 19.60                      | 0.00 |       |      | 7.47 | 13.02 | 20.24 | 0.00 |      |       |
| 20             |                                       | 6.99 | 15.43 | 21.41 | 0.00 |                                        |      | 6.58 | 15.62 | 21.45 | 0.00                      |       |      | 7.86 | 13.05 | 20.25                      | 0.00 |       |      | 7.86 | 12.86 | 20.05 | 0.00 |      |       |

TABLE 16 - Linear measurements (mm) of dental development stages of mandibular second molar tooth (Sagittal view).

| Age<br>(years) | Mandibular Second Molar               |      |       |       |      |                                        |      |      |       |       |                           |       |      |      |       |                            |      |       |      |      |       |       |      |      |       |
|----------------|---------------------------------------|------|-------|-------|------|----------------------------------------|------|------|-------|-------|---------------------------|-------|------|------|-------|----------------------------|------|-------|------|------|-------|-------|------|------|-------|
|                | Mesial Root - Mesio Buccal Root Canal |      |       |       |      | Mesial Root - Mesio Lingual Root Canal |      |      |       |       | Distal Root - Buccal Side |       |      |      |       | Distal Root - Lingual Side |      |       |      |      |       |       |      |      |       |
|                | A'B'                                  | AB   | BC    | AC    | CD   | B'C'                                   | A'B' | AB   | BC    | AC    | CD                        | B'C'  | A'B' | AB   | BC    | AC                         | CD   | B'C'  | A'B' | AB   | BC    | AC    | CD   | B'C' |       |
| 3              | PRESENCE OF CRYPT                     |      |       |       |      | PRESENCE OF CRYPT                      |      |      |       |       | PRESENCE OF CRYPT         |       |      |      |       | PRESENCE OF CRYPT          |      |       |      |      |       |       |      |      |       |
| 4              | 4.74                                  |      |       |       |      | 7.81                                   | 4.08 |      |       |       |                           | 7.81  | 4.85 |      |       |                            |      | 7.81  | 3.71 |      |       |       |      |      | 7.81  |
| 5              | 2.68                                  |      |       |       |      |                                        | 2.56 |      |       |       |                           |       | 2.16 |      |       |                            |      |       | 1.62 |      |       |       |      |      |       |
| 6              | 7.52                                  |      |       |       |      | 10.20                                  | 6.55 |      |       |       |                           | 10.20 | 7.80 |      |       |                            |      | 10.20 | 6.77 |      |       |       |      |      | 10.20 |
| 7              |                                       | 6.54 | 1.80  | 8.22  | 8.01 |                                        |      | 6.01 | 2.15  | 8.01  | 8.01                      |       |      | 7.96 | 2.61  | 10.31                      | 8.01 |       |      | 7.40 | 1.71  | 9.01  | 8.01 |      |       |
| 8              |                                       | 8.51 | 4.47  | 12.47 | 9.04 |                                        |      | 6.32 | 5.14  | 11.03 | 9.04                      |       |      | 8.41 | 3.68  | 11.22                      | 7.60 |       |      | 7.33 | 4.33  | 10.85 | 7.60 |      |       |
| 9              |                                       | 8.72 | 5.76  | 14.01 | 3.54 |                                        |      | 6.79 | 5.77  | 12.29 | 3.29                      |       |      | 8.05 | 6.02  | 13.84                      | 3.51 |       |      | 7.00 | 5.77  | 12.62 | 3.26 |      |       |
| 10             |                                       | 8.96 | 5.27  | 13.83 | 3.29 |                                        |      | 6.05 | 6.97  | 12.79 | 2.50                      |       |      | 8.08 | 5.59  | 13.15                      | 3.25 |       |      | 6.27 | 5.64  | 11.77 | 3.82 |      |       |
| 11             |                                       | 8.41 | 10.32 | 18.63 | 2.53 |                                        |      | 7.72 | 9.77  | 17.00 | 3.01                      |       |      | 7.67 | 10.85 | 18.23                      | 5.46 |       |      | 6.51 | 10.91 | 17.06 | 5.46 |      |       |
| 12             |                                       | 8.82 | 11.13 | 19.20 | 3.60 |                                        |      | 8.00 | 11.50 | 18.94 | 3.60                      |       |      | 8.00 | 9.77  | 17.40                      | 3.30 |       |      | 6.36 | 10.63 | 16.63 | 3.30 |      |       |
| 13             |                                       | 8.16 | 11.63 | 18.75 | 0.00 |                                        |      | 6.99 | 12.47 | 18.89 | 0.00                      |       |      | 7.28 | 11.72 | 17.85                      | 0.00 |       |      | 6.45 | 11.90 | 17.99 | 0.00 |      |       |
| 14             |                                       | 6.53 | 14.89 | 20.65 | 0.00 |                                        |      | 5.89 | 16.19 | 20.94 | 0.00                      |       |      | 7.28 | 12.86 | 19.67                      | 0.00 |       |      | 5.80 | 14.05 | 19.42 | 0.00 |      |       |
| 15             |                                       | 8.93 | 8.60  | 17.37 | 0.00 |                                        |      | 6.80 | 9.84  | 16.21 | 0.00                      |       |      | 8.23 | 10.21 | 18.05                      | 0.00 |       |      | 6.87 | 12.12 | 18.51 | 0.00 |      |       |
| 16             |                                       | 8.62 | 14.81 | 22.22 | 0.00 |                                        |      | 6.87 | 16.20 | 22.52 | 0.00                      |       |      | 7.78 | 14.60 | 21.80                      | 0.00 |       |      | 7.18 | 15.52 | 21.81 | 0.00 |      |       |
| 17             |                                       | 8.59 | 13.52 | 21.26 | 0.00 |                                        |      | 7.20 | 14.59 | 21.12 | 0.00                      |       |      | 7.27 | 15.40 | 21.90                      | 0.00 |       |      | 7.03 | 15.23 | 21.62 | 0.00 |      |       |
| 18             |                                       | 8.05 | 13.74 | 20.82 | 0.00 |                                        |      | 6.54 | 15.25 | 20.68 | 0.00                      |       |      | 7.69 | 12.97 | 20.06                      | 0.00 |       |      | 6.08 | 14.56 | 20.22 | 0.00 |      |       |
| 19             |                                       | 7.96 | 13.24 | 20.39 | 0.00 |                                        |      | 6.05 | 15.75 | 20.72 | 0.00                      |       |      | 7.52 | 12.23 | 19.46                      | 0.00 |       |      | 6.25 | 14.65 | 20.24 | 0.00 |      |       |
| 20             |                                       | 7.88 | 14.87 | 21.28 | 0.00 |                                        |      | 7.54 | 15.01 | 21.16 | 0.00                      |       |      | 7.17 | 14.55 | 20.48                      | 0.00 |       |      | 6.41 | 14.97 | 20.91 | 0.00 |      |       |

TABLE 17 - Dimensions (mm) of dental development stages measured with CBCT.

| Score | MAXILLARY TEETH  |                 |              |                |                 |              |              |
|-------|------------------|-----------------|--------------|----------------|-----------------|--------------|--------------|
|       | Central Incisor  | Lateral Incisor | Canine       | First Premolar | Second Premolar | First Molar  | Second Molar |
| 0     |                  |                 |              |                |                 |              |              |
| 1     |                  |                 |              |                |                 |              |              |
| 2     | >9.60-11.41      | >6.30-8.84      | >7.13-9.10   | >2.28-5.34     | >3.01-3.67      | >6.60-6.99   | >3.00-4.31   |
| 3     | >10.85-11.99     | >9.48-10.51     | >9.65-11.15  | >6.91-8.04     | >6.68-7.66      | >6.48-7.69   | >6.21-7.71   |
| 4     | >7.70-10.03      | >2.67-7.58      | >1.71-6.82   | >1.22-7.25     | >1.08-6.31      | >1.90-7.25   | >1.22-6.02   |
| 5     | >10-13.59        | >10.88-13.86    | >15.25-17.45 | >10.31-13.14   | >10.68-14.69    | >9.71-12.90  | >10.01-12.47 |
| Score | MANDIBULAR TEETH |                 |              |                |                 |              |              |
|       | Central Incisor  | Lateral Incisor | Canine       | First Premolar | Second Premolar | First Molar  | Second Molar |
| 0     |                  |                 |              |                |                 |              |              |
| 1     |                  |                 |              |                |                 |              |              |
| 2     | >8.40-10.40      | >8.19-9.97      | >7.11-9.44   | >4.47-6.30     | >4.69-7.82      | >6.91-7.39   | >1.62-4.59   |
| 3     | >8.55-9.94       | >8.60-10.29     | >9.77-11.76  | >7.69-9.04     | >7.07-8.25      | >5.66-7.47   | >5.89-7.34   |
| 4     | >8.24-10.88      | >5.41-11.56     | >6.03-9.70   | >3.42-7.93     | >2.67-6.18      | >1.50-9.15   | >1.71-6.57   |
| 5     | >10.58-13.24     | >12.26-14.21    | >13.09-15.53 | >12.29-15.13   | >12.96-15.60    | >10.92-14.65 | >8.60-13.69  |

0 – Absence of dental crypt; 1 – Presence of dental crypt; 2 – Dental crown partially formed; 3 – Dental crown totally formed; 4 – Beginning of root formation – open apex; 5 – End of root formation – closed apex.

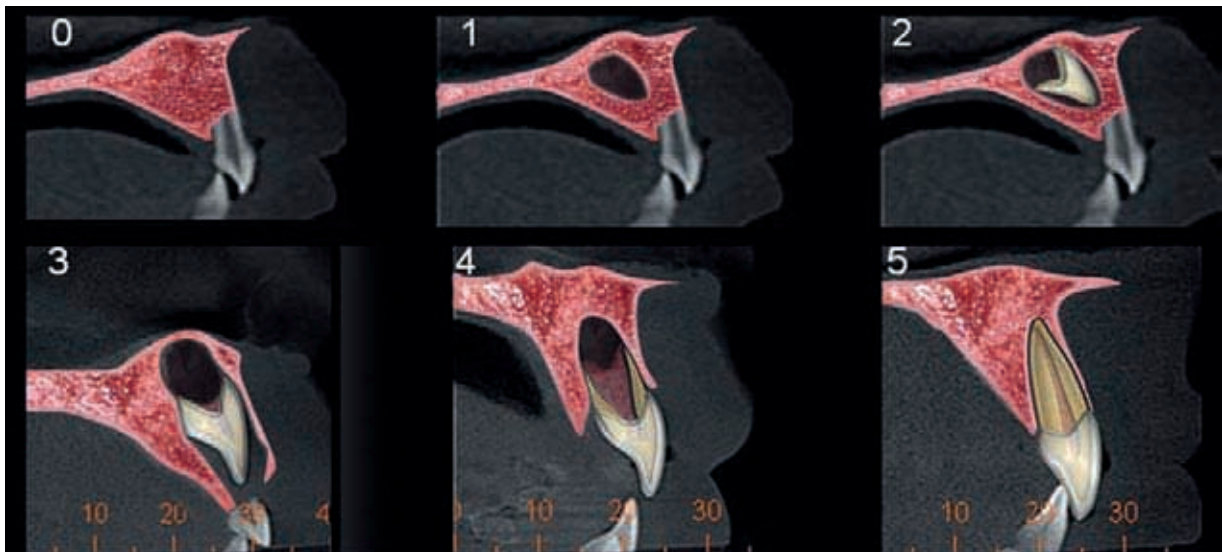


FIGURE 1 - Human permanent dental development stages using CBCT (Sagittal view).

Considering this research is a preliminary essay, the determination of the anatomical landmarks of human teeth with clinical importance may be an initial reference for a dental anatomy study based on the CBCT imaging method.

Growth and development may be estimated using parameters of chronological and biological age.

The indicators of biological age are: stature, weight, mental, sexual, skeletal and dental ages.<sup>23</sup> Dental age may be determined by eruptive chronology and by dental mineralization stages. A high correlation is observed between dental age and chronological age. The measurements obtained in the present study corresponding to different stages of dental

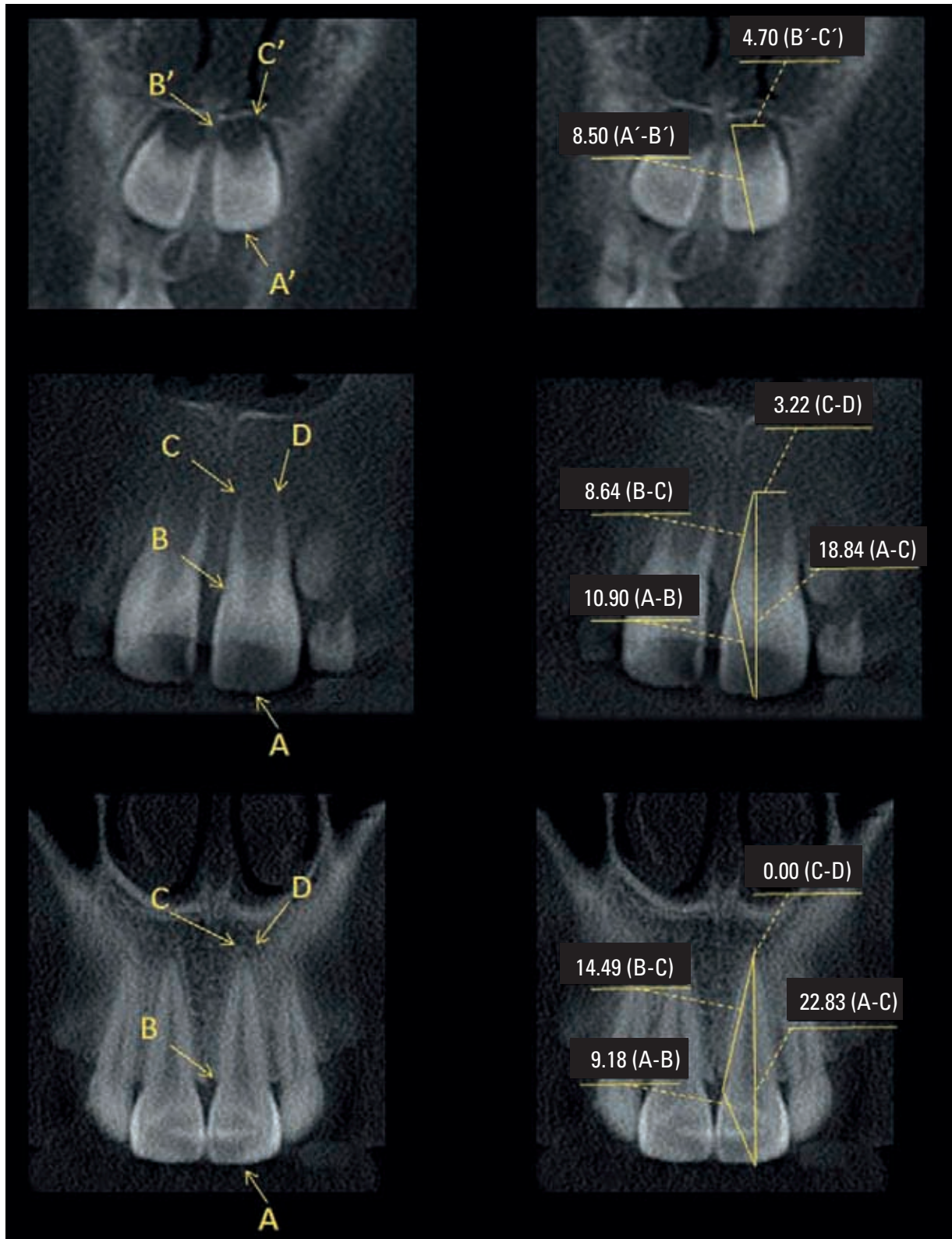


FIGURE 2 - Linear measurements of dental development stages of maxillary central incisor using CBCT (Coronal view).

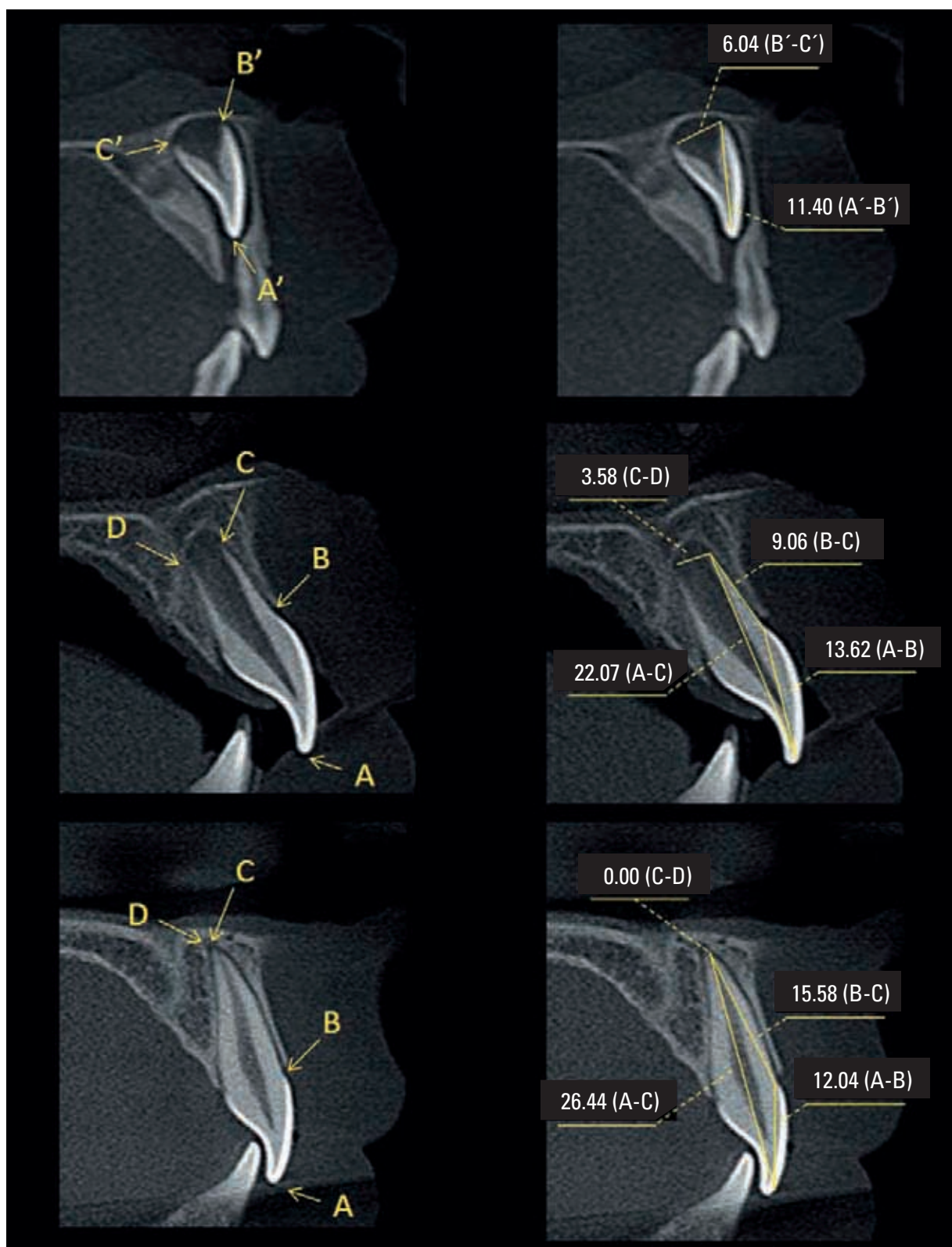


FIGURE 3 - Linear measurements of dental development stages of maxillary central incisor using CBCT (Sagittal view).

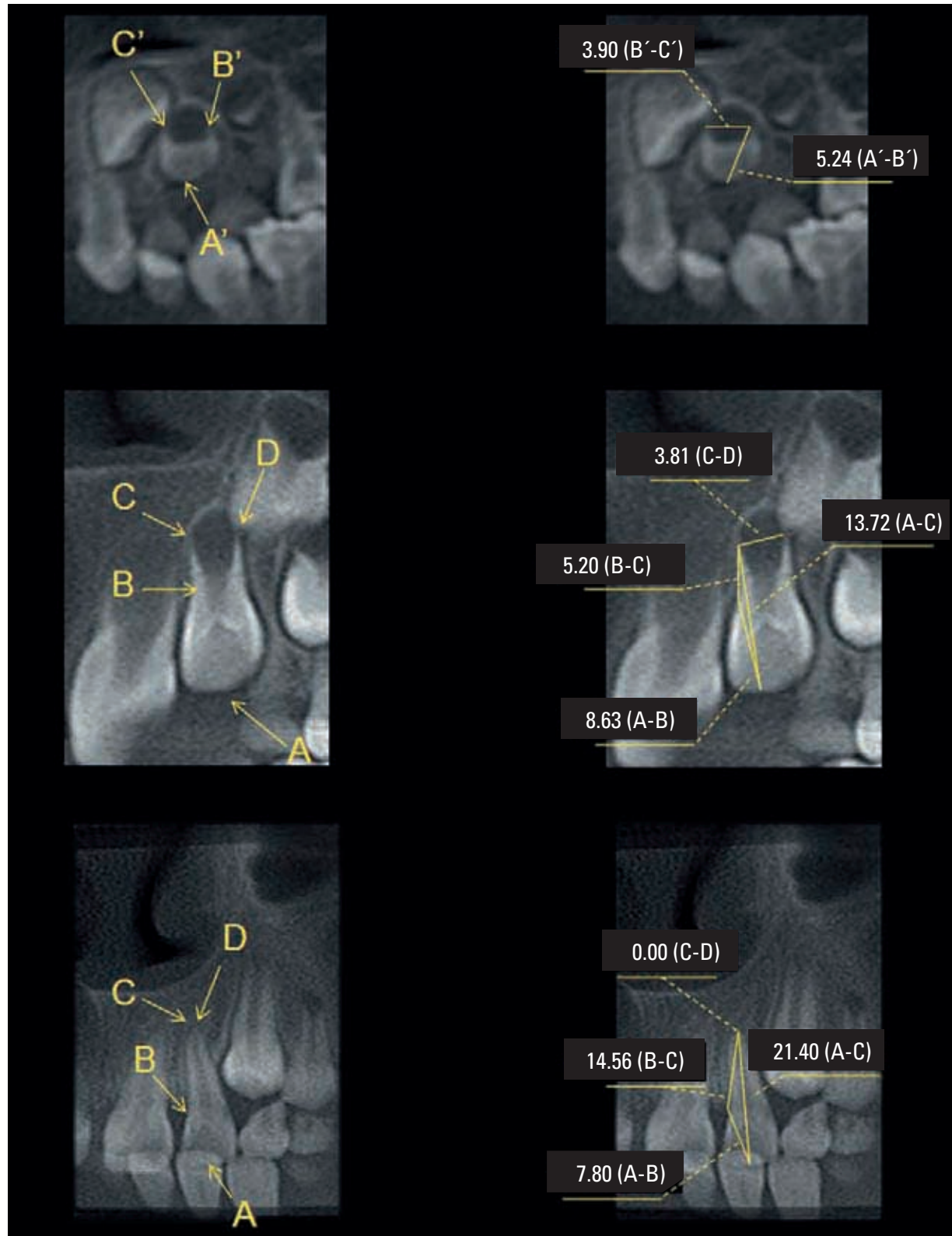


FIGURE 4 - Linear measurements of dental development stages of maxillary lateral incisor using CBCT (Coronal view).

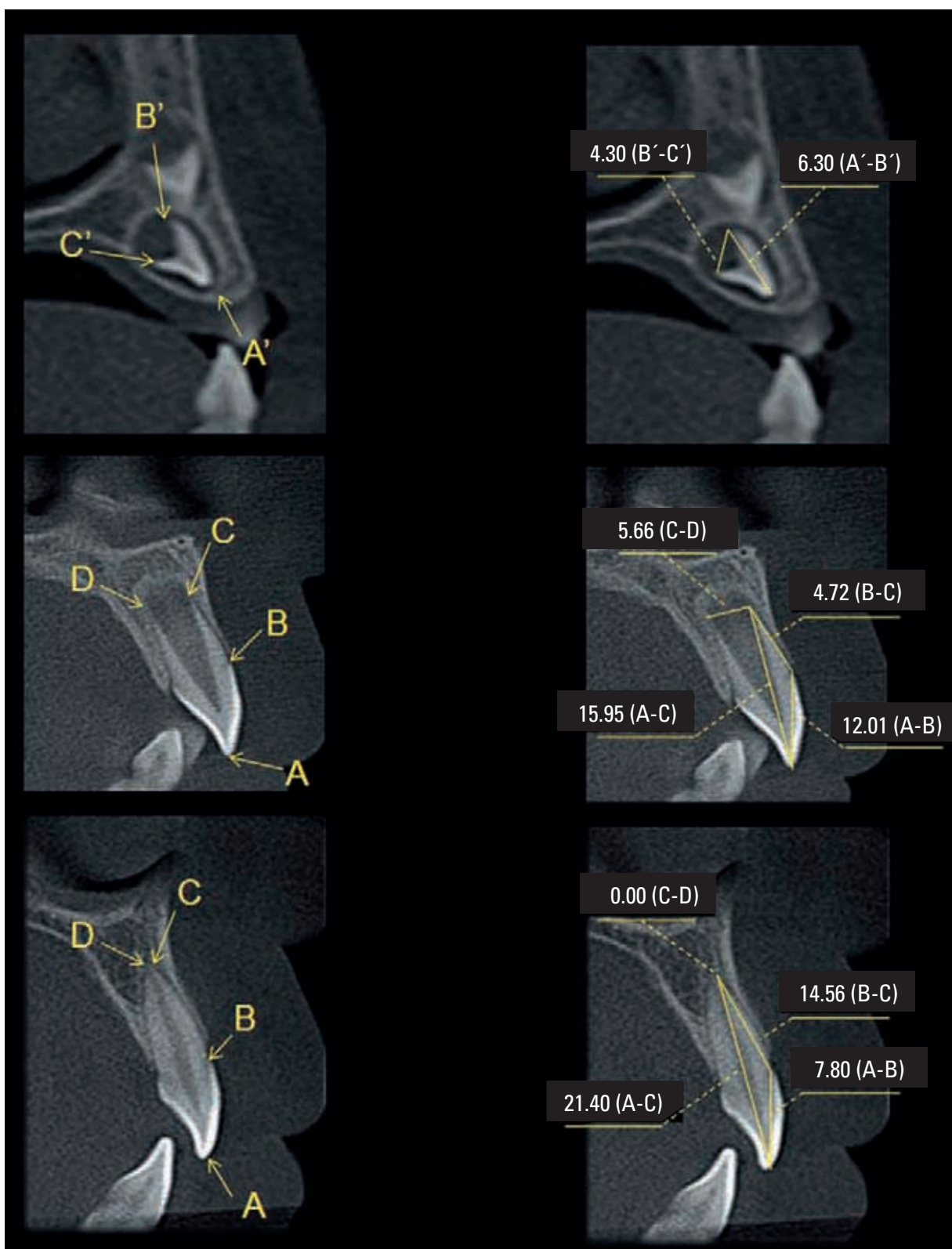


FIGURE 5 - Linear measurements of dental development stages of maxillary lateral incisor using CBCT (Sagittal view).

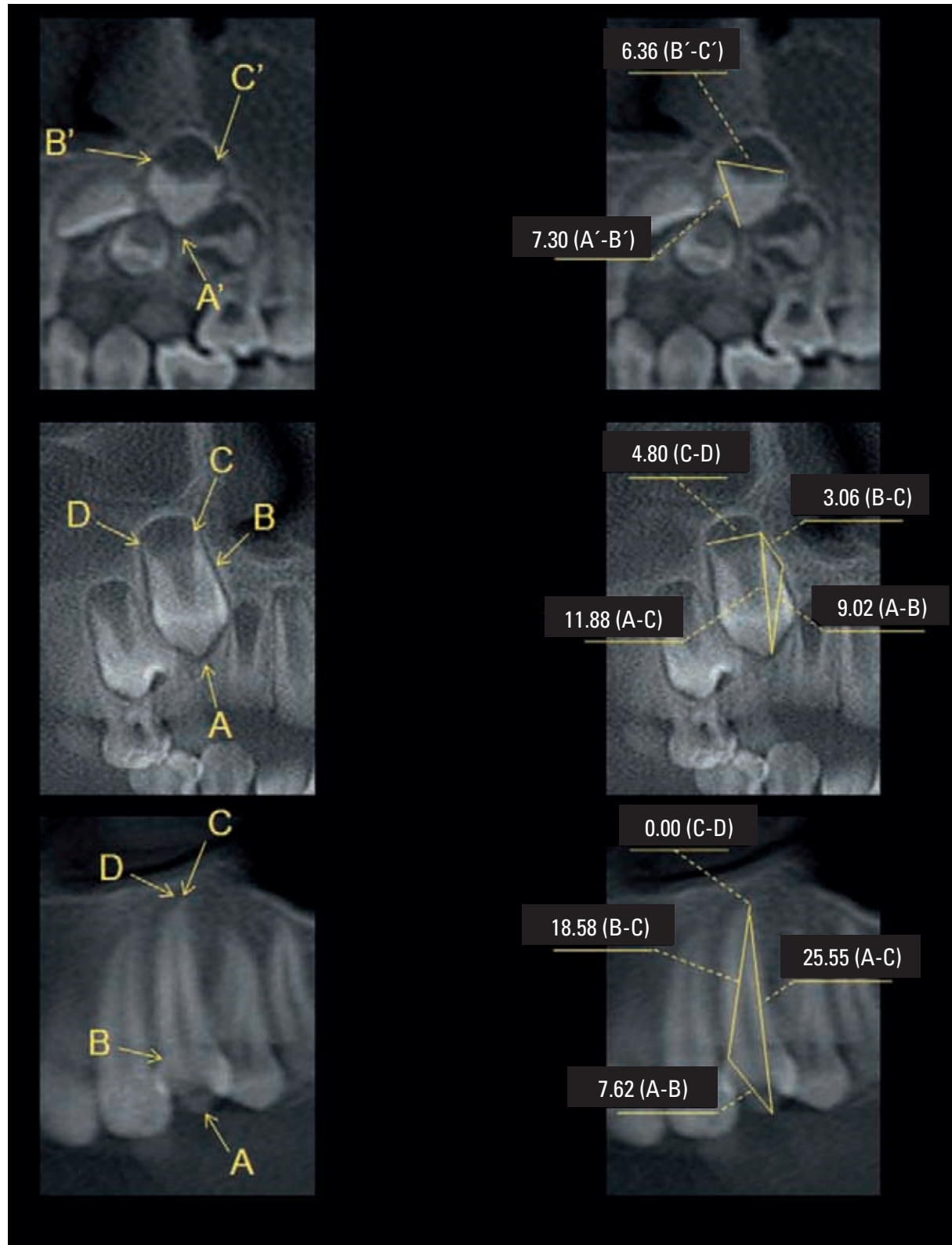


FIGURE 6 - Linear measurements of dental development stages of maxillary canine using CBCT (Coronal view).

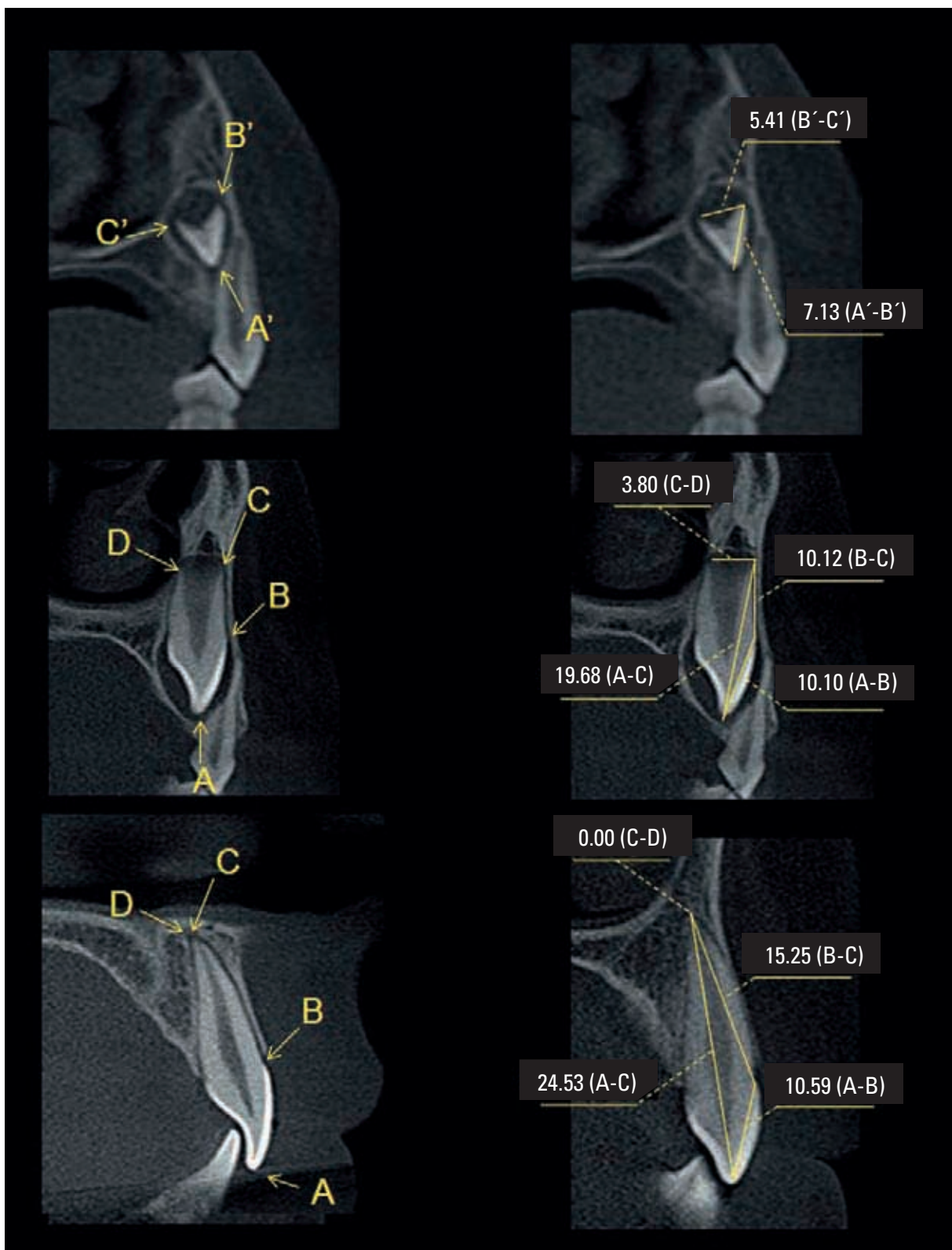


FIGURE 7 - Linear measurements of dental development stages of maxillary canine using CBCT (Sagittal view).

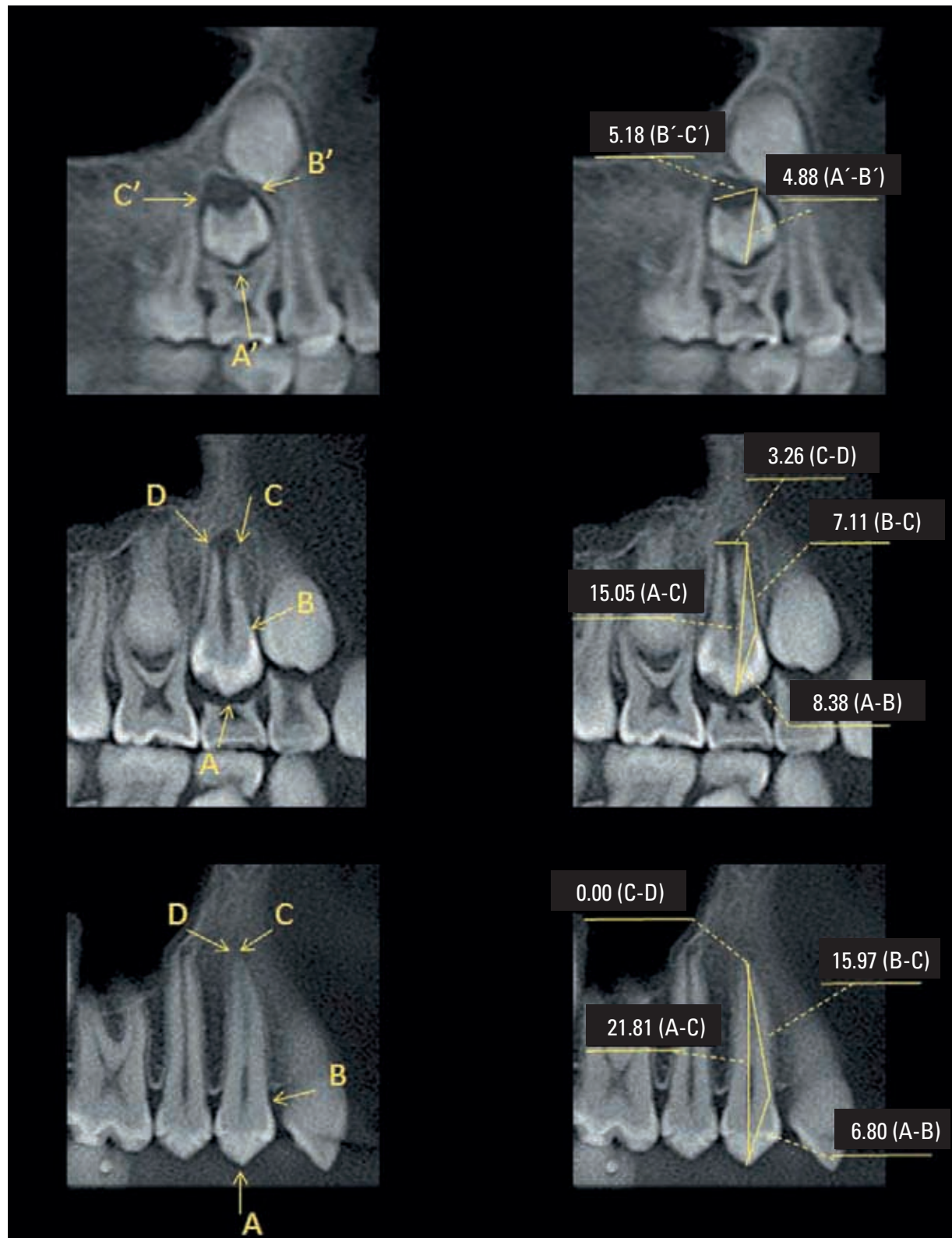


FIGURE 8 - Linear measurements of dental development stages of maxillary first premolar using CBCT (Coronal view).

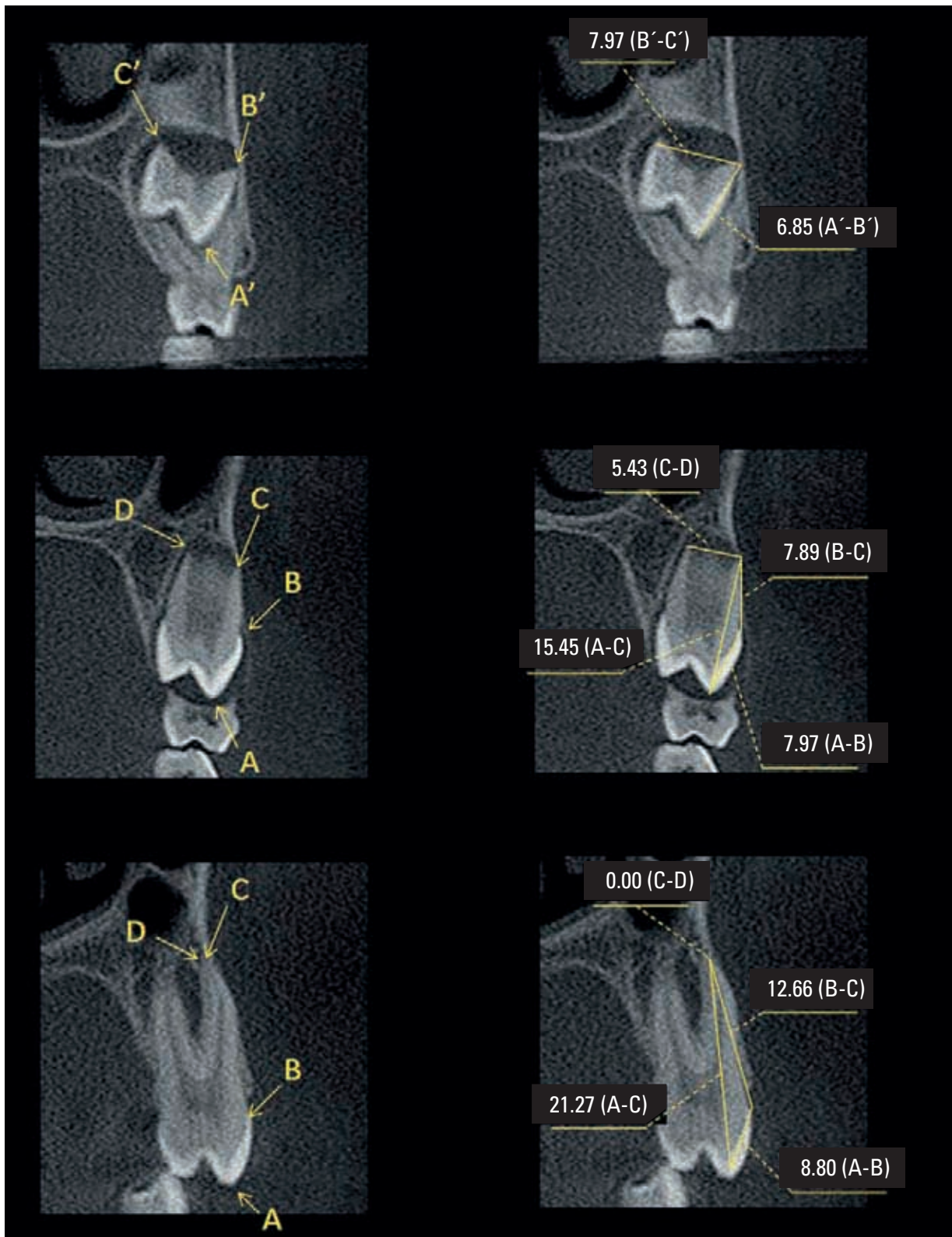


FIGURE 9 - Linear measurements of dental development stages of maxillary first premolar using CBCT (Sagittal view).

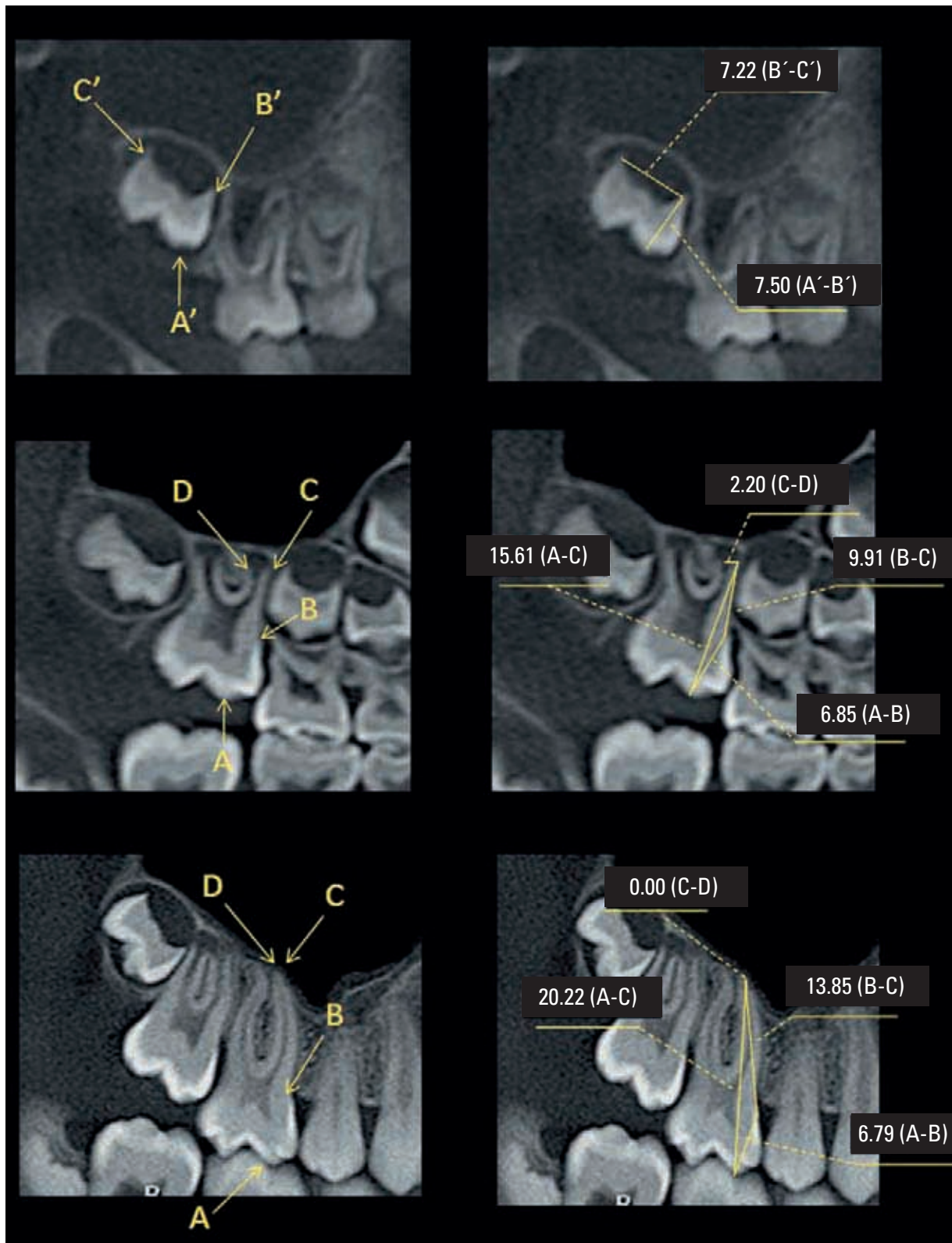


FIGURE 10 - Linear measurements of dental development stages of maxillary first molar using CBCT (Coronal view).

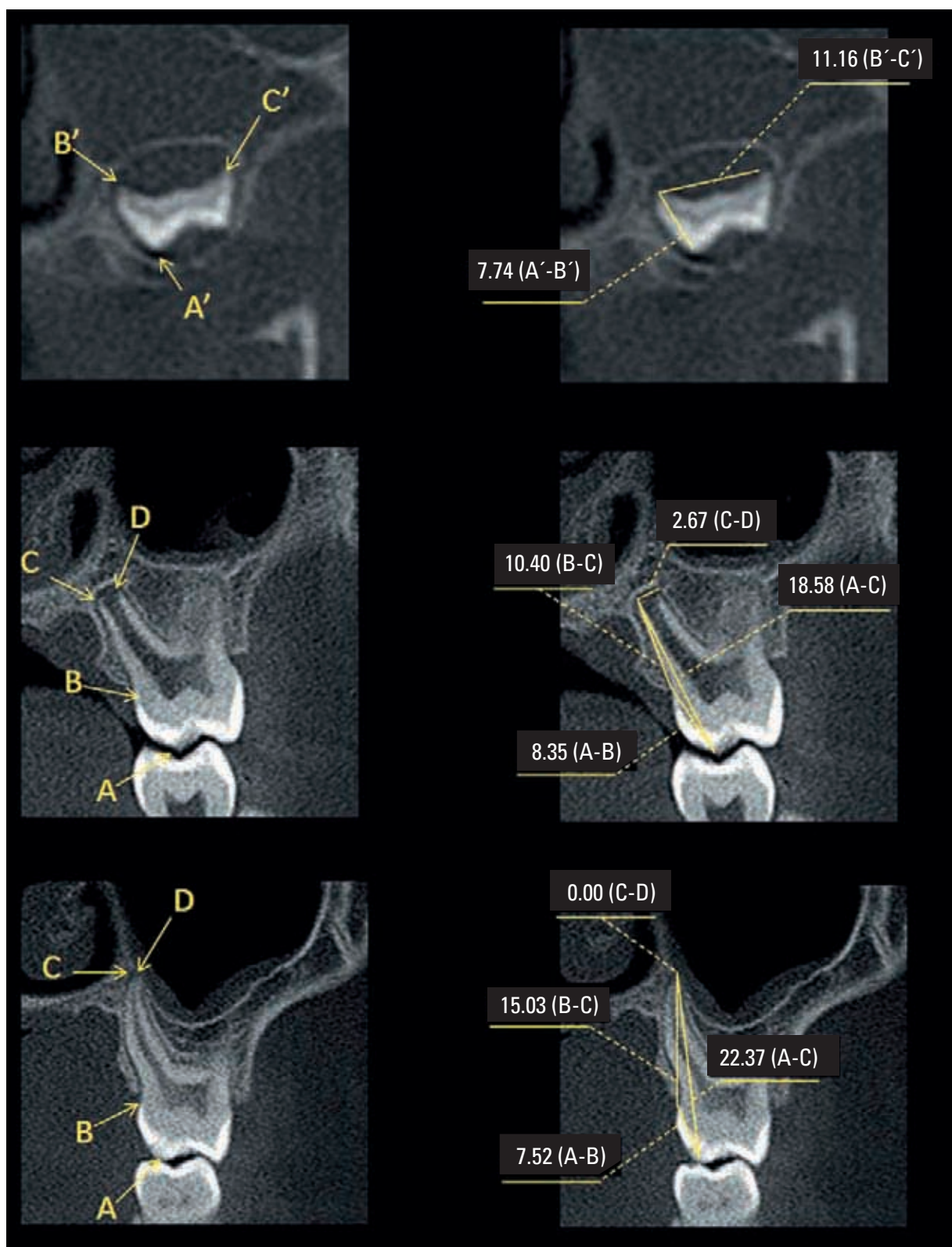


FIGURE 11 - Linear measurements of dental development stages of maxillary first molar using CBCT (Sagittal view).

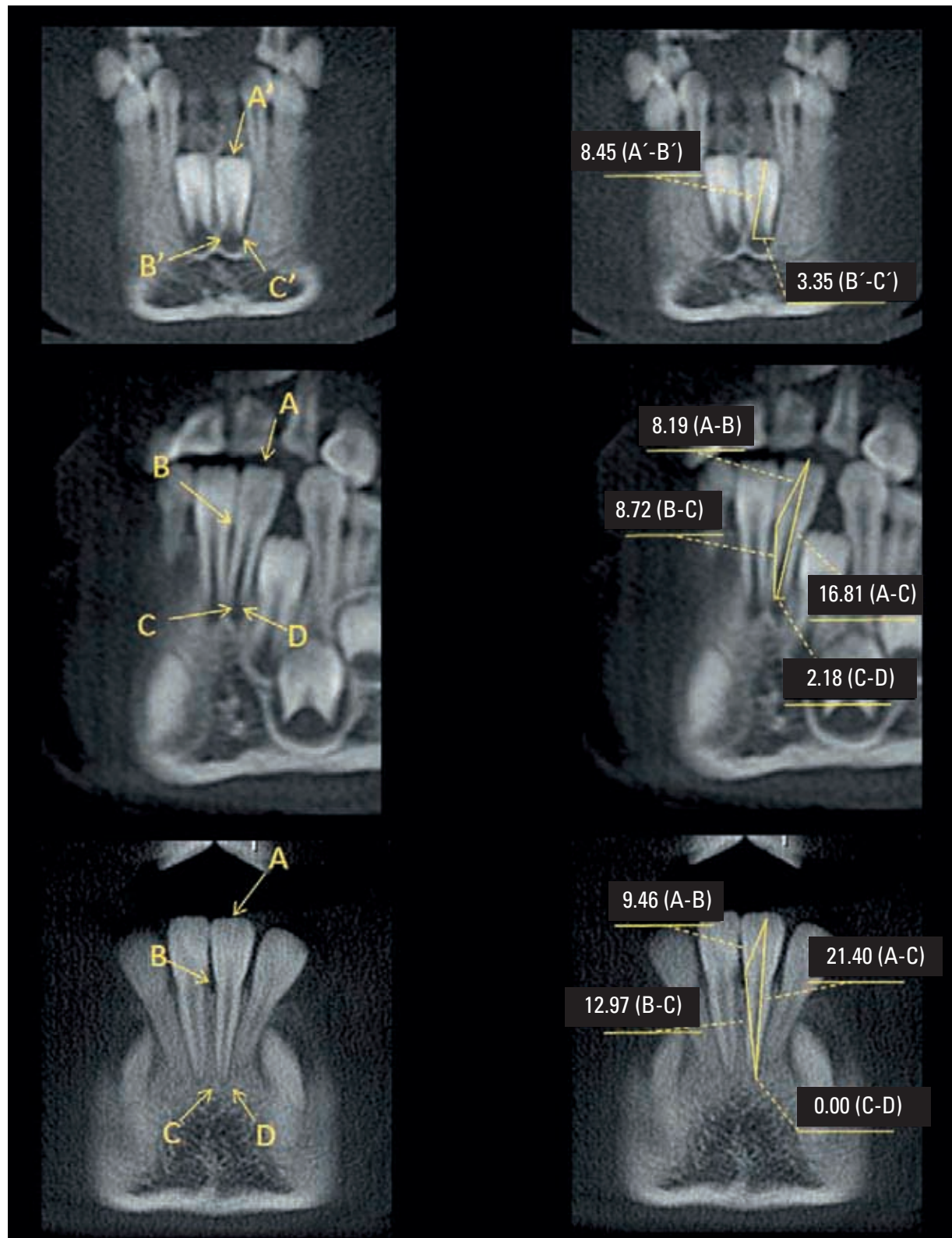


FIGURE 12 - Linear measurements of dental development stages of mandibular central incisor using CBCT (Coronal view).

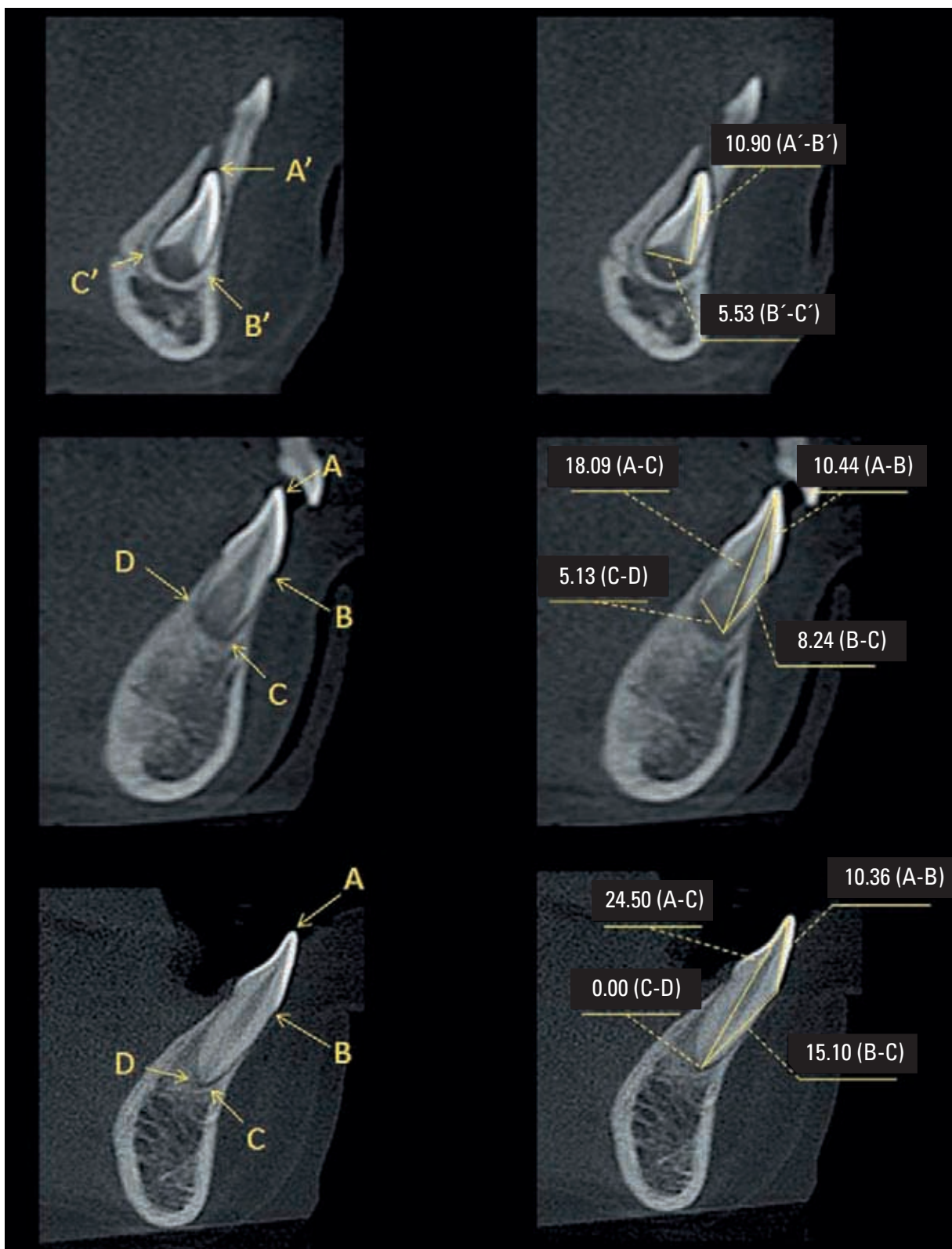


FIGURE 13 - Linear measurements of dental development stages of mandibular central incisor using CBCT (Sagittal view).

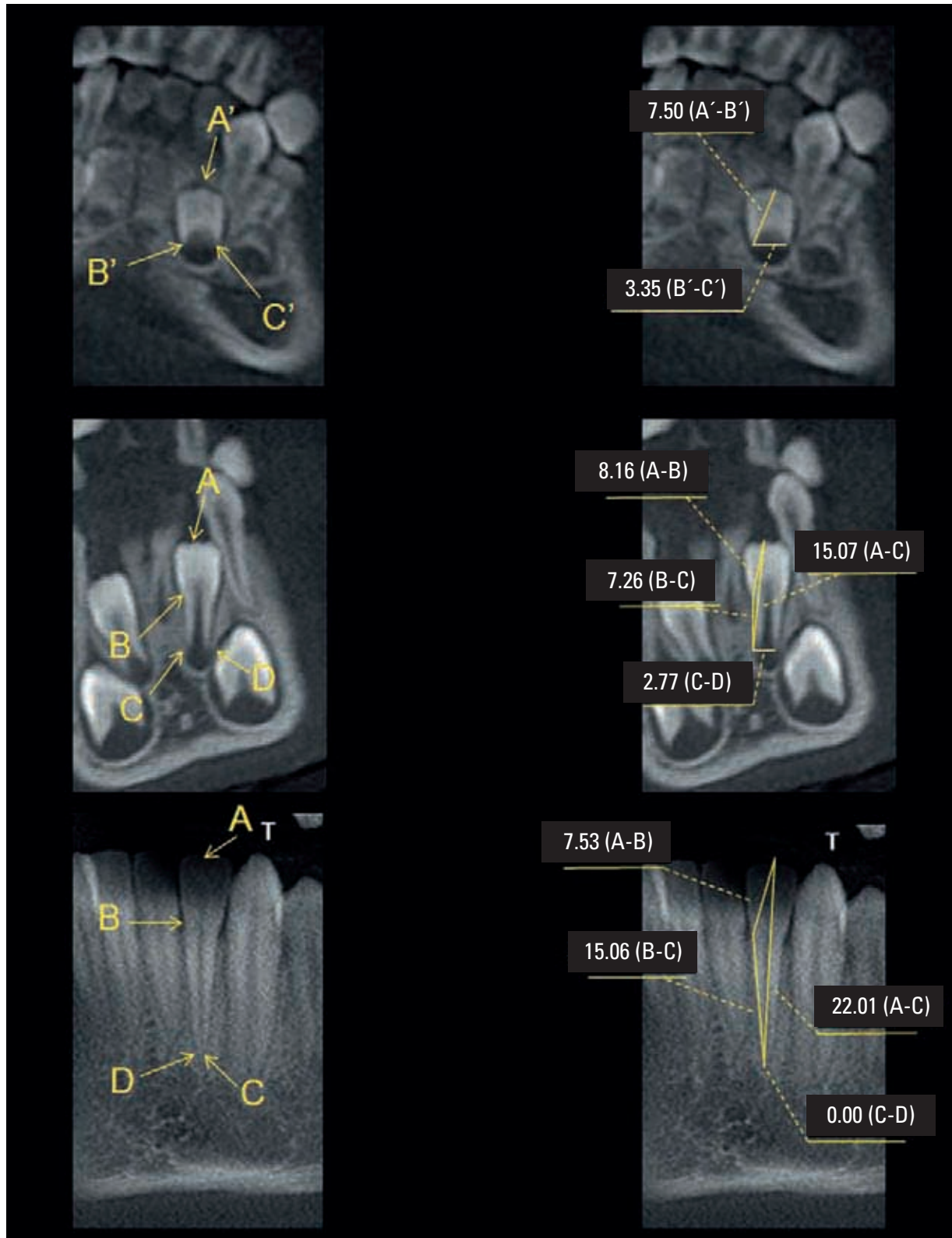


FIGURE 14 - Linear measurements of dental development stages of maxillary lateral incisor using CBCT (Coronal view).

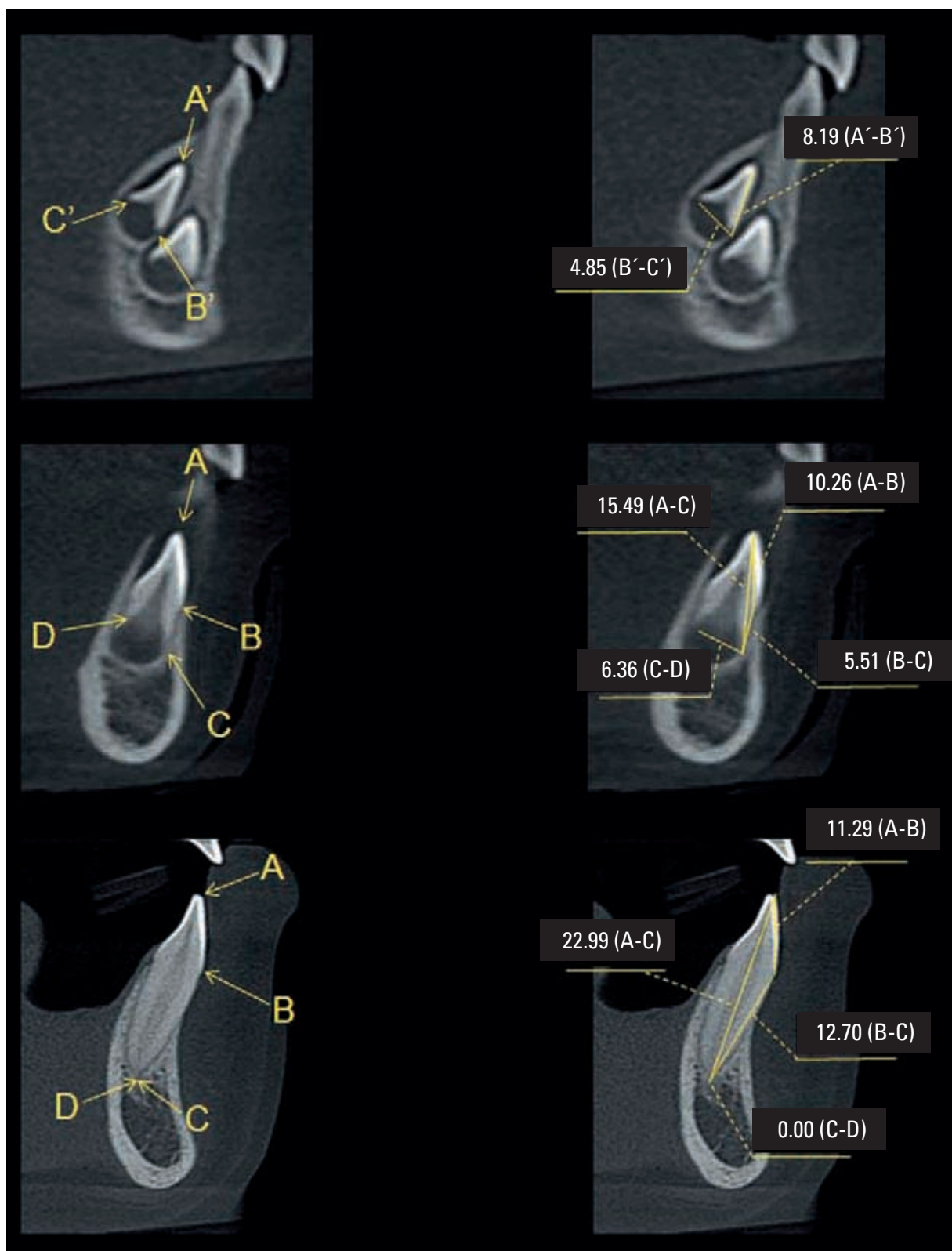


FIGURE 15 - Linear measurements of dental development stages of maxillary lateral incisor using CBCT (Sagittal view).

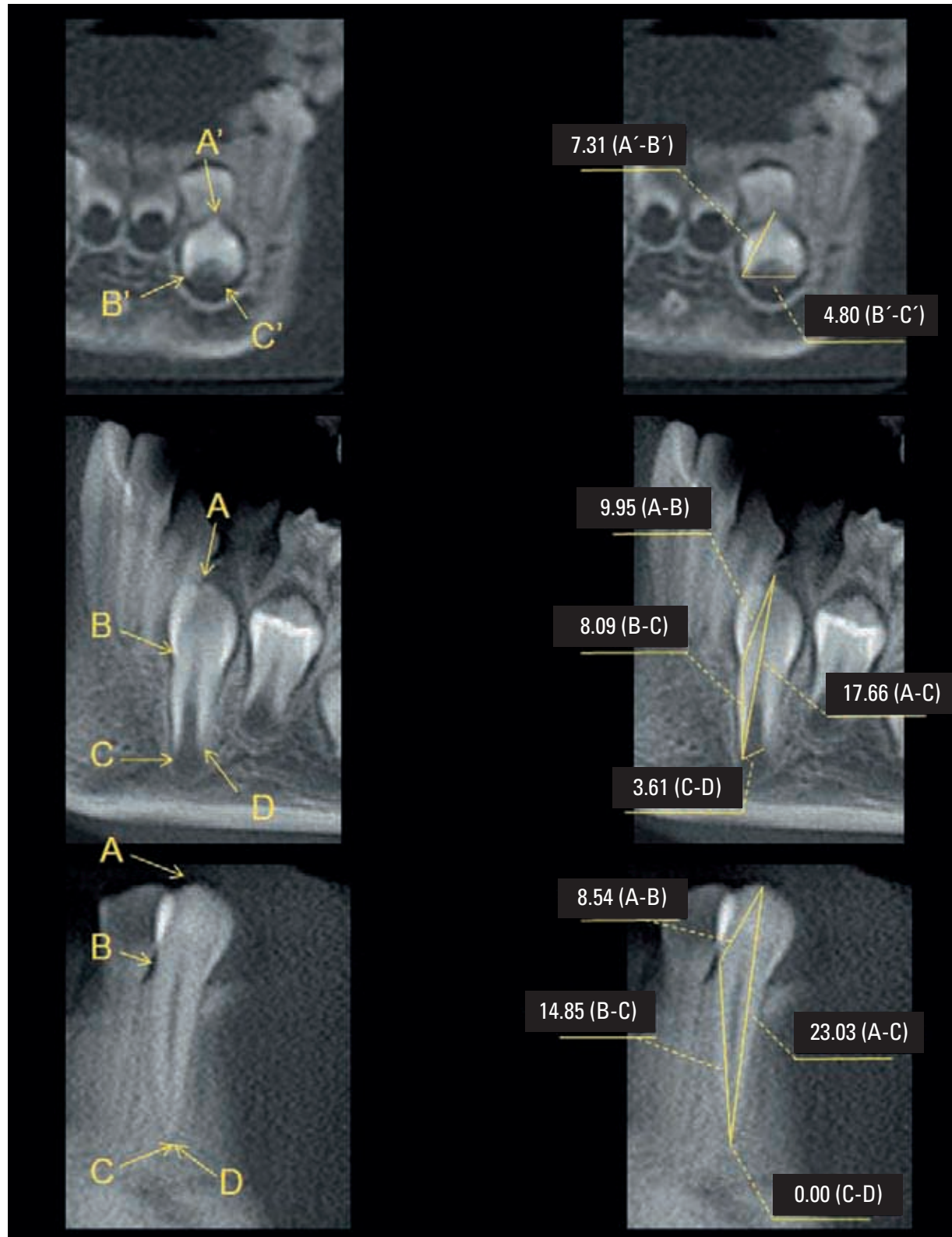


FIGURE 16 - Linear measurements of dental development stages of mandibular canine using CBCT (Coronal view).

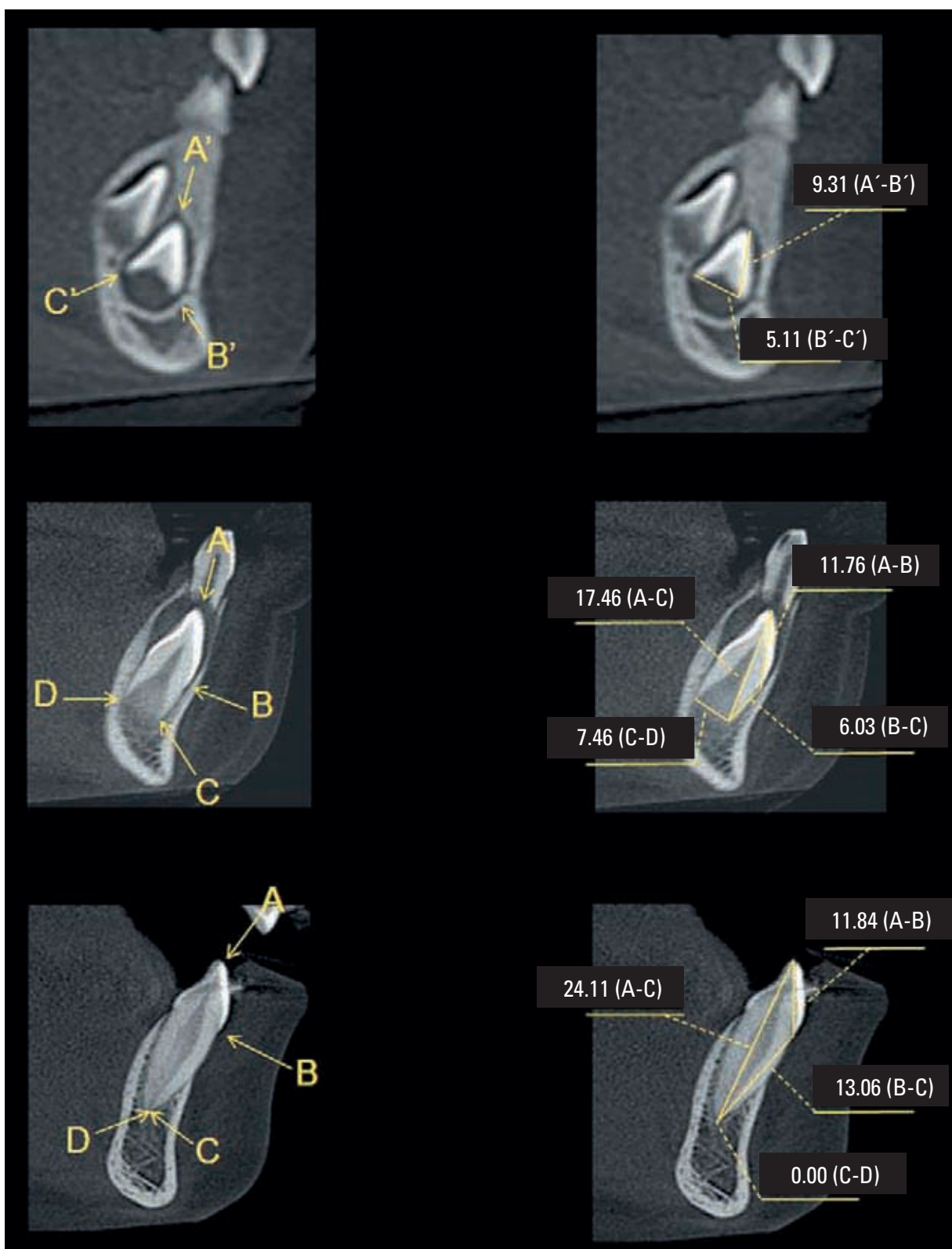


FIGURE 17 - Linear measurements of dental development stages of mandibular canine using CBCT (Sagittal view).

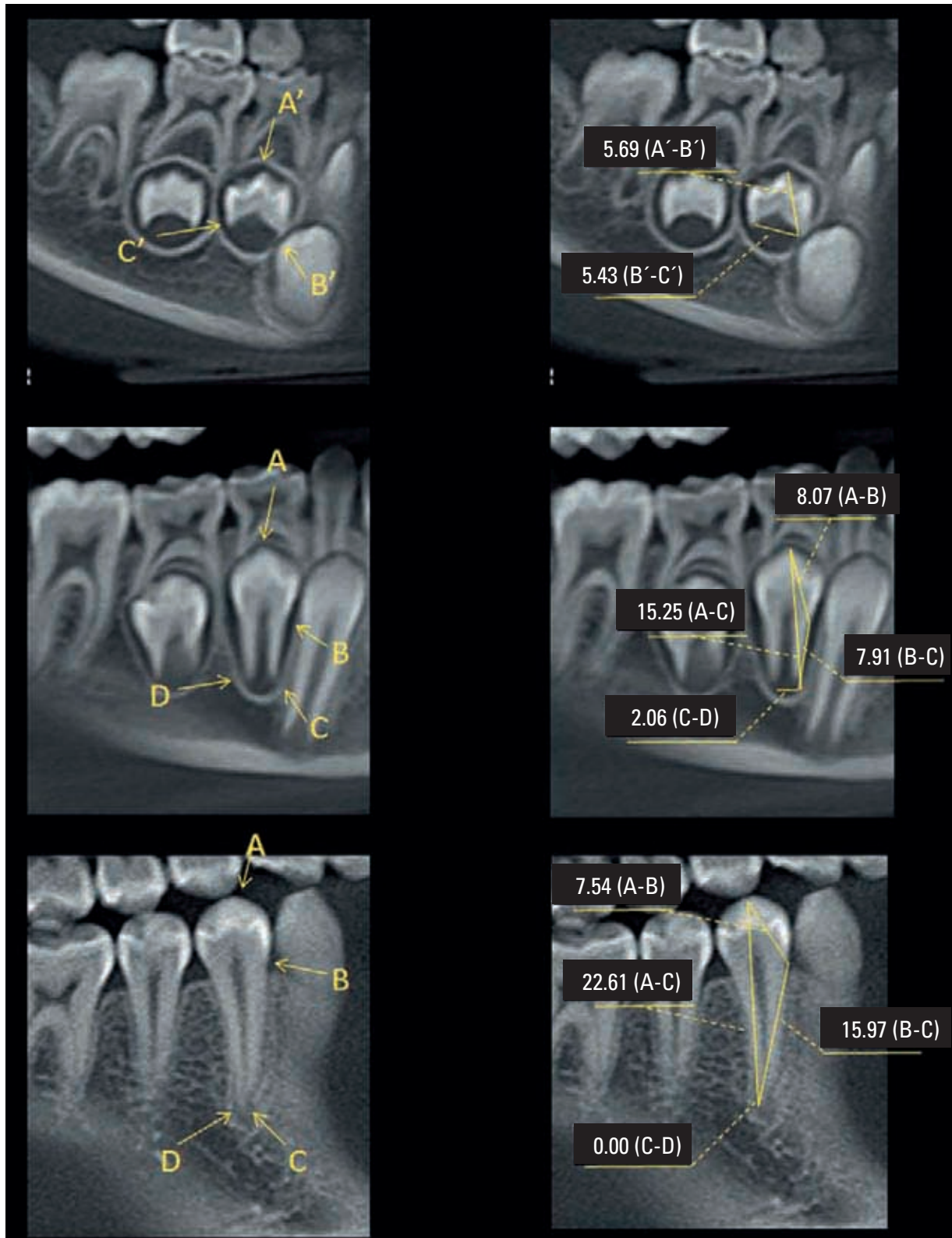


FIGURE 18 - Linear measurements of dental development stages of mandibular first premolar using CBCT (Coronal view).

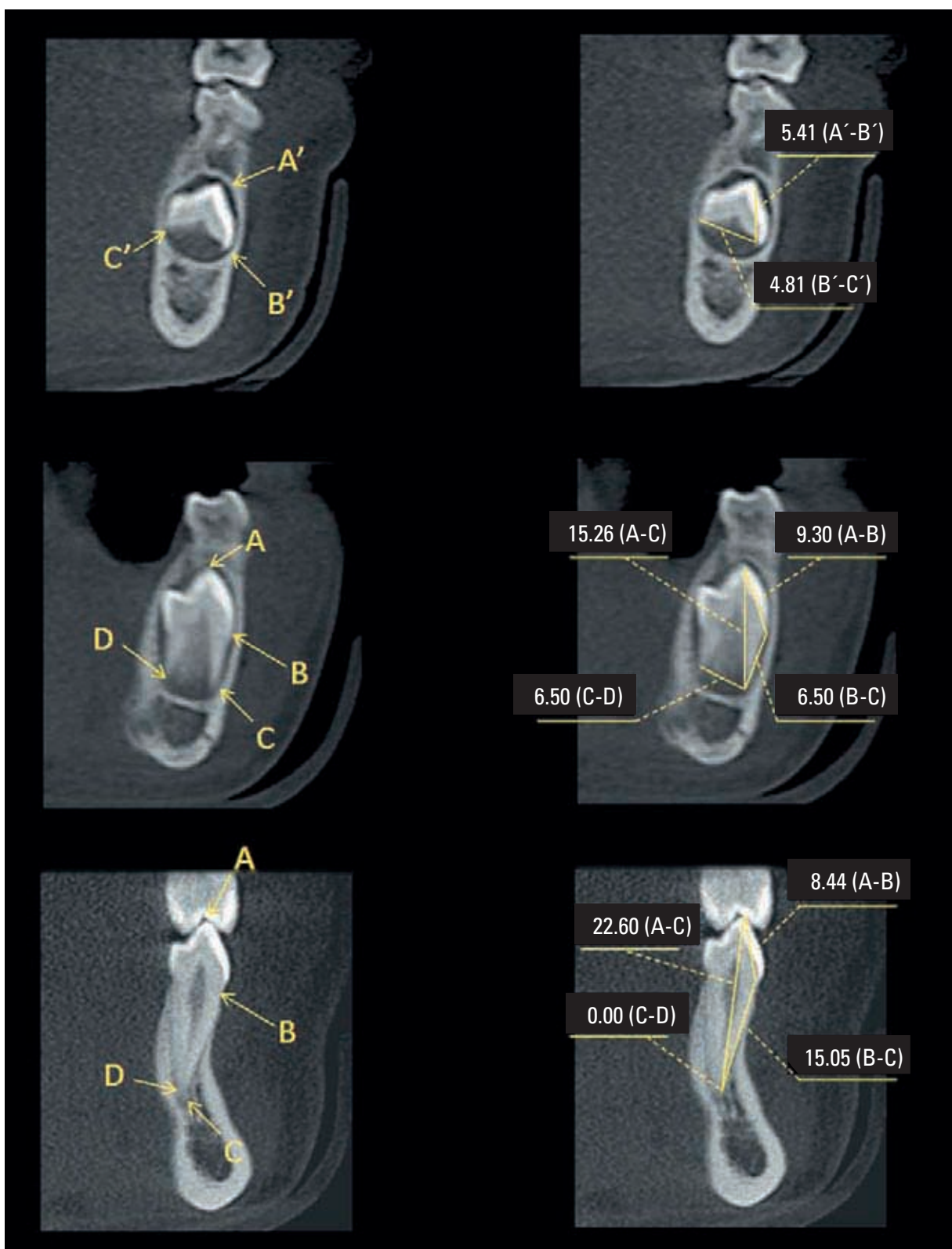


FIGURE 19 - Linear measurements of dental development stages of mandibular first premolar using CBCT (Sagittal view).

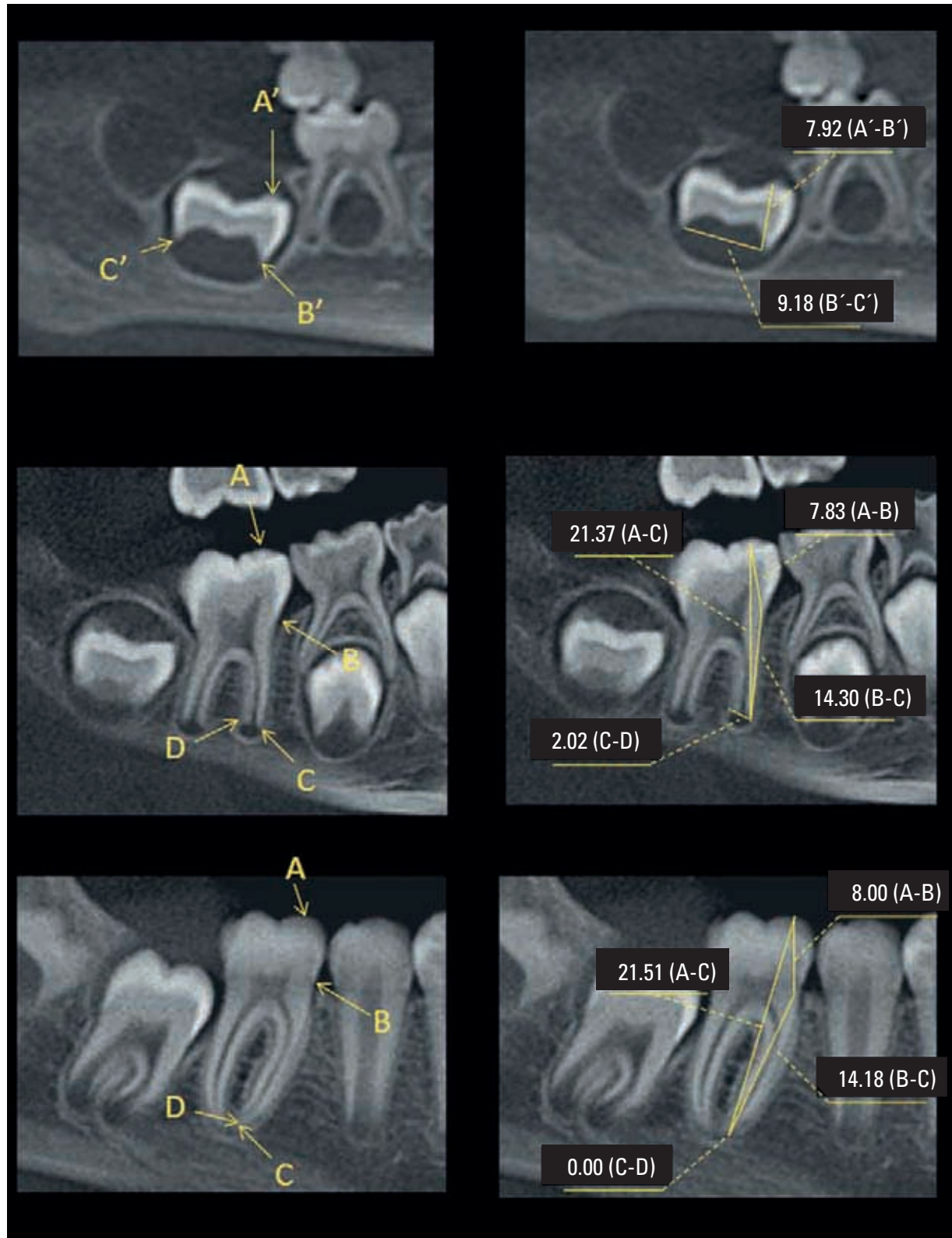


FIGURE 20 - Linear measurements of dental development stages of mandibular first molar using CBCT (Coronal view).

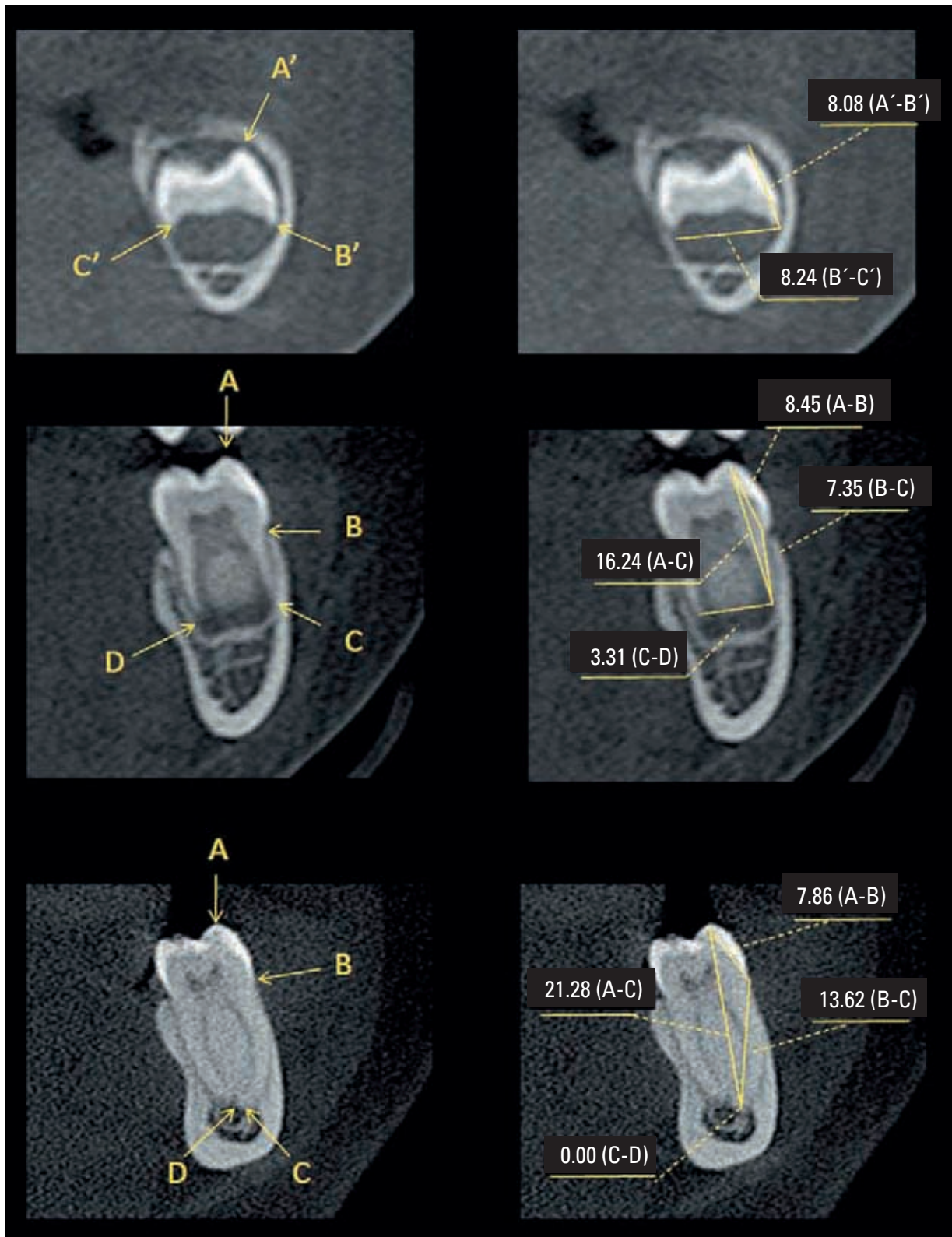


FIGURE 21 - Linear measurements of dental development stages of mandibular first molar using CBCT (Sagittal view).

development (3 to 20 years of age) represent a reference value of length, which should be associated with caution to maturation stage or skeletal age.

The present study was conducted using databases from private radiology clinics, in subjects whose genetic, nutritional, physiologic, pathologic, socioeconomic, and housing patterns were not standardized. The measurements acquired on dental groups are in accordance with estimates from previously published investigations.<sup>9,36,50</sup> However, this tool constitutes a noninvasive technique which permits *in vivo* studies. Investigations with observation methods using conventional radiographs to evaluate the development of human permanent teeth, chronology and sequence of eruption represent the most widely employed study models.<sup>20,21,34,35,44,49</sup>

A classical study by Nolla<sup>35</sup> reported that every dentist treating children must have a good understanding of the development of the dentition. The variability in tooth development may indicate differences between mean values. The author used serial oral radiographs of twenty-five boys and twenty-five girls, and suggested stages of development of human permanent teeth, which were graded on a scale from 0 to 10 (0- absence of crypt; 1- presence of crypt; 2- start of calcification; 3- one-third of crown completed; 4- two thirds of crown completed; 5- crown almost completed; 6- crown completed; 7- one-third of root completed; 8- two-thirds of root completed; 9- root almost completed - open apex; 10- apical end of root completed). Mean differences in the general sequence of development were not apparent between genders and few development differences were found between right and left teeth.

The possibility of obtaining information on three-dimensional anatomic structures *in vivo* with image handling has great potential and constitutes an achievement for all dental areas.<sup>6</sup> Liu et al<sup>25</sup> determined the accuracy of volumetric analysis of teeth *in vivo* using CBCT. The volume of 24 bicuspid teeth extracted for orthodontic purposes were determined. The measurements slightly deviated

from the volumes within -4% to 7%. Smoothing operations reduce volume measurements. Currently, no requirements for accuracy of volumetric determinations of tooth volume have been established. Baumgaertel et al<sup>4</sup> investigated the reliability and accuracy of dental measurements made on CBCT reconstructions. Thirty human skulls were scanned with dental CBCT, and 3-dimensional reconstructions of the dentitions were generated. Ten measurements (overbite, overjet, maxillary and mandibular intermolar and intercanine widths, available arch length, and required arch length) were made directly on the dentitions of the skulls with a high-precision digital caliper and on the digital reconstructions with commercially available software. Dental measurements from CBCT volumes can be used for quantitative analysis. A small systematic error was found, which became statistically significant only when combining several measurements. An adjustment for this error allowed improved accuracy.

Several studies have used the CBCT measurement tool to determine distances between maxillofacial anatomical structures.<sup>1,4,7,19,25,29-31,45</sup> CBCT measurements have more important applications and reliability than conventional imaging methods.<sup>5,11-13,15,45</sup>

## CONCLUSIONS

Under the tested conditions and within the limitations of this preliminary study, one can conclude that CBCT images of different development stages may contribute to treatment diagnosis, planning and outcome. The dimensions of dental crowns and roots may have good clinical and research application. However, further studies are recommended to minimize variables in the methodology.

## ACKNOWLEDGMENTS

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# Skeletal displacements following mandibular advancement surgery: 3D quantitative assessment

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## Abstract

**Objective:** To evaluate changes in the position and remodeling of the mandibular rami, condyles and chin with mandibular advancement surgery through the superimposition of 3D Cone-Beam Computed Tomography (CBCT) models. **Methods:** This prospective observational study used pre-surgery and post-surgery CBCT scans of 27 subjects presenting skeletal Class II with normal or horizontal growth pattern. An automatic technique of cranial base superimposition was used to assess positional and/or remodeling changes in anatomic regions of interest. Displacements were visually displayed and quantified by 3D color maps. Descriptive statistics consisted of mean values, standard deviations and minimum/maximum displacements. Changes greater than 2 mm were considered clinically relevant, and a categorization was done. Positive and negative displacements showed each region directional tendency. To test if displacements in anatomic regions were associated with each other, Pearson correlation coefficients were used under a 95% significance level. **Results:** The chin moved anterior-inferiorly  $6.81 \pm 3.2$  mm on average and the inferior portion of the rami moved laterally (left:  $2.97 \pm 2.71$  mm; right:  $2.34 \pm 2.35$  mm). Other anatomic regions showed  $<2$  mm mean displacements, but with evident individual variability. Significant statistical correlations were positive and moderate. The condyles, posterior border and superior portion of the rami showed a bilateral correlation, and the superior and inferior portion of the rami an ipsilateral correlation. **Conclusion:** This 3D method allowed clear visualization and quantification of surgery outcomes, with an anterior-inferior chin displacement and a lateral movement on the inferior portion of the rami, but with considerable individual variability in all the evaluated anatomic regions.

**Keywords:** Cone-Beam Computed Tomography. Image processing, Computer-assisted. Surgery, computer-assisted. Computer simulation. Orthodontics. Surgery, oral.

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## INTRODUCTION

Bilateral sagittal split ramus osteotomy (BSSO) is frequently performed in cases of mandibular advancement surgery. Despite its popularity, post-surgical instability due to displacement of the condyle from its seated position in the glenoid fossa in the three planes of space (ie, sagittal, vertical, and transverse) remains an area of concern.<sup>1</sup>

A post-surgical superior and posterior displacement of the condyle can happen with surgery, and it has been described to be correlated to the amount of mandibular advancement.<sup>2-5</sup> The association of condylar displacement and treatment relapse has been described,<sup>5,6</sup> and the control of the proximal segment was considered to be the most important aspect in the stability of this surgical modality.<sup>7</sup>

Assessment of surgical treatment outcomes using Cone-Beam Computed Tomography (CBCT) has the potential to unravel the interactions between the dental, skeletal and soft tissue components that contribute to treatment response.<sup>8</sup> The use of 3-dimensional (3D) superimposition tools allows the identification and quantification of bone displacement and remodeling.<sup>9,10</sup>

Previous studies<sup>9,11-14</sup> have used the 3D virtual models superimposition technique to assess post-surgical outcomes and stability in Class III patients, but the post-surgical outcomes of Class II correction have not been evaluated by this method.

The purpose of the present study was to tri-dimensionally assess surgical displacements of the condyles, rami (superior, inferior and posterior) and chin after mandibular advancement, testing directional correlation between them.

## METHODS

For this prospective observational study, twenty-seven patients (9 males and 18 females; mean age  $30.04 \pm 13.08$  years) who were submitted to orthognathic surgery at the UNC Memorial Hospital, with an attending resident from the

Department of Oral and Maxillofacial Surgery, were recruited. All patients underwent orthodontic treatment and had mandibular advancement surgery by means of a bilateral sagittal split osteotomy (BSSO). Nine of them also had genioplasty as an adjunctive procedure. CBCT scans were taken before surgery and after surgery at splint removal with the NewTom 3G (Aperio Services LLC, Sarasota, FL, 34236). Two of those patients had at least 1 scan done with the NewTom 9000 (Aperio Services LLC, Sarasota, FL) which has a smaller field of view (FOV), therefore, the chin was not included.

All patients had skeletal discrepancies severe enough to justify an orthognathic surgery. Patients with anterior open bite were excluded, so that the entire sample presented a skeletal Class II with normal or horizontal growth pattern. Lip-palatal fissures, problems resulting from trauma or degenerative conditions like rheumatoid arthritis were also excluded. Informed consent was obtained from all subjects. All patients agreed in having CBCTs in different phases of treatment as it was described in the experimental protocol approved by UNC ethical committee.

The imaging protocol involved a 36-second head CBCT scanning with a field of view of 230 x 230 mm. All CT scans were acquired with the patient in centric occlusion. The 3D models were constructed from CBCT images with a voxel dimension of 0.5x0.5x0.5 mm. Image segmentation of the anatomic structures of interest and the 3D graphic rendering were done by using the ITK-SNAP<sup>15</sup> open-source software (<http://www.itk-snap.org/>). Virtual models corresponding to the cranial bases (Fig 1); condyles (right and left); posterior rami (right and left); superior rami (right and left); inferior rami (right and left) and chin were built (Fig 2).

The pre-surgery and post-surgery models were registered based on the cranial base, since this structure is not altered by surgery. A fully automated voxel-wise rigid registration method was

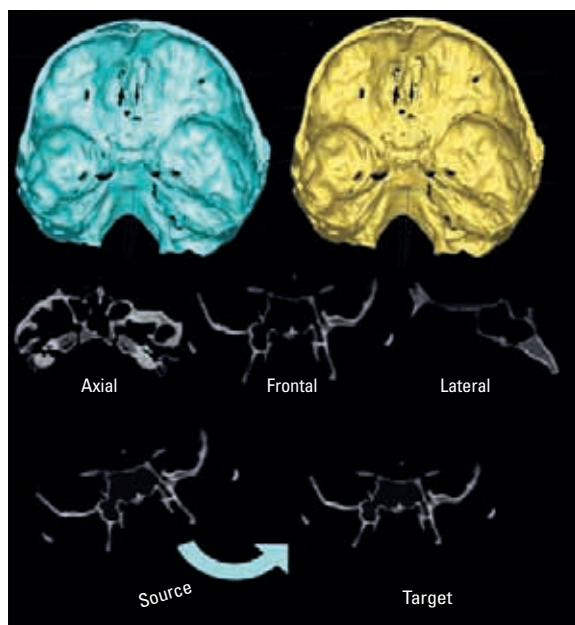


FIGURE 1 - Registration of CBCTs generated 3D virtual models using the cranial base surface through a fully automated voxel-wise method. Pre-surgery cranial base was used as a reference (source) for the post-surgery one (target) which were relocated along with the virtual maxillary and mandibular models.

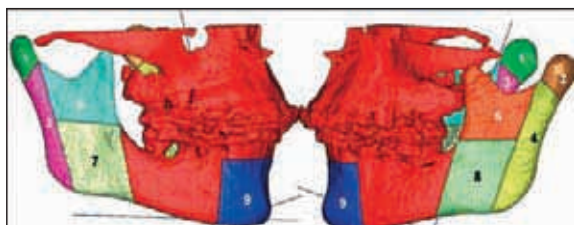


FIGURE 2 - Anatomic regions of interest: (1) Right condyle; (2) Left condyle; (3) Right posterior ramus; (4) Left posterior ramus (5) Right superior ramus; (6) Left superior ramus; (7) Right inferior ramus; (8) Left inferior ramus and (9) Chin.

used through the IMAGINE free software (developed by NIH and modified at UNC, <http://www.ia.unc.edu/dev/download/imagen/index.htm>).<sup>9</sup> The software compares both images using the intensity of gray scale for each voxel of the region, so that the pre-surgical cranial base was used as reference for the superimposition of post-surgery models (Fig 1).

Following the registration step, all the re-oriented virtual models, originally saved in a .GIPL format were converted to a SGL open inven-

tor format (IV) by the free software VOL2SURF (<http://www.cc.nih.gov/cip/software.html>), allowing the quantitative evaluation of greatest displacements using the CMF application software (Maurice Müller Institute, Bern, Switzerland).<sup>16</sup>

The previously proposed color maps method<sup>17</sup> was used to generate the closest-point distances between the surfaces. The CMF software calculates thousands of color-coded surface distances in millimeters between before and after-treatment 3D models by using surface triangles at two different time points, so that the difference between the two surfaces at any location can be quantified. The isoline (contour line) tool was recently included in the method and considered a technique improvement, since it is used to quantitatively measure the greatest displacement (mm) for the specific anatomic regions of interest (Fig 3).

The quantitative changes were visualized using color maps, which can be used to indicate inward (blue) or outward (red) displacement between superimposed structures. An absence of change is indicated by the green color code. For example, in mandibular advancement surgery, the forward chin displacement would be shown in a red color code; in mandibular set-back surgery the chin surfaces would be shown in a blue color code.

Semi-transparency constitutes another method used in this study for visualization of the location and direction of skeletal displacements, with one of the models in an opaque view superimposed to another in a partially transparent view. This method for quantitative change exhibition at multiple locations has been validated and used since 2005.<sup>9</sup>

Positive values indicated an anterior-inferior displacement of the chin while negative values indicated a posterior-superior displacement. For the condyles, positive values represented a posterior-superior displacement and negative values indicated anterior-inferior movements. For the rami posterior borders, positive values represented posterior displacements and negative values indicated anterior displacements.

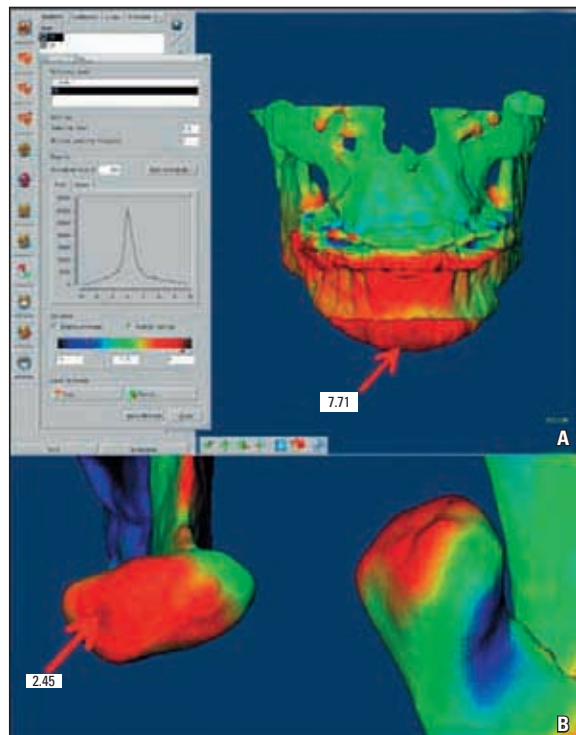


FIGURE 3 - The ISOLINE tool allowed the identification of the greatest displacement of a specific anatomic region. **A)** Example of a 7.71 mm chin advancement between pre-surgery and after splint removal (surgical outcomes). **B)** Right condyle displaced 2.45 mm posterior-superiorly after surgery.

The lateral portions of the mandibular rami were divided in two parts (superior and inferior) aiming to identify the complex torque or medial/lateral movement of this region. This way, positive values represented a lateral displacement of the rami, and negative values showed a medial displacement. When both portions of the ramus showed displacements in opposite directions, it indicated a torque movement of this anatomic region.

To assess surgical outcomes, the largest displacements between pre-surgery/post-surgery (splint-removal) were computed for all anatomic regions of interest.

To check the reproducibility of greatest displacements' measurements done by the isolines, 10 randomly selected superimpositions were measured twice, at a 2-week interval and

compared through intraclass correlation coefficient ( $P < 0.001$ ). The agreement between the measurements was high for all anatomic regions: chin ( $r=0.98$ ); condyles ( $r=0.92$ ); posterior borders ( $r=0.97$ ); superior rami ( $r=0.97$ ) and inferior rami ( $r=0.95$ ).

Descriptive statistics consisting of mean values, standard deviations and minimum/maximum displacements were done. Since changes greater than 2 mm can be considered clinically relevant, a categorization shows the number of patients that had displacements greater than 2 mm, between 2 mm and -2 mm and smaller than -2 mm, along with the mean values, standard deviations, and minimum and maximum values for each group. Descriptive statistics was divided in positive and negative displacements according to each region directional tendency.

To test if displacements in anatomic regions were associated with each other, i.e., if changes at the condyles and/or ramus were associated with changes at the chin, the Pearson correlation coefficients were used under 95% significance level.

## RESULTS

Mean displacements of all the evaluated anatomic regions showed that the chin and the inferior portion of the rami presented changes greater than 2 mm, which are considered clinically relevant. The chin moved anterior-inferiorly  $6.81 \pm 3.2$  mm on average and the inferior portion of the rami moved laterally  $2.97 \pm 2.71$  mm on the left side and  $2.34 \pm 2.35$  mm on the right side (Table 1 and Fig 4).

All the other anatomic regions showed mean displacements smaller than 2 mm, but the individual variability was evident, with the maximum displacements ranging outside the 2 mm limit (Table 1 and Fig 5).

Condylar maximum displacements, for example, ranged between -3.7 mm and +3.2 mm. Figure 6 shows a patient who underwent a condyle displacement of +3.2 mm.

Considering changes greater than 2 mm as being clinically relevant, it is possible to quantify the number of anatomic regions that displaced significantly. As one should expect, the chin had a displacement greater than 2 mm with surgery in all the patients ( $n=25$ ). Looking at the posterior border of the rami (right and left,  $n=54$ ), 8 had displacements smaller than -2 mm and 6 greater than 2 mm. For the condyles (right and left,  $n=54$ ) 2 showed displacements smaller than -2 mm and 11 greater than 2 mm (Table 2).

The superior portion of the rami (right and left,  $n=54$ ) underwent displacements smaller than -2 mm in 3 patients and greater than 2 mm in 15. After the chin, the inferior portion of the rami was the region with the most relevant changes, showing displacements smaller than -2 mm in 3 cases and greater than 2 mm in 35 (right and left,  $n=54$ ) (Table 2).

Correlations of displacements between the evaluated anatomic regions by means of a Pearson correlation coefficient showed that all the significant statistical correlations were positive and moderate (Table 3). The chin anterior displacement was correlated with the lateral movement of the superior portion of the right ramus ( $r=0.46$ ,  $p=0.02$ ).

TABLE 1 - Descriptive statistics of surgical displacements.

| Region                  | Pre-surgery /Post-surgery |           |         |                |
|-------------------------|---------------------------|-----------|---------|----------------|
|                         | Number of patients        | Mean (mm) | SD (mm) | Min / Max (mm) |
| Chin                    | 25                        | 6.81      | 3.20    | 2.5/15.8       |
| Posterior ramus (left)  | 27                        | 0.08      | 2.32    | -3.2/6.1       |
| Posterior ramus (right) | 27                        | -0.09     | 1.84    | -2.8/4.1       |
| Condyle (left)          | 27                        | 0.98      | 1.46    | -3.7/3.2       |
| Condyle (right)         | 27                        | 0.81      | 1.40    | -2.4/2.9       |
| Superior ramus (right)  | 27                        | 0.62      | 1.94    | -2.9/3.5       |
| Inferior ramus (right)  | 27                        | 2.34      | 2.35    | -3.0/5.8       |
| Superior ramus (left)   | 27                        | 1.57      | 1.92    | -1.9/5.7       |
| Inferior ramus (left)   | 27                        | 2.97      | 2.71    | -2.5/7.0       |

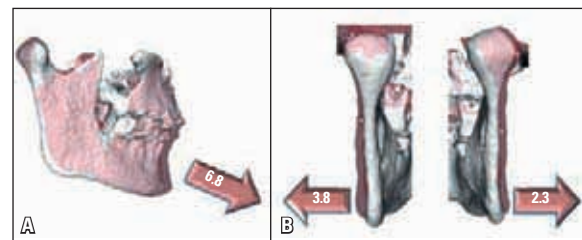


FIGURE 4 - **A)** Semi-transparent visualization showing a 6.8 mm mean mandibular advancement measured at the chin. **B)** Proximal segment lateral displacement after mandibular advancement surgery. The sagittal osteotomy probably acted like a wedge and the condyles as a fulcrum, causing the inferior rami to be the anatomic region with the greatest mean displacement after the chin.

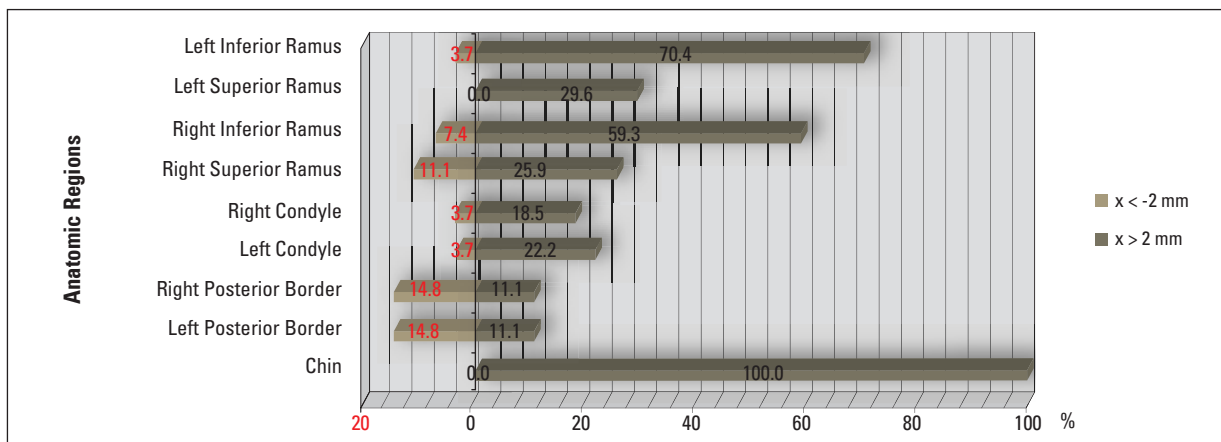


FIGURE 5 - Clinically relevant displacements for each anatomic region. Percentage of patients with changes > 2 mm and < -2 mm.

TABLE 2 - Descriptive statistics of surgical displacements: number of patients showing displacements greater than 2 mm, between 2 mm and -2mm and smaller than -2 mm, along with the mean values, standard deviations, and minimum/maximum values for each group.

| PRE-SURGERY / SPLINT REMOVAL  |    |       |      |       |       |
|-------------------------------|----|-------|------|-------|-------|
| Chin (n=25)                   |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 0  | -     | -    | -     | -     |
| $-2 \leq x \leq 2$            | 0  | -     | -    | -     | -     |
| $x > 2$                       | 25 | 6.81  | 3.20 | 2.50  | 15.80 |
| Left Posterior Border (n=27)  |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 4  | -3.00 | 0.22 | -3.20 | -2.70 |
| $-2 \leq x \leq 2$            | 20 | -0.05 | 1.15 | -2.00 | 1.60  |
| $x > 2$                       | 3  | 5.03  | 1.29 | 3.60  | 6.10  |
| Right Posterior Border (n=27) |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 4  | -2.40 | 0.32 | -2.80 | -2.10 |
| $-2 \leq x \leq 2$            | 20 | -0.13 | 1.27 | -2.00 | 1.40  |
| $x > 2$                       | 3  | 3.23  | 1.03 | 2.10  | 4.10  |
| Left Condyle (n=27)           |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 1  | -3.70 | -    | -3.70 | -3.70 |
| $-2 \leq x \leq 2$            | 20 | 0.78  | 1.00 | -1.40 | 1.90  |
| $x > 2$                       | 6  | 2.45  | 0.40 | 2.10  | 3.20  |
| Right Condyle (n=27)          |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 1  | -2.40 | -    | -2.40 | -2.40 |
| $-2 \leq x \leq 2$            | 21 | 0.56  | 1.10 | -1.80 | 1.80  |
| $x > 2$                       | 5  | 2.50  | 0.26 | 2.20  | 2.90  |
| Right Superior Ramus (n=27)   |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 3  | -2.57 | 0.31 | -2.90 | -2.30 |
| $-2 \leq x \leq 2$            | 17 | 0.26  | 1.35 | -1.90 | 2.00  |
| $x > 2$                       | 7  | 2.86  | 0.34 | 2.60  | 3.50  |
| Right Inferior Ramus (n=27)   |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 2  | -2.65 | 0.49 | -3.00 | -2.30 |
| $-2 \leq x \leq 2$            | 9  | 0.70  | 1.38 | -1.80 | 2.00  |
| $x > 2$                       | 16 | 3.89  | 1.01 | 2.60  | 5.80  |
| Left Superior Ramus (n=27)    |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 0  | -     | -    | -     | -     |
| $-2 \leq x \leq 2$            | 19 | 0.65  | 1.40 | -1.90 | 2.00  |
| $x > 2$                       | 8  | 3.76  | 0.97 | 3.00  | 5.70  |
| Left Inferior Ramus (n=27)    |    |       |      |       |       |
|                               | N  | Mean  | SD   | Min   | Max   |
| $x < -2$                      | 1  | -2.50 | -    | -2.50 | -2.50 |
| $-2 \leq x \leq 2$            | 7  | -0.30 | 1.44 | -1.30 | 1.90  |
| $x > 2$                       | 19 | 4.46  | 1.33 | 2.30  | 7.00  |

The posterior movement of the left and right ramus posterior border showed correlation ( $r=0.69$ ,  $p<0.0001$ ). The posterior movement of the left ramus posterior border also correlated to the superior portion of the ramus on the same side ( $r=0.42$ ,  $p<0.03$ ).

Posterior-superior displacements of the condyles were correlated between left and right

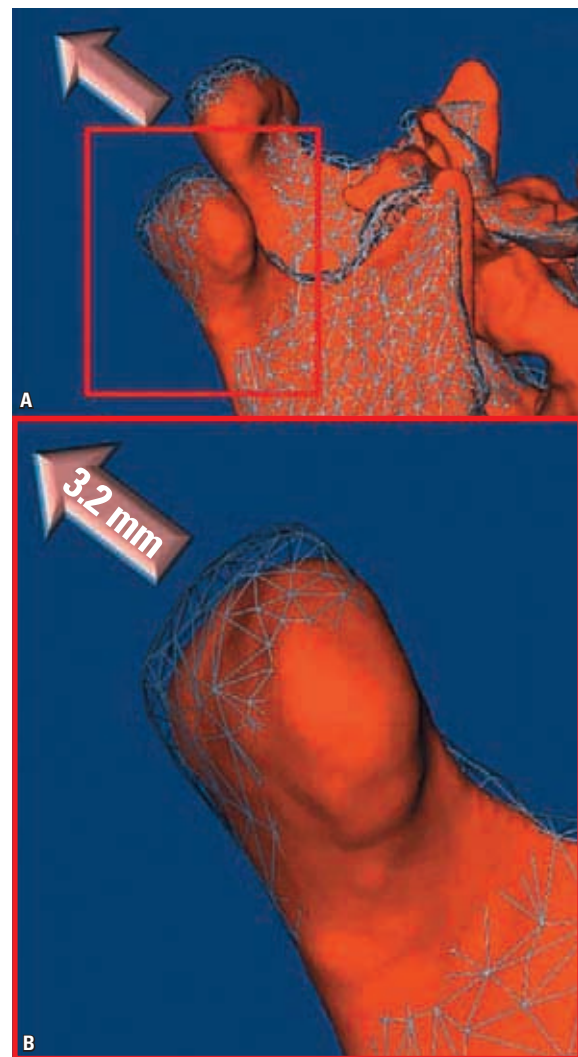


FIGURE 6 - **A)** Mesh-transparencies visualization showing a condyle displacement of 3.2 mm after surgery. **B)** Close-up view of the displaced condyle.

TABLE 3 - Pearson correlation coefficients for the surgical displacements between all anatomical regions. The upper right part of the table shows r values and the lower part p values. Statistically significant values are in bold.

|                    | Chin        | Left Post. Border | Right Post. Border | Left Condyle | Right Condyle | Right Sup. Ramus | Right Inf. Ramus | Left Sup. Ramus | Left Inf. Ramus |
|--------------------|-------------|-------------------|--------------------|--------------|---------------|------------------|------------------|-----------------|-----------------|
| Chin               |             | -0.26             | -0.18              | -0.34        | -0.28         | <b>0.46</b>      | 0.22             | 0.08            | 0.09            |
| Left Post. Border  | 0.21        |                   | <b>0.69</b>        | -0.06        | -0.07         | -0.05            | 0.12             | <b>0.42</b>     | 0.22            |
| Right Post. Border | 0.40        | <b>&lt;.0001</b>  |                    | -0.14        | 0.18          | -0.12            | 0.06             | 0.12            | 0.24            |
| Left Condyle       | 0.10        | 0.75              | 0.49               |              | <b>0.66</b>   | -0.33            | -0.14            | -0.21           | -0.31           |
| Right Condyle      | 0.17        | 0.73              | 0.37               | <b>0.00</b>  |               | -0.22            | 0.04             | -0.30           | -0.21           |
| Right Sup. Ramus   | <b>0.02</b> | 0.79              | 0.56               | 0.10         | 0.28          |                  | <b>0.58</b>      | <b>0.46</b>     | 0.09            |
| Right Inf. Ramus   | 0.30        | 0.56              | 0.76               | 0.49         | 0.86          | <b>0.00</b>      |                  | 0.21            | -0.18           |
| Left Sup. Ramus    | 0.71        | <b>0.03</b>       | 0.56               | 0.30         | 0.14          | <b>0.01</b>      | 0.30             |                 | <b>0.66</b>     |
| Left Inf. Ramus    | 0.67        | 0.27              | 0.24               | 0.11         | 0.28          | 0.65             | 0.36             | <b>0.00</b>     |                 |

( $r=0.66$ ,  $p=0.0002$ ). The superior portions of the rami were also correlated between sides ( $r=0.46$ ,  $p=0.0148$ ).

On both sides, the superior and inferior portion of the ramus were correlated, showing a lateral movement tendency (right:  $r=0.58$ ,  $p=0.0016$ ; left:  $r=0.66$ ,  $p=0.0002$ ).

## DISCUSSION

In conventional cephalometrics, the cranial base often is used for superimpositions because it shows minimal changes after neural growth is completed. In 3D image analysis, registration can be based on choice of stable surfaces or landmarks. While landmark location in 2D is hampered by identification of hard and soft tissues on x-rays due to the superimposition of multiple structures, locating 3D landmarks on complex curving structures is significantly more difficult.<sup>19</sup> There are no suitable operational definitions for craniofacial landmarks in the three

planes of space (coronal, sagittal, and axial). In the context of facial changes, superimposition should not rely on landmark identification nor on best-fit techniques on structures that may have changed between image acquisitions.<sup>18</sup>

The major strength of the superimposition method used in this study is that registration does not depend on the precision of the 3D surface models. The cranial base models are only used to mask anatomic structures that do not change with growth and treatment. The registration procedure actually compares voxel by voxel of gray level CBCTs images, containing only the cranial base, and calculates the rotation and translation parameters between the two time-point images.

Regional superimposition in the cranial base does not completely define the movement of the mandible relative to the maxilla<sup>9,10,20-23</sup>. Previous studies<sup>20,22,24-26</sup> revealed that relative displacement of mandibular and maxillary skeletal and

dental components is critical because the resulting information may differ from conclusions formulated from the cranial base superimposition.

Although a 3D superimposition study presents additional information when compared to traditional cephalometric methods, analysis of the 3D morphology poses methodological challenges. Current methods, including methods used in commercially available software (Geomagic Studio, Geomagic U.S. Corp, Research Triangle Park, NC, 27709 and Vultus, 3dMD, Atlanta, GA, 30339), calculate the closest point between two surfaces. However, the closest point is not necessarily the corresponding point in both surfaces.

The quantification utilizing isolines in this study determined the absolute maximum change in the anatomic region, where positive or negative values based on operator observation aided the assessment of the direction of displacement. For example, positive values at the chin indicate an anterior-inferior displacement, but it's not possible to distinguish how anterior and how inferior the displacement is. A method that quantifies vectorial displacements is being developed at UNC, which will be able to analyze shape correspondence between two structures, and in the future will improve directional evaluation. Another issue is that differences between the surfaces are not only a result of displacement as this method suggests, there may occur a remodeling process too.

It has been advocated in the literature<sup>27</sup> that a precise repositioning of the condyles during surgery would ensure stability of the surgical results and reduce temporomandibular joint noxious effects. It might improve postoperative masticatory function, but the extent of condylar change that is compatible with normal function post-surgically is still unknown. In this study, mild mean condylar displacements with surgery (left  $0.98 \pm 1.46$  mm and right  $0.81 \pm 1.40$  mm) were observed, but some patients experienced an important condylar displacement up to 3.7 mm anterior-inferiorly and 3.2 mm posterior-superiorly.

The use of devices for preserving the preoperative position of the mandibular condyle during bilateral sagittal split osteotomy has been proposed, but it was concluded that there is no scientific evidence to support its routine use in orthognathic surgery, which makes the condylar positioning a critical procedure to be handled.<sup>28</sup>

With the increased use of rigid fixation, there has been a decrease in the amount of relapse but an increase in the amount of force transmitted to the condyles. Gradual advancement of the mandible by distraction osteogenesis slowly overcomes the soft-tissue envelope and may decrease the amount of force exerted on the condyles. Using an animal model to measure the magnitude of pressure associated with immediate versus gradual mandibular advancement, it was found that the superior joint space fluid pressures increased and remained elevated over a 5-week period after immediate advancement, contrasting with the results of gradually advancement of the mandible where the pressures were elevated but returned to near baseline prior to the activation the following day. Based on these findings, the authors could conclude that it is likely that gradual advancement of the mandible by distraction osteogenesis produces less force and causes less condylar resorption than large mandibular advancement stabilized with rigid fixation, but further studies are needed to compare methods for mandibular advancement.<sup>29</sup>

This study found that the inferior portion of the rami was the region with the most relevant displacements after the chin, showing displacements smaller than -2 mm in just 3 rami of a total of 54 and greater than 2 mm in 35 (right and left). The average lateral displacement was  $2.97 \pm 2.71$  mm on the left side and  $2.34 \pm 2.35$  mm on the right side. These results agree with another study<sup>1</sup> that found an increased transverse intergonion distance with a mean of 5.0 mm in 44 of 45 patients after

BSSO using miniplates for fixation. The sum of mean displacements for right and left sides of the inferior portion of the rami was 5.28 mm in the present study, very close to the results of the study cited above<sup>1</sup> even with the different measurement methods.

Besides the chin and the inferior portion of the rami, all the other anatomic regions showed mean displacements smaller than 2 mm, but with the maximum displacements ranging beyond the clinical acceptable limit. Relevant displacements of distal and proximal mandibular segments and surgically induced posterior condylar displacement seem to be important surgical risk factors for postoperative condylar resorption. Although these displacements are hard to predict during surgery, it might be an area of concern especially for those patients who are at a high risk of condylar resorption.<sup>30</sup>

## CONCLUSIONS

Superimposition of 3-dimensional (3D) virtual surface models allowed clear visualization and quantification of outcomes of mandibular advancement surgery.

On average, mandibular advancement surgery resulted in clinically significant (greater than 2 mm) anterior-inferior chin displacement as well as lateral movement on the inferior portion of the rami. On the other hand, a considerable individual variability was observed for all the evaluated anatomic regions, with changes ranging beyond the clinically acceptable limit.

Bilateral changes were significantly correlated for condyles, posterior border and superior portion of the rami, and ipsilateral displacements correlation occurred between superior and inferior portion of the rami, showing a lateral movement tendency.

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# Transverse effects of rapid maxillary expansion in Class II malocclusion patients: A Cone-Beam Computed Tomography study

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## Abstract

**Objective:** The aim of this study was to evaluate by Cone-Beam Computed Tomography (CBCT) transversal responses, immediately and after the retention period, to rapid maxillary expansion (RME), in Class II malocclusion patients. **Methods:** Seventeen children (mean initial age of 10.36 years), with Class II malocclusion and skeletal constricted maxilla, underwent Haas' protocol for RME. CBCT scans were taken before treatment (T1), at the end of the active expansion phase (T2) and after the retention period of six months (T3). The scans were managed in Dolphin software, where landmarks were marked and measured, on a coronal slice passing through the upper first molar. The paired Student's t-test was used to identify significant differences ( $p < 0.05$ ) between T2 and T1, T3 and T2, and T3 and T1. **Results:** Immediately after RME, the mean increase in maxillary basal, alveolar and dental width was 1.95 mm, 4.30 mm and 6.89 mm, respectively. This was accompanied by buccal inclination of the right ( $7.31^\circ$ ) and left ( $6.46^\circ$ ) first molars. At the end of the retention period, the entire transverse dimension increased was maintained and the dentoalveolar inclination resumed. **Conclusions:** The RME therapy was an effective procedure to increase transverse maxillary dimensions, at both skeletal and dentoalveolar levels, without causing inclination on anchorage molars in Class II malocclusion patients with skeletal constricted maxilla.

**Keywords:** Rapid maxillary expansion. Transverse effects. Cone-Beam Computed Tomography. Class II malocclusion.

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## INTRODUCTION

Class II Division 1 malocclusions are strongly related to transverse problems, presenting a significantly reduced maxillary width when compared to normal occlusion.<sup>2,22,25,26</sup> However, its diagnosis is often passed unnoticed at clinical examination as transverse deficiency is camouflaged by the Class II skeletal pattern itself. The upper teeth occlude in a more anterior region of the mandible, showing an apparent normal transverse development, even in the presence of maxillary transverse deficiency.<sup>28</sup> Upper molars tend to incline buccally to compensate the insufficient skeletal and alveolar base. For this reason, rapid maxillary expansion (RME) may be considered before treating Class II Division 1 malocclusion patients.<sup>26</sup>

RME has been the treatment chosen by many orthodontists for correction of skeletal maxillary constriction in growing patients.<sup>10,11</sup> The key feature of RME is that the force applied to the teeth and alveolar processes by activating the expander screw promotes the opening of the midpalatal suture. The stability of the new transverse dimension is also a fundamental part of the treatment, which turns the retention phase as important as the active phase,<sup>15</sup> with the expander appliance having to remain in place for at least three months.<sup>13</sup> The Haas expander appliance is widely used in orthodontics because its screw is covered by an acrylic block that enhances the contact with the lateral walls of palate, thus increasing the anchorage, improving the orthopedic effect, and decreasing tooth movement.<sup>11</sup>

Until recently, frontal cephalometric radiographs were the most precise methods for evaluating the transverse effects of RME. However, the difficulties inherent to the technique not always allowed the precise location and identification of craniofacial structures. With the use of the Cone-Beam Computed Tomography (CBCT) images, not only a three-dimensional visualization of the whole craniofacial complex is possible, but also precise and reliable

measurements of the changes caused by RME, since there is neither image superposition nor size distortion.<sup>8</sup>

Despite the numberless articles on rapid maxillary expansion effects,<sup>12,15,24</sup> the literature is still scarce in studies evaluating only the results from the expander appliance in Class II malocclusion patients. The objective of the present study was to evaluate, using CBCT, the dental and skeletal transverse effects of rapid maxillary expansion immediately and after a retention period, with Haas expander appliance in Class II malocclusion patients.

## MATERIAL AND METHODS

This prospective clinical study was performed at the Department of Orthodontics of the Federal University of Rio de Janeiro after being approved by the research ethics committee of the Institute of Collective Health Studies (0052.0.239.000-09). Seventeen children (8 boys and 9 girls with mean ages of 10.67 and 10.05 years, respectively) presenting Class II, Division 1 malocclusion and skeletal transverse deficiency were selected for the study.

The inclusion criteria were: ages between 7-12 years; Class II molar (unilateral or bilateral) and skeletal ( $ANB \geq 4^\circ$ )<sup>21</sup> relationship; maxillary skeletal transverse deficiency (distance from J point to facial frontal line  $> 12$  mm);<sup>20</sup> and stage before pubertal growth spurt.<sup>6</sup>

Even not being an exclusion criterion, none of the patients had visible posterior crossbite. The transverse problem was first evaluated clinically and diagnosed as atresia, when the patient projected the mandible until a Class I relationship, and the posterior relationship was edge to edge or in crossbite.<sup>16</sup>

All patients were submitted to RME protocol established by Haas for patients younger than 14 years of age.<sup>11,13</sup> The appliances were standardized by 0.047-in stainless steel wire (Rocky Mountain Orthodontics) and 11 mm expander screw

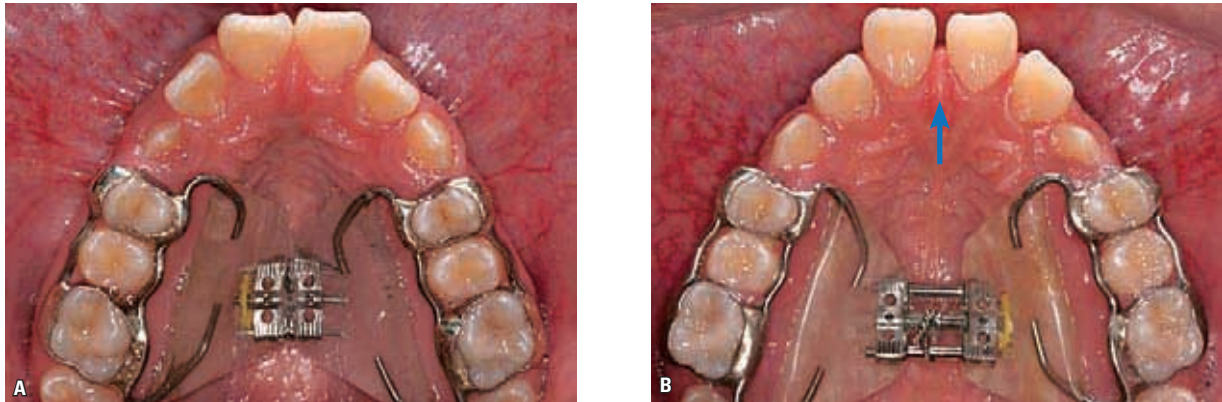


FIGURE 1 - Occlusal oral pictures with the Haas expander appliance: **A)** Before the beginning of screw activation, **B)** Immediately after screw stabilization (blue arrow shows the opening of the inter-incisors diastema).

(Dentaurum, Magnum model, 600.303.30) (Fig 1, A). The first screw activation was of one complete turn (0.8 mm), in the same day of appliance installation, and the following activations were of two 1/4 turn per day (0.2 mm per turn, 0.4 mm daily) until the palatine surface of the upper molar contacted the buccal surface of the lower molar, when the patient projected the mandible to a Class I relationship. This active expansion treatment varied from 2-3 weeks. After this, the screw was stabilized with a 0.012-in double thread ligature (Fig 1, B) and kept in place passively for the following six months when the appliance was then removed.

CBCTs were performed before treatment (T1), immediately after screw expander stabilization (T2), and 1-2 days after appliance removal (T3). All scans were taken with the same Cone-Beam machine (i-CAT, Imaging Sciences International, Hatfield, Pennsylvania, USA), according to a standard protocol (120 KVP, 3-8 mA, FOV = 13x17 cm, voxel = 0.4 mm, and scan time = 20s). The scans performed in T1 and T2 were saved in DICOM (digital imaging and communication in medicine) format, and with Dolphin Imaging software® version 11.0 (Dolphin Imaging, Charsworth, California, USA), it was possible to reconstruct 3D images for analysis.

Using specific software functions, before the measurements, it was possible to standardize

head image positions according to the axial, coronal, and sagittal planes<sup>4</sup> at all studied times: The axial plane, passing through right and left orbital points as well as right porion; coronal plane, passing through left and right porion, perpendicular to the chosen axial plane; and sagittal plane, passing through nasion point, perpendicular to the chosen axial and coronal planes (Fig 2).

After standardization, the coronal plane and the 3D reconstructions of the images were used for determining the coronal slice and position of the landmarks (Fig 3). The most anterior coronal slice showing the entire palatal root of the first upper molar was chosen. All the landmarks were identified on the selected coronal slice. Landmarks and measurements were previously described by Podesser et al,<sup>18</sup> as follows (Fig 4):

- Right and Left Maxillary (rMx and lMx): Right and left points in which the axial plane, by passing tangentially at the more inferior contour of nasal cavity, meets the buccal-alveolar contour of the maxilla.

- Right and Left Maxillary Alveolar (rMa and lMa): The most inferior and medial point of the buccal-alveolar process in relation to the upper first permanent molar.

- Right and Left Molars Cusp (rMc and lMc): The most inferior and medial point of the mesial-buccal cusp of the upper first permanent molar.



FIGURE 2 - Three-dimensional image of the head position after standardization by the axial, coronal and sagittal reference planes. Dolphin Imaging® 11.0, orientation tool.

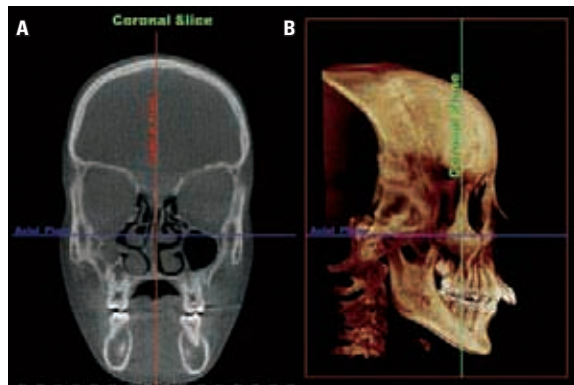


FIGURE 3 - A) Coronal slice used to identify the landmarks and measurements; B) 3D right lateral image, with the coronal plane passing through the right upper first molar. Dolphin Imaging® 11.0.

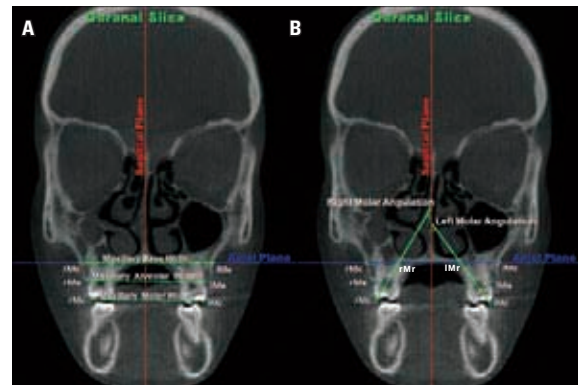


FIGURE 4 - Coronal slice images with the landmarks identified (rMx, lMx, rMa, lMa, rMc, lMc, rMr e lMr) and measurements: A) linear measurements (Maxillary base width, Maxillary alveolar width, Maxillary dental width); B) angular measurements (Right and Left molar angulation). Dolphin Imaging® 11.0, Digitize/Measurement tool.

- Right and Left Root Molars (rMr and lMr): The most superior and medial point of the palatine root of the upper first permanent molar.

The Linear measurements (mm) were maxillary basal width (rMx-lMx), maxillary alveolar width (rMa-lMa), and maxillary dental width (rMc-lMc), whereas angular measurements were right (rMc.rMr.sagittal plane) and left (lMc.lMr.sagittal plane) dentoalveolar angulation.

In order to avoid possible measurement errors, two similar monitors were used, including the software. This allowed CBCT images to be simultaneously handled for locating planes and landmarks in all three study period of times (T1, T2, T3) for each patient, where T1 was always the reference. Measurements, regarding each period of time, were taken separately by the same examiner within a 1-week interval.

### Error of the method

Prior to the measurements, 15 scans were randomly selected in order to determine the reproducibility of the measurement performed in the present study. The 3D position of the head image was standardized, landmarks identified and measurements were obtained in two different periods within a 2-week interval under the same conditions. Intra-class correlation test was applied to verify the intra-observer agreement (95% interval confidence) for all variables. Agreement index was greater than 0.95 for all variables studied.

### Statistical analysis

Means, standard deviations, minimum and maximum values were calculated for each variable at T1, T2, and T3, as well as changes occurring between T1 and T2, T2 and T3, and T1 and T3 were recorded. After normal data distribution was confirmed by the Kolmogorov-Smirnov non-parametric test, statistically significant differences between T2 and T1, T3 and T2, and T3 and T1 were identified using paired Student's t test ( $p < 0.05$ ). All statistical analyses were carried out using SPSS software version 16.0 (SPSS Inc., Chicago, IL, USA).

TABLE 1 - Descriptive analysis of measurements obtained in pre-treatment (T1), immediately after expansion (T2) and after 6 months retention (T3).

|                          | T1 (n=17) |       |       |      | T2 (n=17) |       |       |      | T3 (n=16) |       |       |      |
|--------------------------|-----------|-------|-------|------|-----------|-------|-------|------|-----------|-------|-------|------|
|                          | Mean      | Min.  | Max.  | SD   | Mean      | Min.  | Max.  | SD   | Mean      | Min.  | Max.  | SD   |
| Maxillary Base Width     | 60.13     | 54.96 | 66.28 | 3.24 | 62.08     | 56.55 | 67.45 | 3.43 | 61.78     | 56.30 | 65.92 | 3.29 |
| Maxillary Alveolar Width | 53.53     | 46.98 | 57.70 | 3.17 | 57.83     | 51.41 | 61.68 | 2.88 | 58.22     | 51.87 | 61.88 | 3.27 |
| Maxillary Dental Width   | 51.39     | 47.79 | 55.25 | 2.34 | 58.19     | 53.22 | 61.47 | 2.38 | 57.28     | 52.23 | 61.13 | 2.62 |
| Right Molar Angulation   | 36.23     | 30.96 | 43.81 | 3.80 | 43.54     | 35.07 | 51.74 | 5.44 | 37.82     | 27.51 | 49.40 | 5.53 |
| Left Molar Angulation    | 36.88     | 30.31 | 44.19 | 4.17 | 43.34     | 37.16 | 54.12 | 5.10 | 38.15     | 30.29 | 45.69 | 4.58 |

n = sample number; Min = minimum; Max = maximum; SD = standard deviation.

TABLE 2 - Results regarding transverse changes between pre-treatment and post-expansion (T2 – T1), post-expansion and retention (T3 – T2), and initial and retention (T3 – T1).

|                          | T2-T1 (n=17) |      |      |                   | T3-T2 (n=16) |      |      | T3-T1 (n=16) |      |      |                   |
|--------------------------|--------------|------|------|-------------------|--------------|------|------|--------------|------|------|-------------------|
|                          | Mean         | SE   | SD   | %screw activation | Mean         | SE   | SD   | Mean         | SE   | SD   | %screw activation |
| Maxillary Base Width     | 1.95***      | 0.18 | 0.74 | 29.10             | -0.29        | 0.16 | 0.64 | 1.66***      | .23  | .92  | 24.97             |
| Maxillary Alveolar Width | 4.30***      | 0.30 | 1.20 | 65.38             | 0.39         | .22  | 0.89 | 4.69***      | 0.33 | 1.32 | 72.32             |
| Maxillary Dental Width   | 6.89***      | 0.33 | 1.31 | 102.84            | -0.91**      | 0.24 | 0.95 | 5.89***      | 0.34 | 1.38 | 91.08             |
| Right Molar Angulation   | 7.31***      | 0.85 | 3.40 | ---               | -5.71***     | 0.81 | 3.26 | 1.74         | 0.92 | 3.66 | ---               |
| Left Molar Angulation    | 6.46***      | 0.95 | 3.79 | ---               | -5.19***     | 0.76 | 3.05 | 1.27         | 0.56 | 2.22 | ---               |

n = sample number; SE = standard error; SD = standard deviation; Level of significance = \*  $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

## RESULTS

The midpalatal suture opened in all patients. This could be clinically visualized within 3-5 days after the beginning of the expander activation by the increase of inter-incisor diastema (Fig 1, B) and then confirmed in the CBCT image at T2 (Fig 5).

The mean screw activation was 7 mm (min. = 5.6 mm and max. = 9 mm).

During the retention period, one of the patients returned without the appliance, which was replaced by a removable retention appliance, but data at T3 were not computed.

The results regarding to the descriptive analysis and Student's t test are presented in Tables 1 and 2.

## DISCUSSION

Rapid maxillary expansion has been widely used since the mid 60's.<sup>9,10</sup> Numberless protocols and appliances have been proposed for correction of transverse skeletal discrepancies. In 1961, Haas<sup>9</sup> described a technique for construction of

a dental-mucous-bone-supported expansion appliance and its effects have been evaluated since then.<sup>11,12</sup> The objective of the present study was to evaluate, immediately after RME, as well as

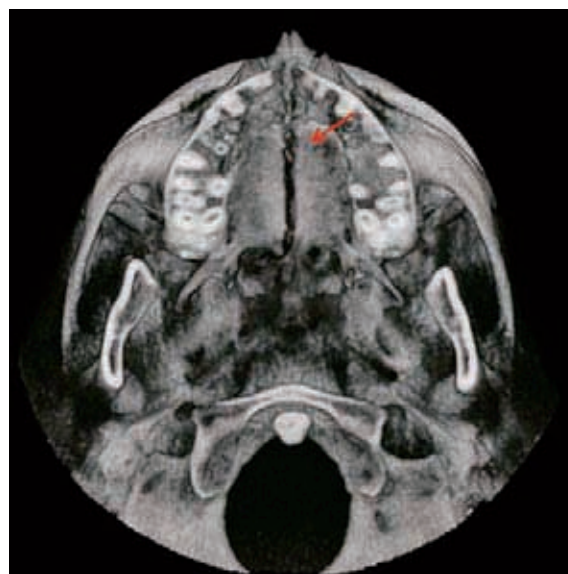


FIGURE 5 - Three-dimensional reconstruction showing the opening of the midpalatal suture in T2 (Dolphin Imaging®).

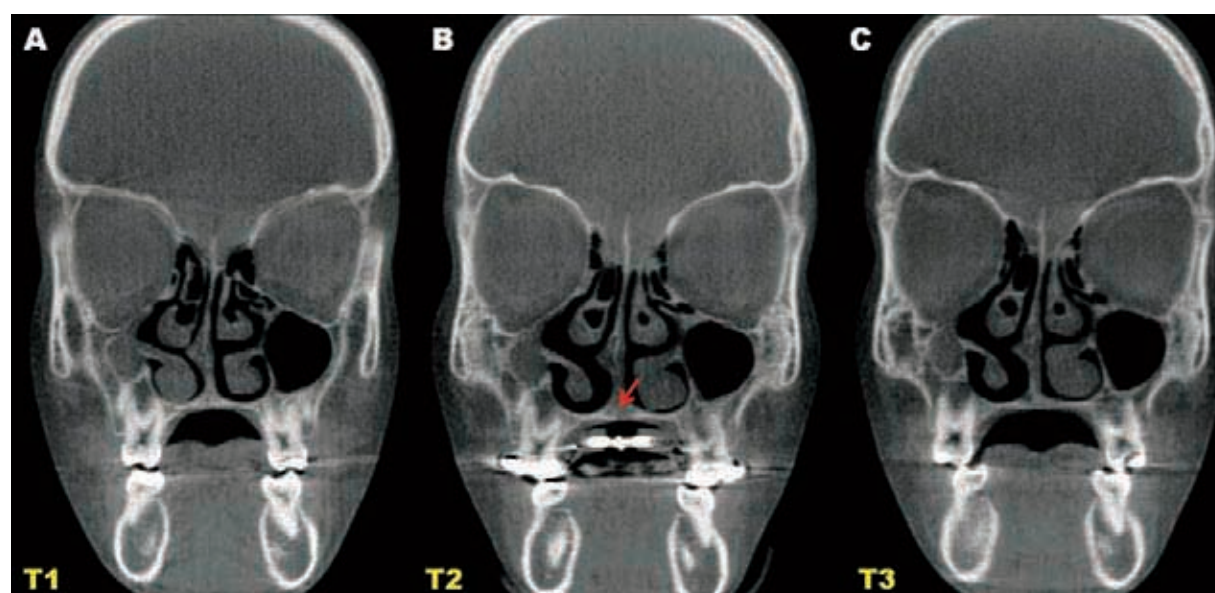


FIGURE 6 - Coronal slice used to measurements at T1, T2 and T3. **A)** Pre-treatment, crossbite not present in centric relation occlusion; **B)** Immediately after the transverse discrepancy correction, showing the palatal suture opened with slight inferior displacement (arrow) and an increase of the dentoalveolar angulation; **C)** After 6-months of retention, the transverse dimension increased, showing the buccal posterior crossbite tendency and the palatal dentoalveolar angulation. Dolphin Imaging® 11.0.

during and after the retention period, the transverse effects of the Haas expander in Class II malocclusion patient, since this treatment is so requested in this malocclusion.

The expansion protocol applied in this study was efficient for all patients. The opening of the midpalatal suture was easily confirmed on CBCT images realized at T2 (Fig 5), and none of the patients reported pain during the active or the retention period, just a light discomfort at the moment of the screw activation during the first 3 days. Treatment timing was an important issue to be considered, since it has been demonstrated that patients who underwent to RME before pubertal growth spurt exhibited greater skeletal effects, as well as greater bone stability when compared to later treatment.<sup>14</sup> The successful results observed in our study can be attributed to the choice of the appliance, which provided maximum anchorage when used in the appropriate skeletal maturation period.<sup>13</sup>

Standardization of the amount of screw expander activation seems to be ideal to evaluate the transverse effects. However, we thought this is ethically wrong as the patients had different orthodontic needs, i.e., some might need more expansion while for others the amount of activation might not be enough. In order to make it possible to evaluate and to compare the results with previous studies, the transverse effects were proportionally analyzed according to the amount of screw activation in each patient.

Immediately after screw expander stabilization, all measurements were found to be highly significant (Table 2). Maxillary basal width increased, on average, 1.95 mm (29.10% of the screw activation), which was similar to what was found by Podesser et al.<sup>19</sup> Alveolar and dental widths showed significantly greater results in our study, 4.3 and 6.9 mm, respectively, compared to 2.6 and 3.6 mm found elsewhere.<sup>19</sup> Such difference may be related to the fact that the expander was removed at the end of

the active period for CBCT performing, which might have allowed some relapse, unlike our study, in which the expander was only removed at the end of the retention period.

Several studies reported a downward movement of the maxilla during the midpalatal suture opening following RME.<sup>1,5,9,23</sup> This can happen because the center of resistance of the maxilla is located above the force application point, causing a buccal inclination of the dentoalveolar structures of the maxilla, with a downward displacement of the central region of the maxilla.<sup>17,27,29</sup> This effect could also be observed in our study, visually, on CBCT images at T2 (Fig 6) and through the significant increase of the buccal inclination of the first upper molars (7.31°/6.46°) and the greater increase of the dental width than the total amount of screw activation (102.84%).

During the retention period (T3-T2), basal and alveolar maxillary widths did not change significantly ( $p > 0.05$ ). The 6-months of retention with Haas expander not only kept the new transverse dimension, but also allowed a significant decrease in dentoalveolar angulation (-5.71° / -5.19°), decreasing the maxillary dental width (-0.91 mm). As reported by previous studies,<sup>5,11,24</sup> the increase in transverse dimension, on the frontal view, in this study also occurred as a triangular form with the apex located superiorly. At the end of the retention period, it was observed that basal, alveolar, and dental maxillary widths were highly significantly ( $p < 0.001$ ) greater than those measured at T1 (1.66 mm, 4.69 mm and 5.89 mm, respectively), corresponding to 24.97%, 72.32%, and 91.08% of the total of the screw activation. Similar results were found by Ballanti et al.<sup>3</sup>, who used computed tomography to evaluate the RME effects after 6-months retention with Hyrax-type expander. The molar widths at the apex and crown increased, respectively, 5.1 mm and 6.1 mm for a total

activation of 7 mm. Meanwhile, Garib et al<sup>7</sup> found greater results at the basal and dental (crown) levels with the Haas appliance, respectively, 5.5 mm and 8.1 mm. Nevertheless, the retention period (3-months) was shorter and some relapse might be still expected.

The strong association between skeletal transverse deficiency and Class II, Division 1 malocclusions, even in the absence of posterior cross-bite, shows the importance of this discrepancy correction avoiding dental compensations.<sup>2,22,25,26</sup> Our results showed that the RME with the Haas expander in Class II malocclusion patients did not change significantly the upper molar angulation. At the end of the retention period, dentoalveolar angulation was not found to be statistically different from that recorded at T1 despite the changes observed during the evaluation period. This demonstrates that the increase in dental width caused by RME had indeed promoted an effective

translation movement in the anchorage teeth. Ballanti et al<sup>3</sup> also obtained the same results using Hyrax-type appliance, whereas Garib et al<sup>7</sup> found significantly increased inclination of the molars at the end of their study. The 3-months of retention may not have been enough for molars to resume to their initial inclination.

## CONCLUSIONS

All the Class II malocclusion patients evaluated had a significant increase in the skeletal and dental transverse dimension, without causing significant changes in the anchorage molars. The 6-months retention period allowed the transverse skeletal increase to be maintained and to return to the initial dentoalveolar inclination.

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# 3D simulation of orthodontic tooth movement

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## Abstract

**Objective:** To develop and validate a three-dimensional (3D) numerical model of a maxillary central incisor to simulate tooth movement using the Finite Element Method (FEM).

**Methods:** This model encompasses the tooth, alveolar bone and periodontal ligament. It allows the simulation of different tooth movements and the establishment of centers of rotation and resistance. It limits the movement into the periodontal space, recording the direction, quantifying tooth displacement and initial stress in the periodontal ligament.

**Results:** By assessing tooth displacements and the areas that receive initial stress it is possible to determine the different types of tooth movement. Orthodontic forces make it possible to quantify stress magnitude in each tooth area, in the periodontal ligament and in the alveolar bone. Based on the axial stress along the periodontal ligament and the stress in the capillary blood vessel (capillary blood stress) it is theoretically possible to predict the areas where bone remodeling is likely to occur. **Conclusions:** The model was validated by determining the modulus of elasticity of the periodontal ligament in a manner consistent with experimental data in the literature. The methods used in building the model enabled the creation of a complete model for a dental arch, which allows a number of simulations involving orthodontic mechanics.

**Keywords:** Finite elements. Periodontal ligament. Tooth movement. Orthodontic forces. Axial stress.

## INTRODUCTION

The finite element method (FEM) enables the investigation of biomechanical issues involved in orthodontic treatment<sup>14</sup> and stimulates the currently increasing scientific interest in tooth movement. The development of a numerical model makes it possible to quantify and evaluate the effects of orthodontic loads applied in order to

achieve initial tooth movement. One of the main features of the finite element method lies in its potential to analyze complex structures. This is possible when the numerical model behaves in a manner equivalent to the structure one wishes to analyze. In the case of tooth movement, the numerical model should respond in a manner equivalent to the clinical behavior of a moving tooth

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in terms of stress, strain and displacement. Additionally, FEM can be used to determine, through reverse calculations, the mechanical properties of tissues such as the periodontal ligament.<sup>10</sup>

The periodontal ligament is a dense fibrous connective tissue composed primarily of collagen fibers arranged in bundles, vascular and cellular elements, and tissue fluids.<sup>5,6,19</sup> The periodontium comprises the root cementum, periodontal ligament and alveolar bone. The periodontal ligament mediates the process of bone resorption and neoformation in response to orthodontic forces, although the mediator of the tooth movement *per se* is not force itself, but rather the magnitude of the stress generated in the periodontium.<sup>3</sup> The stress-strain experienced in the periodontium due to orthodontic forces contribute to alveolar bone remodeling through the recruitment of osteoblastic and osteoclastic cells, ultimately bringing about tooth movement.<sup>5,9,12,18</sup> Melsen et al<sup>16</sup> argue that it is the changes caused by stress-strain of the periodontium, and not any compression or tension forces, that release a cascade of biological reactions leading to tooth movement. They demonstrated that the stress exerted by the stretching of periodontal ligament fibers induces bone remodeling and that the stress generated by the application of force tends to create areas of tension and compression around the tooth, whose boundaries cannot be easily demarcated.

Because orthodontic treatment involves the delivery of forces to produce movements we can base our analysis on biomechanics. The analysis should begin by determining the properties of the materials involved and, with the aid of FEM, we can quantify the phenomena involved in tooth movement. Several tissues and materials used in orthodontics have had their properties identified, such as bones, teeth and stainless steel. However, the properties of the periodontal ligament are not fully known.

Several authors have described periodontal ligament properties using different methods.

Experimental tests have been performed *in vivo* and *in vitro* using animals and humans.<sup>5,12,18</sup> Linear, homogeneous and isotropic features have been ascribed to the periodontal ligament and used to describe its behavior.<sup>3,4,8-11,20,21,22</sup> Some authors have determined the coefficient of elasticity of the periodontal ligament using FEM in specific and unique situations.<sup>5,10,18,21</sup> Others<sup>2,16</sup> have attributed nonlinear mechanical properties to the periodontal ligament, based on micro-CT scans of anatomical specimens, although these features are dependent on individual morphological and anatomical variations. As emphasized by Geramy,<sup>7</sup> the literature contains a wide range of values for the modulus of elasticity of the periodontal ligament. Therefore, with the aid of FEM and by determining the modulus of elasticity of the periodontal ligament it will be possible to investigate or evaluate the relationship between tooth movement and orthodontic forces. This method enables the quantification not only of the force system being applied, but also the stress-strain experienced by the tissues that comprise the periodontium.

The purpose of this study is to validate a three-dimensional numerical model using Finite Elements to assist in studies involving orthodontic mechanics. To this end we created a three-dimensional model of a maxillary central incisor tooth taking into account the periodontal ligament “fibers”.

## MATERIAL AND METHODS

### Properties

The mechanical properties of organic tissues and orthodontic materials were drawn from the orthodontic literature.<sup>4,5,7,9,10,12</sup> The properties are the input data required for the numerical model, which is based on the finite element method. The structures that make up this model are composed of organic tissues and metallic materials with different mechanical properties in terms of characteristics and values, as following.

## Teeth

In order to simplify the tooth structure as a single body to suit the desired analysis, the values used to characterize tooth properties were: 20,000 N/mm<sup>2</sup> for the modulus of elasticity<sup>8,9,11,18</sup> and 0.30 for the Poisson's ratio.<sup>10,12,21,22</sup>

## Bone

The dental alveolus is composed of a thin layer of cortical bone which communicates directly with the periodontal fibers.

Several authors describe it as a homogeneous and isotropic material with a linear and elastic behavior. The mechanical properties found in the literature<sup>4,11,12,22</sup> assign to the alveolar cortical bone a mean value of 13,800 N/mm<sup>2</sup> (modulus of elasticity) and 0.30 (Poisson's ratio).

## Brackets

Orthodontic brackets are made of stainless steel and have defined properties such as 180,000 N/mm<sup>2</sup> for the modulus of elasticity and 0.30 for the Poisson's ratio.<sup>8</sup>

## Periodontal ligament

Since the literature comprises a wide array of values assigned to the modulus of elasticity of the periodontal ligament<sup>7</sup> the modulus of elasticity had to be determined using reverse calculations. The results were compared with values obtained experimentally by Jones et al,<sup>10</sup> who quantified the initial tooth displacement in vivo by subjecting it to an orthodontic force.

The mean value for tooth displacement obtained experimentally served as a basis for comparison with the displacements obtained in computer simulations in this study. Based on this comparison the modulus of elasticity of the periodontal ligament was determined.

## Finite elements

The FEM-based numerical model that represents this system was developed with the com-

puter program Ansys, version 8.1.<sup>24,25</sup> Each component comprised in the model was discretized into finite elements.<sup>4,14</sup>

## The tooth and alveolar cortical bone

The tooth<sup>27</sup> and alveolar cortical bone were discretized into Shell63 elements with a thickness of 0.25 mm. Figure 1 shows the model of the tooth and the alveolus using finite elements.

## Periodontal ligament

The fibers of the periodontal ligament were discretized into Beam4 elements. The geometric properties attributed to the fibers of the periodontal ligament were established, noting that a large portion of the ligament (75%) is composed of collagen fibers arranged in bundles that extend from the root cementum to the alveolar cortical bone.<sup>5</sup> Thus, to represent a bundle of fibers, we assigned a value of 1 mm diameter to each fiber drawn in the model, which amounts to about 75% of intra-alveolar space filled with periodontal fibers. Figure 2 shows the connection between the tooth and alveolus through the periodontal fibers (A), with emphasis on the apical (B) and cervical (C) areas.

TABLE 1 - Materials properties.

| Properties                  | Tooth  | Alveolus | Bracket | Periodontal Ligament |
|-----------------------------|--------|----------|---------|----------------------|
| Modulus of Elasticity (MPa) | 20,000 | 13,800   | 180,000 | 0.059                |
| Poisson's ratio             | 0.30   | 0.30     | 0.30    | 0.49                 |

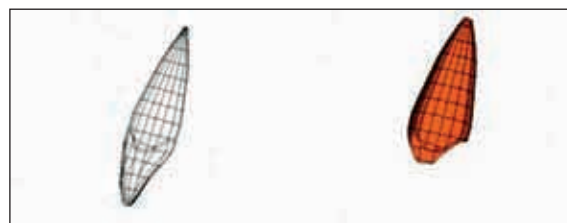


FIGURE 1 - Tooth and alveolus models in finite elements.

## Bracket

The bracket was discretized into Shell63 elements with a thickness of 1.40 mm, which corresponds to the distance between the bracket base and the bracket slot.

## Finite element model

The numerical model consists of 1,026 finite elements distributed among tooth, alveolus, periodontal fibers and bracket. Figure 3 shows the complete model and its respective reference axes. The tooth dimensions were obtained from the dental anatomy literature.<sup>27</sup>

## Boundary conditions

Boundary conditions were applied in an attempt to replicate the conditions of the experiment conducted by Jones et al,<sup>10</sup> who used a de-

vice that produced a constant 0.39 N force in the midpoint of the labial surfaces of one central incisor in ten experimental patients. The initial displacements were measured at a site in the incisal edge of the tooth crown with the aid of a laser beam measuring apparatus.

To reproduce the experimental conditions, the alveolar area of the model had its movements restricted in all directions, thereby limiting tooth movement within the periodontal space (Fig 4). Furthermore, a 0.39 N force was applied to the midpoint of the bracket in the model, as properly described by its directional components x, y, z.

## RESULTS AND DISCUSSION

### Model validation

To validate the three-dimensional numerical model, tooth displacement results were compared

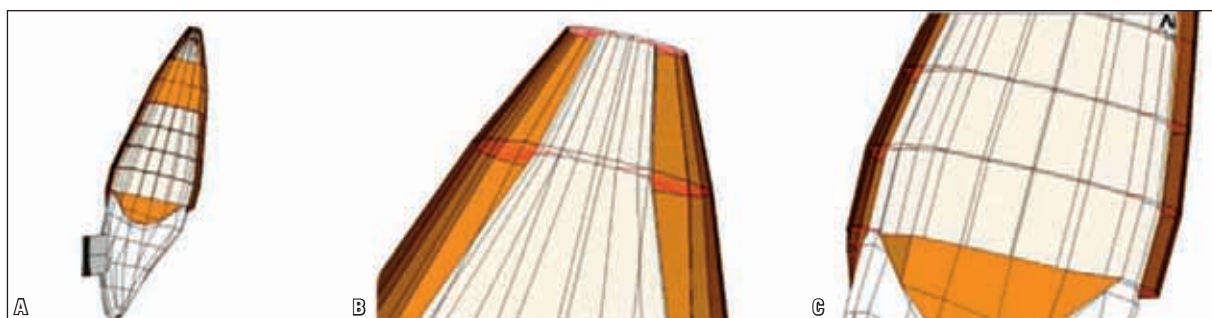


FIGURE 2 - Finite element model with the periodontal fibers connecting the tooth and alveolus.

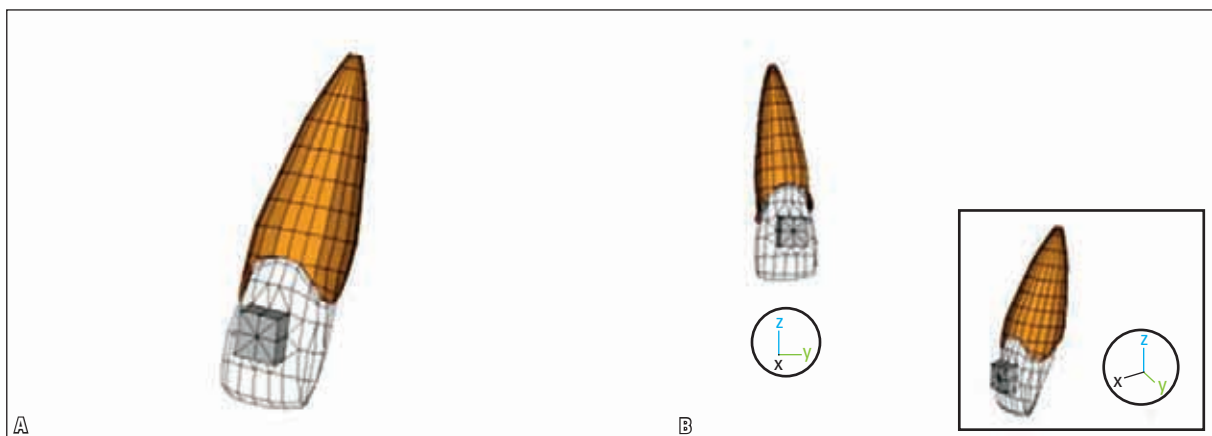


FIGURE 3 - Complete finite element model.

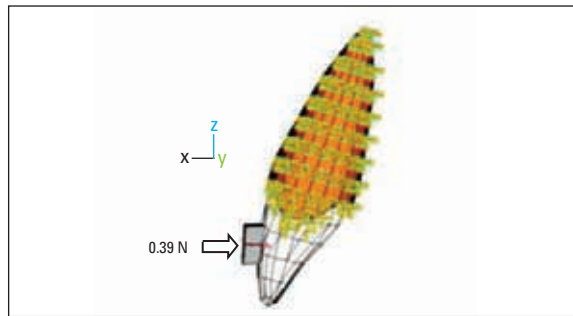


FIGURE 4 - Boundary conditions applied to the model: force of 0.39 N in the bracket and restrictions to alveolar movements.

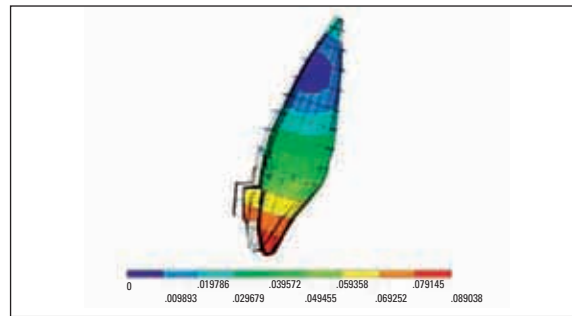


FIGURE 5 - Tooth displacement (mm) resulting from a 0.39 N load.

with those obtained by Jones et al,<sup>10</sup> in which the mean displacement found for the central incisors of the ten experimental subjects was 0.0877 mm with a standard deviation of 0.0507.

To determine central incisor displacement different values were assigned to the modulus of elasticity of the periodontal ligament fibers. With the value of 0.059 MPa, the incisal edge of the crown exhibited a tooth displacement of 0.089 mm (Fig 5). This value shows a difference of 1.46% compared with the value experimentally determined by Jones et al<sup>10</sup> (0.087 mm). Despite this difference, it is possible to validate the results obtained with the finite element model by considering the morphological and geometric differences and according to the standard deviation value found experimentally.

Based on this result it is valid to assign the value of 0.059 MPa to the modulus of elasticity of the periodontal ligament fibers. The validation of this model allows further study through variations in load parameters (forces and moments).

Table 1 summarizes the values assigned to the properties of the materials used in the numerical model.

### Study of axial stress

In addition to the results found for tooth displacements, the axial stress of the periodontal fibers was also obtained.

The classical concept of “optimal force” advocates that in order to produce orthodontic movement in such a manner as to allow the periodontal ligament and alveolar bone tissue to restore normality, the root surface should undergo stress that is slightly higher than the stress exerted by the blood in the capillary vessel<sup>6</sup> (capillary blood stress) of 15 to 20 mm Hg or equivalent to 20 to 26 gf/cm<sup>2</sup> (0.0026 N/mm<sup>2</sup> or 0.0026 MPa). Vessel compression hinders blood flow in areas of tension and compression of the periodontal fibers.<sup>19</sup> Kavarizadeh et al<sup>12</sup> used histological analysis to conclude that the periodontal areas where greater stress arises from the application of orthodontic forces also promote a greater recruitment of bone tissue remodeling cells. Whenever an orthodontic force is applied to a tooth, the root moves closer to the alveolus wall, thereby stretching the periodontal ligaments on the side where the force was applied while compressing the opposite side. Thus, the vascular system that works naturally under local capillary blood stress is compressed and blood flow hindered. This process “injuries the tissues” and promotes the release of inflammatory response mediators, which ultimately trigger the process of bone remodeling.<sup>6,19</sup>

Based on this information, which links the stress to the process of bone remodeling, a criterion was established to compare the axial stress obtained from the numerical model with capillary blood stress.

### Axial stress and their comparison with capillary blood stress

Force on the crown = 0.39 N

The axial stress measured in the periodontal ligament fibers for a 0.39 N force applied to the bracket midpoint are illustrated in Figures 6 and 7A.

By observing the color scale and the magnitude of the axial stress along the periodontal fibers, the stress of greater magnitude clearly occurs in the cervical areas of the root. However, it is only in those cervical areas (labial and palatal) that stress magnitude exceeds capillary blood stress ( $0.0026 \text{ N/mm}^2$ ). It is therefore possible to assert that, in theory, it is only in those areas that the processes leading to bone remodeling occur.

On the other hand, stress of small magnitude, i.e., lower than capillary blood stress, occur in the apical root area along the periodontal fibers. Therefore, the magnitude of the applied force can be considered negligible in light of the desired tooth movement and it therefore does not trigger the process of bone remodeling in this area.

#### *Classification of resulting tooth movement*

The color scale indicates that in the apical area, the stress along the periodontal fibers are compressive stress (-) on the labial side

and tensile stress (+) on the palatal side. The labial surface of the cervical area displays tensile stress (+) and compressive stress (-) on the palatal side. This fact, in conjunction with the observation of axial stress and tooth displacement, make it possible to classify the different types of tooth movements. We can thus note a non-controlled tipping movement, whereby the rotation center lies between the signal transition areas where the axial stress along the periodontal fibers are equal to zero, i.e., between the center of resistance and the root apex (Fig 7, A). This movement occurs when a force applied to the crown moves the root apex in the opposite direction of the applied force.

Marcotte<sup>15</sup> reports that in the center of rotation, stress are equal to zero. We can thus, with the aid of the axial stress, categorize the types of tooth movement in light of the forces applied to the dental crown and the location of the rotation center of the tooth.

Figure 7B shows the direction, magnitude and orientation of the displacement achieved by applying a force of 0.39 N, which further strengthened the reliability of the information obtained through the axial stress. This figure shows that the displacements around the root apex are oriented in the opposite direction of those found in the incisal edge.

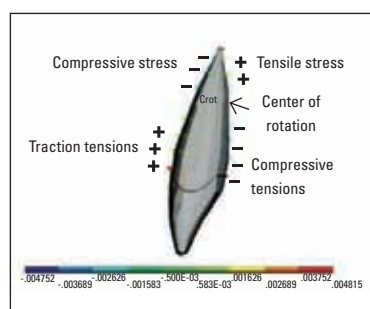


FIGURE 6 - Axial stress ( $\text{N/mm}^2$ ) resulting from a 0.39 N load.

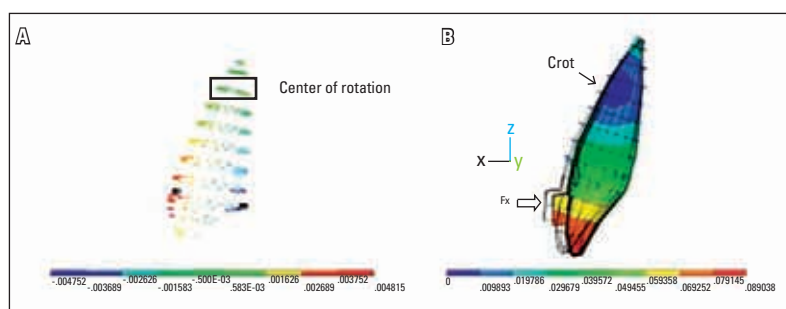


FIGURE 7 - View of the center of rotation under a 0.39 N load: **A)** axial stress, **B)** displacement.

Force on the crown = 0.70 N

A 0.39 N force was efficient enough to produce just a slight tipping movement in the upper central incisor, relative to the bone remodeling processes. In other words, this negligible force was capable of triggering the recruitment of remodeling cells in the cervical area only. Proffit and Fields<sup>19</sup> recommend forces between 0.30 N and 0.60 N to generate a tipping movement, while the magnitude of the force depends on the area of periodontal support. To identify the effects of excessive force, the magnitude of the applied force was increased to 0.70 N, a force considered to be above the force required for an efficient tipping movement of an upper central incisor.<sup>19</sup> Figures 8 and 9A show the axial stress resulting from a 0.70 N force.

By observing the color scale and the magnitude of the axial stress along the periodontal fibers it becomes clear that the stress of greater magnitude occur in the cervical area of the root, both in the tension and compression sides.

Unlike the previous case, however, the periodontal fibers that envelope almost the entire root area display stress levels which are higher than capillary blood stress (0.0026 N/mm<sup>2</sup>) except in the area around the center of rotation (Fig 9, A).

#### *Classification of resulting tooth movement*

Similarly to the previous case, the color scale shows that along the periodontal fibers the compressive stress (-) are in the labial area of the root apex and the tensile stress (+) are on the palatal side. On the labial surface of the cervical area the tensile stress (+) are on the labial side and the compressive stress (-) are on the palatal side, which discloses a uncontrolled tipping movement.

Figure 9B shows the direction, magnitude and orientation of the displacement achieved by applying a 0.70 N force, which strengthen the reliability of the information obtained through the axial stress. This figure shows that the displacements

around the root apex are also oriented in the opposite direction of those found in the incisal edge.

#### *Force and moment of force on the crown*

In cases of tooth movement with root movement control, it is advisable to apply to the bracket a force combined with a moment of force. With this procedure it is possible to generate different types of tooth movement, including uprighting, torque and translatory (bodily) movement. Control is exercised through a Moment/Force ratio<sup>13,15,19</sup> (M/F).

Thus, in order to obtain a translatory movement a 0.70 N force was applied, as in the previous case, and a 7.5 Nmm moment of force applied around the y axis. In this case, the M/F ratio which produced the translatory movement was 10.7:1. The moment of force acts as a root torque to be applied to the bracket by a supposed rectangular orthodontic archwire.

Figure 10 shows the boundary condition applied to achieve the translatory movement with the simultaneous loading of force and moment of force.

Figure 11 shows the axial stress obtained by simultaneously applying force and moment of force. By observing the color scale and the magnitude of the axial stress along the periodontal fibers it becomes clear that both exhibit nearly identical magnitude, distributed along the vertical axis of the root, on the labial and palatal surfaces. Several authors<sup>1,6,13,15,19</sup> claim that translatory movement entails a greater distribution of stress along the entire root length and that stress distribution along the root is relatively uniform.

In this case, nearly all of the root area surrounded by the periodontal fibers displays stress levels above capillary blood stress (0.0026 N/mm<sup>2</sup>), confirming that in order to achieve the translatory movement of the central incisor the loads should be those recommended by Proffit and Fields<sup>19</sup>, between 0.70 N and 1.20 N, depending on the periodontal area of the tooth while maintaining

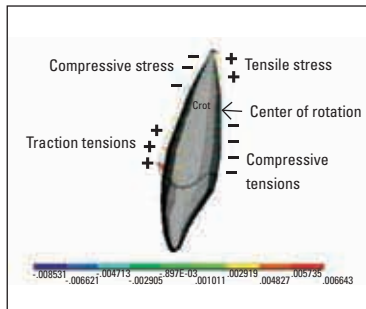


FIGURE 8 - Axial stress (N/mm<sup>2</sup>) resulting from a 0.70 N load.

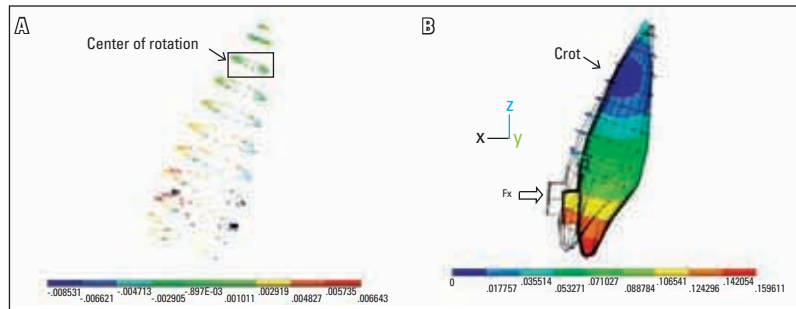


FIGURE 9 - View of the center of rotation under a 0.70 N load: **A)** axial stress, **B)** displacement.

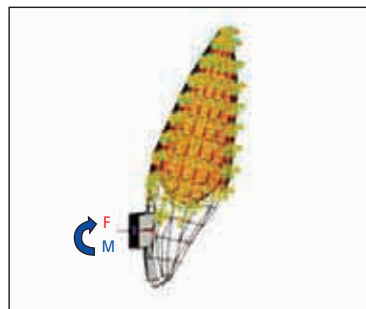


FIGURE 10 - Boundary conditions applied to the model: 0.70 N force and 7.5 Nmm moment of force onto the bracket and restrictions to alveolar movements.

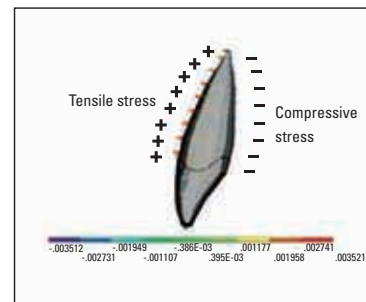


FIGURE 11 - Axial stress (N/mm<sup>2</sup>) resulting from simultaneously loading of force and moment of force.

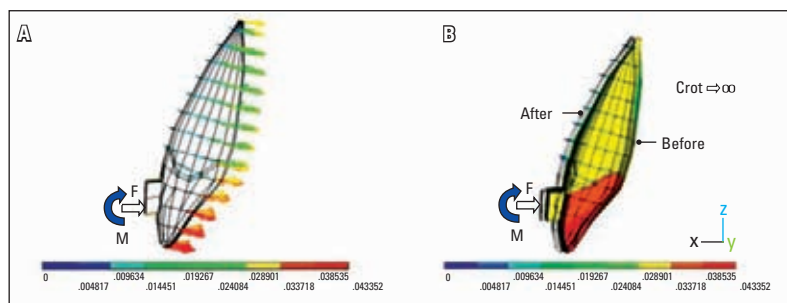


FIGURE 12 - Tooth displacement orientation resulting from the simultaneous loading of force and moment of force onto the bracket.

the same M/F ratio (10.7:1) which determines the direction of tooth movement.

Figure 11 also shows, regarding the long axis of the tooth, that along the periodontal fibers the compressive stress (-) are on the palatal side and the tensile stress (+) are on the labial side.

### Classification of resulting tooth movement

Figure 12 shows the direction, magnitude and orientation of the displacement obtained as a result of force and moment of force application at a 10.7:1 ratio. The displacement occurs in parallel to the initial position, disclosing the

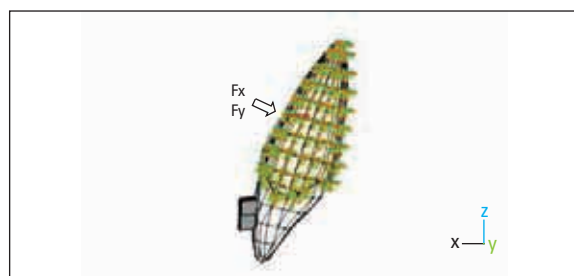


FIGURE 13 - Boundary conditions resulting from the application of force to the center of resistance (CRes).

translatory movement in light of the forces applied while the center of rotation is located in an infinitely distant point from the tooth.

Another way to achieve translatory movement is through the application of a force to the center of resistance. For this it is necessary to locate the center of resistance of the tooth.

#### Application of force to the center of resistance (CRes)

The orthodontic literature agrees that the application of a force to the center of resistance of a tooth promotes translatory movement<sup>1,6,13,15,19</sup>. For anatomical reasons, we do not apply, in conventional orthodontic treatment (force applied to the bracket), a force directly to the center of resistance, since the latter lies along the area of the root embedded in the alveolar bone. However, by means of lever mechanics (cantilever, power arm)<sup>1,15</sup> as well as in computer simulation it is possible to accomplish this movement.

The location of the center of resistance of the tooth was found to be at approximately 39.91% of the tooth height, measured from the alveolar crest. Burstone<sup>1</sup> and Marcotte<sup>15</sup> argue that the center of resistance of a single-rooted tooth is located around 40% of the root height, also measured

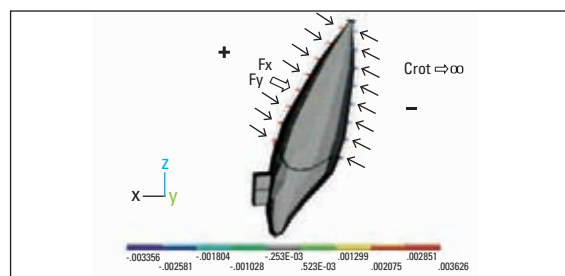


FIGURE 14 - Axial tensions (N/mm<sup>2</sup>) resulting from force applied to the center of resistance (CRes).

from the alveolar crest. Some authors<sup>6,17</sup> assert that the center of resistance is located at 33% and others,<sup>13,26</sup> at 66% of the root height.

Figure 13 shows the new boundary condition applied to restrain all alveolar movements. The forces were applied perpendicularly to the long axis and directly to the center of resistance of the tooth.

To produce a translatory movement with a resultant force perpendicular to the longitudinal axis of the tooth at a force of 0.70 N in the horizontal direction (x), an additional 0.22 N force was added in the vertical direction (z).

#### Axial stress and capillary blood stress

Stress distribution appeared to be uniform along the root axis, as shown in Figure 14.

By observing the color scale and the magnitude of the axial stress along the periodontal fibers it is clear that the stress is distributed with virtually identical magnitude along the tooth axis. In this case, as in the previous case, the areas of the palatal and labial surfaces exhibit stress levels that exceed capillary blood stress. Observations of the color scale also revealed that, regarding axial tensions, the tensile stress (+) are on the labial surface and the compressive stress (-) are on the lingual surface.

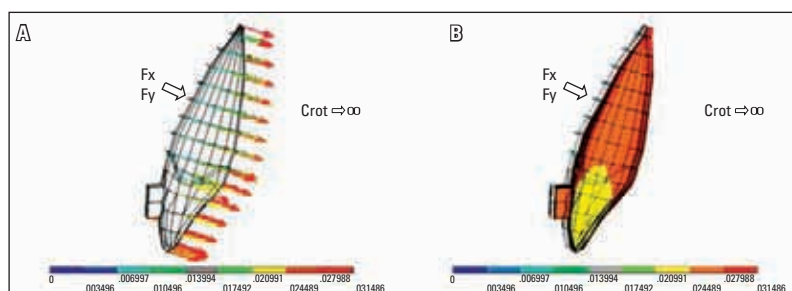


FIGURE 15 - Translatory movement resulting from the application of force to the center of resistance (CRes): **A)** resulting vectors, **B)** resulting displacement.

### Classification of resulting tooth movement

Translatory movement, which occurred due to axial stress, was also confirmed by means of graphs showing the vectors and the total resulting displacement. Displacement occurred parallel to the tooth axis, evidencing the translatory movement (Figs 15, A and B), with the center of rotation located at infinity.

The methods used in the construction of this model served as the basis for building a complete model of a dental arch, which allows studies involving various orthodontic appliances.

## CONCLUSIONS

1) To enable quantification of the parameters involved in studies of orthodontic mechanics a three-dimensional numerical model of a maxillary central incisor was validated.

2) The value of  $E=0.059$  MPa ( $0.059$  N/mm<sup>2</sup>) assigned to the modulus of elasticity of the periodontal ligament fibers enabled the validation of the numerical model.

3) The axial stress measured in the model show consistent values and assist in setting an appropriate value for use in computer simulations, by FEM.

4) The definition of a criterion that compares axial stress with the stress exerted by the blood in the capillary vessel ( $0.0026$  N/mm<sup>2</sup>) made it possible to predict which areas are likely to trigger the onset of bone remodeling.

5) A computer model enables the visualization and quantification of root and crown movements as well as the positioning of the center of rotation and the center of resistance of the tooth, which is of primary importance in determining tooth movement type.

6) The model presented in this study enables changes in loading parameters (forces and moment of forces) and in boundary conditions, thereby allowing the creation of a complete model for a dental arch, to evaluation of different orthodontic mechanics alternatives.

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# Canine angulation in Class I and Class III individuals: A comparative analysis with a new method using digital images\*

Lucyana Ramos Azevedo\*\*, Tatiane Barbosa Torres\*\*, David Normando\*\*\*

## Abstract

**Objectives:** This study aimed to determine the mesiodistal angulation of canine crowns in individuals with Class III malocclusion in comparison with Class I individuals. **Methods:** Measurements were taken from digital photographs of plaster models and imported into an imaging program (Image Tool). These procedures were repeated to assess random method error (Dahlberg's formula), and analyze reproducibility by intraclass correlation. The sample consisted of 57 patients with complete permanent dentition, untreated orthodontically and divided into two groups according to their malocclusion: Group I consisted of 33 patients with Class I malocclusion, 16 males and 17 females, mean age 27 years; Group II comprised 24 patients with Class III malocclusion, 20 males and 4 females, mean age 22 years. **Results:** Random error for canine angulation ranged from 1.54 to 1.96 degrees. Statistical analysis showed that the method presented an excellent reproducibility ( $p < 0.01$ ). Results for canine crown angulation showed no statistically significant difference between maxillary canines in the Class I and Class III groups, although canine angulation exhibited, on average, 2 degrees greater angulation in Class III individuals. Mandibular canines, however, displayed a statistically significant difference on both sides between Class I and Class III groups ( $p = 0.0009$  and  $p = 0.0074$ ). Compared with Class I patients, angulation in Class III patients was lower in mandibular canines and tended to follow the natural course of dentoalveolar compensation, routinely described in the literature. **Conclusion:** The results suggest that dental compensation often found in literature involving the incisors region, also affects canine angulation, especially in the lower arch.

**Keywords:** Mesiodistal angulation. Canine. Class III malocclusion. Class I malocclusion.

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## INTRODUCTION

Inclination and angulation have been the subject of orthodontic studies since the days when Angle<sup>4</sup> systemized orthodontic treatment by developing the edgewise appliance, where inclinations and angulations are controlled through bends in the archwires, which are inserted in bracket slots.

Some time ago, orthodontists realized the advantages of bracket angulation,<sup>10</sup> but no consensus has been reached concerning the appropriate amount of angulation for each tooth. Thus, the possibility arose of designing individual brackets for each type of tooth, employing archwires with no bends, or manufacturing brackets tailored for each individual patient.

A key step in this direction was the study on "The Six Keys to Normal Occlusion," describing six common characteristics of 120 models of optimal natural occlusion, which should be the goals of orthodontic treatment.<sup>2</sup> In this study, the second key concerns tooth crown angulation. By analyzing the angle formed by the intersection of the buccal axis of the clinical crown with a line running perpendicular to the occlusal plane and passing through the center of the clinical crown, it was found that clinical crowns are usually angulated mesially at varying degrees, depending on the group of teeth being examined. In this study, dental crown angulation was determined by measuring the angle formed between clinical crown and occlusal plane. Models were cut beforehand in the center of the clinical crowns with the aid of a plastic protractor. A recent study examined 61 study models with normal, natural occlusion in Brazilians,<sup>12</sup> and showed that most individuals exhibited only one to three occlusion keys. The most frequently observed characteristics were curve of Spee (100%), tight proximal contacts (42.6%) and proper dental crown inclinations (34.4%). Mesial angulation of dental crowns was found in 27.9% of the sample.

The Straight-Wire technique makes use of

brackets preadjusted or tailored for each individual tooth, allowing each tooth to be ideally positioned until treatment completion. Since its inception, the original proposal<sup>2</sup> provided, in addition to the use of standard brackets in many patients, for the use of different prescriptions to suit the different types of malocclusion, treatments and the desired or possible positioning of the teeth after treatment. In other words, the tailoring of a customized orthodontic appliance according to the features of each malocclusion. The concept of normality and the potential of orthodontics have been redefined since the 1970s, when these precepts were formulated.

Originally, compensations<sup>3</sup> were related to inclinations (torque) on incisor brackets to compensate for the skeletal discrepancies that had not been addressed in their entirety during orthodontic treatment. In the case of Class III malocclusion, a buccal torque was applied to maxillary incisors and a lingual torque on mandibular incisors. Changes induced in the arches derive from dental compensation in cases of skeletal malocclusion, as reflected in the buccolingual tipping of the teeth in the opposite direction of the skeletal error. Thus, many cases of mild skeletal Class III malocclusion, that do not require surgical treatment, could be solved simply by performing dental compensation at the end of treatment. Achieving such outcome would require case customization since each patient has unique skeletal and dental characteristics.<sup>5</sup> Thus, manipulating canine angulation can play an important part in compensating for orthodontic skeletal error.

One of the many changes made to the original system calls for modifying canine angulation in cases of compensation. Angulations of 8° and 5° for maxillary and mandibular canines, respectively, in treating Class I malocclusion, were changed to 11° on maxillary canines while mandibular canines were left with no angulation whatsoever in treatments aimed

at compensating for Class III malocclusions.<sup>5</sup> The purpose of these changes was to increase or maintain the perimeter of the upper arch and reduce or maintain the perimeter of the lower arch, thereby encouraging the creation of an anterior positive overjet, introducing greater compensation and increasing the potential for malocclusion correction, despite the skeletal error.

Despite growing interest in modifying tooth angulation and inclination described by the study on the six keys to normal occlusion<sup>2</sup>, few studies have examined the reliability of the measurements when employing a particular method. Although several methods have been described for measuring tooth inclination (torque),<sup>2,6,9,13,14</sup> few investigations have evaluated the error inherent in the method used to analyze tooth angulation.<sup>14</sup>

A recent study<sup>6</sup> described a new method to measure tooth angulation and torque using volumetric computed tomography (VCT). To this end, tomographic slices were made of the anterior teeth of two individuals with facial patterns II and III, respectively. After evaluation, it was concluded that computed tomography (CT) can be a useful means for evaluating tooth torque and angulation, greatly contributing to research involving tooth positioning as well as orthodontic treatment customization since it enables professionals to check tooth positioning on an individual basis. Furthermore, it is a distortion-free test. However, these tooth angulation measurements on models and CTs should be made with caution because these are relatively new methods that still require further studies to prove their efficacy and, particularly, reliability. The risk radiation and high cost of CT scans should also be emphasized.

A device was recently introduced, which was specifically designed to measure the angulation and inclination of dental crowns.<sup>14</sup> Plaster models were attached to a table and the long axis on the crown of each tooth was determined. Once each model had been correctly positioned and

attached, the table was rotated in L shape until the long axis of each tooth crown coincided with a marking made centrally in a magnifying glass, which was fixed to the table. The number of gear teeth, rotated from its zero point (previously defined during device calibration), corresponded to the value of each angle, as it was measured. Reproducibility was confirmed by analysis of systematic error using Student's t-test. The random error observed in tooth angulation measurements ranged between 0.30 and 1.33. With the advent of this new device it became possible to establish mean angulation and inclination values for dental crowns of Brazilian patients with normal occlusion. The results revealed a mean angulation of 7.13° for maxillary canines and 2.43° for mandibular canines.

Compensatory orthodontic treatment of Class III malocclusions requires the identification of these initial compensations, which are present prior to treatment and should be maintained or enhanced whenever possible. Thus, it seems reasonable to believe that canine crown angulation facilitates incisor positioning and promote natural dental compensation in Class III malocclusion cases. This occurs when maxillary canines are angulated more mesially, allowing maxillary incisor proclination, while mandibular canines should be uprighted, enabling mandibular incisor retroclination and preventing or minimizing anterior crossbite.<sup>5</sup> However, what seems like clinical evidence, and is built into the prescriptions of brackets used in cases where it is possible to maintain or increase any compensation naturally observed in Class III individuals, actually requires further scientific assessment to support or not the changes incorporated into the orthodontic appliances used for this purpose. Simple methods to allow orthodontists to identify whether or not these natural compensations do exist, or even to quantify them reliably, would enable clinicians to expand this concept in a scientifically sound manner.

## MATERIAL AND METHODS

The sample used in this study was selected from private orthodontic practices and consisted of 57 patients in the stage of permanent dentition.

With the purpose of conducting a comparative analysis of permanent canine angulations among Class I and Class III individuals, the sample was divided into two groups. The first group was comprised of 33 Class I patients with incipient orthodontic problems, i.e., cases where orthodontic treatment would be limited to minor movements (closure of diastema, mild crowding, posterior molar crossbite, among others), without previous orthodontic treatment (Fig 1). The second group consisted of 24 individuals with Class III malocclusion (Fig 2). Patients with tooth loss, agenesis, bi-maxillary protrusion, syndromes and moderate or severe crowding were excluded from the sample because these factors might affect canine angulation.

Canine angulations were obtained from standardized digital photographs of each quadrant of the initial plaster models of the sample patients, taken with a digital camera (Canon Rebel 6.0 megapixels, Tokyo, Japan) with a 18-55 mm lens. (Fig 3). These models were placed on a glass plate (A), at a distance of 20 cm from the camera (B). At the bottom of each model a black device was placed with a marking in the center, used as reference to centralize the canines (C). The camera lens was laid on a wax plate in order to optimize lens direction (D).

A total of 228 photographs were taken and exported to a computer program (Adobe Photoshop 7.0) in order to draw the occlusal plane (Fig 4). Those images were subsequently imported into an imaging program (UTHSCSA ImageTool™ software, University of Texas Health Science Center, San Antonio, Texas, USA) where permanent canine angulations were measured. The occlusal plane was drawn from the midpoint between the



FIGURE 1 - Plaster models of a Class I individual with incipient malocclusion, used in the sample.



FIGURE 2 - Plaster models of a Class III individual included in the sample.

central incisors to the mesiobuccal cusp of the first permanent molar. Subsequently, Image Tool was used to trace the long axis on the clinical crown of the canine, and from the intersection of these two lines (occlusal plane and long axis) the angulation value for the clinical crown on the plaster model was obtained (Fig 4).

To analyze the method error, the initial plaster model quadrants of all patients were photographed again 30 days later and all the steps previously described were repeated to obtain new canine angulation measurements.

The random error was calculated according to Dahlberg's formula ( $S^2 = \sum d^2 / 2n$ ) and an analysis of the reproducibility of the measurements was performed using the intraclass correlation test, both with a confidence level of 95%. One outlier with a value far below the other measurements taken for tooth 43, in the Class III group, was excluded from the evaluation.

Means, standard deviations, mean differences, analysis of the normal distribution and independent t-test were used to detect differences between canine angulations in the Class I and Class III groups.

## RESULTS

At first, normal distribution was observed for canine angulations in both groups ( $p > 0.05$ ) (Table 1). Random error difference ranged from 1.54 to 1.96 between measurements (Table 1). Regarding the reproducibility analysis (intraclass correlation), statistical analysis revealed excellent method reproducibility.

Canine angulations in both groups were analyzed by comparing the measurements of each canine in the Class I groups with its analogue in the Class III group.

Results showed that mean angulations of right maxillary canines in the Class I group ( $x = 7.92^\circ$ ) were not statistically different ( $p = 0.22$ ) when compared with the means for the same teeth in the Class III group ( $x = 9.97^\circ$ ) (Table 2).

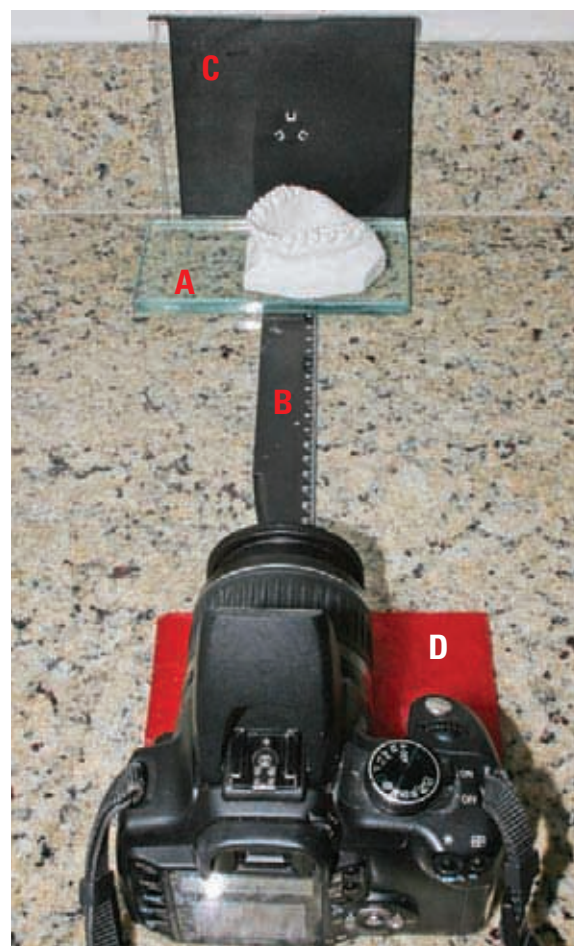


FIGURE 3 - Method used for standardizing photographic snapshots of the plaster models: A= 10 mm glass plate, B= 20 cm millimeter ruler, C= black plastic plate with mark indicating the center of the object (back sleeve of a compact disc/CD), D= wax plate.

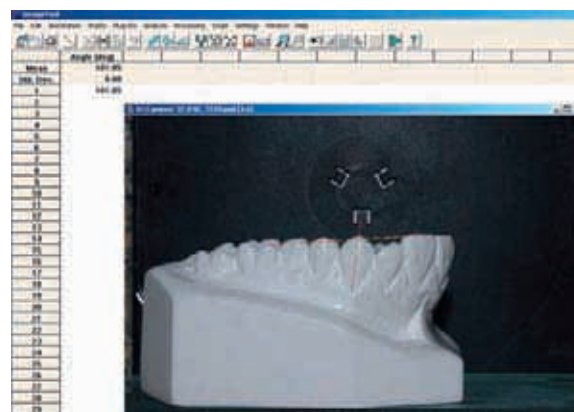


FIGURE 4 - Photograph of the study model exported to the imaging program used to obtain the canine angle measurements.

TABLE 1 - Random error (Dahlberg's formula), method reproducibility (intraclass correlation) and normal distribution analysis of values obtained for canine angulations in Class I and Class III groups.

|                           | CLASS I |        |        |        | CLASS III |        |        |        |
|---------------------------|---------|--------|--------|--------|-----------|--------|--------|--------|
| Tooth                     | 13      | 23     | 33     | 43     | 13        | 23     | 33     | 43     |
| Random error              | 1.77    | 1.74   | 1.73   | 1.55   | 1.54      | 1.96   | 1.53   | 1.65   |
| Intraclass correlation    | 0.91**  | 0.92** | 0.94** | 0.96** | 0.95**    | 0.93** | 0.93** | 0.96** |
| Level of reproducibility  | EXC     | EXC    | EXC    | EXC    | EXC       | EXC    | EXC    | EXC    |
| Normal Distrib. (P value) | >0.05   | >0.05  | >0.05  | >0.05  | >0.05     | >0.05  | >0.05  | >0.05  |

\*\* p<0.01; EXC= Excellent reproducibility.

TABLE 2 - Angulation means (angle complement), standard deviations (SD), mean differences and p value (independent t-test) in groups I and Class III.

|       | CLASS I       |      | CLASS III      |      | CLASS I X CLASS III |          |
|-------|---------------|------|----------------|------|---------------------|----------|
| Tooth | Mean          | SD   | Mean           | SD   | Diff. between means | p-value  |
| 13    | 82.08 (7.92°) | 5.81 | 80.03 (9.97°)  | 6.61 | 2.04                | 0.22(ns) |
| 23    | 81.87 (8.13°) | 6.10 | 79.90 (10.1°)  | 6.89 | 1.97                | 0.26(ns) |
| 33    | 86.73 (3.27°) | 6.99 | 92.78 (-2.78°) | 5.48 | -6.04               | 0.0009** |
| 43    | 86.22 (3.78°) | 7.87 | 91.67 (-1.67°) | 7.60 | -5.45               | 0.0074** |

ns= non-significant; \*\* p<0.01.

Mean angulations of left maxillary canines in the Class I group ( $x=8.13^\circ$ ) were not statistically different either ( $p=0.26$ ), when compared with the means for the same teeth in the Class III group ( $x=10.1^\circ$ ) (Table 2).

Furthermore, mean angulations of right mandibular canines in the Class I group ( $x=3.78^\circ$ ) were statistically different ( $p=0.007$ ) when compared with the means for the same teeth in the Class III group ( $x=-1.67^\circ$ ) (Table 2). Mean angulations of left mandibular canines in the Class I group ( $x=3.27^\circ$ ) were also statistically different ( $p=0.0009$ ) when compared with the means for the same teeth in the Class III group ( $x=-2.78^\circ$ ) (Table 2).

In summary, the clinical crowns of maxillary canines were similarly turned mesially in both groups, although slightly more pronounced in Class III individuals. Moreover, mandibular canines in the Class I group had their clinical crowns turned mesially, while their analogues in the Class

III group were either upright or had their clinical crowns turned distally (Figs 5 and 6).

## DISCUSSION

The primary aim of this study was to examine whether there were differences in permanent canine angulations among individuals presenting with Class I and Class III malocclusions using a simplified method that made use of photos scanned from plaster models and exported to an image manipulation program for simple angle reading (Image Tool).

There have been few studies on the degree of reliability of measurements taken from models, perhaps because this was originally considered a direct method. However the modifications used in this study showed that the method used to measure canine crown angulations, as well as being very simple to use, is remarkably reproducible, displaying a random error of less than  $2^\circ$  (Table 1).

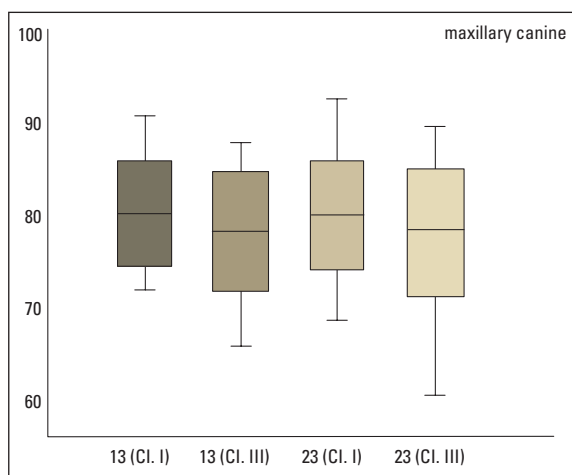


FIGURE 5 - Boxplot for values of maxillary canine angulations in the Class I (Cl. I) and Class III (Cl. III) groups.

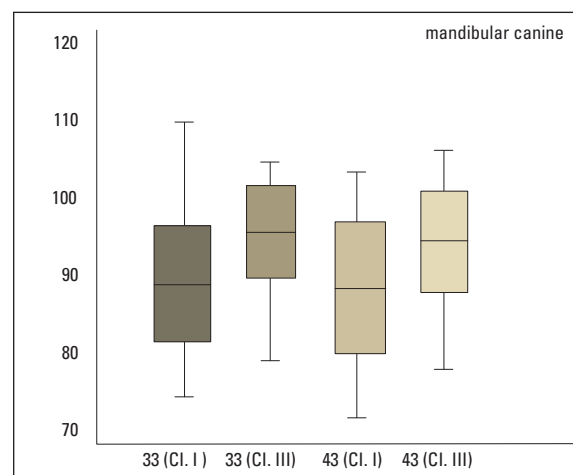


FIGURE 6 - Boxplot for values of mandibular canine angulations in the Class I (Cl. I) and Class III (Cl. III) groups.

A few methods have been described to measure tooth angulation, some are simple to employ such as measurements taken directly from the models using a plastic protractor,<sup>2</sup> while others require major technological resources, such as computed tomography.<sup>6</sup>

Thanks to advances in technology, dentistry has benefitted from modern computer programs that simplify diagnosis. Grounded in this premise, this study employed a computer imaging program capable of accurately reading canine angulation from standardized digital photographs of plaster models. This methodology differs from the original proposal that led to the development of preadjusted brackets.<sup>2</sup> One major difference refers to the occlusal plane, which in this study is represented by a line linking the midpoint between the incisors and the mesio-buccal cusp of the first molar. This plane is not always parallel to that of Andrews, notably in cases of malocclusion.

Correctly defining the mesiodistal angulation of teeth after treatment has been the goal of many researchers. The values found by Andrews<sup>2</sup> and described as normal, 11 degrees for maxillary

canines and 5 degrees for the mandibular canines, both positive, were crucial factors in the development of a fully programmed orthodontic appliance called Straight-Wire. It was designed to impart to brackets certain features to ensure that teeth would be properly positioned at the end of orthodontic treatment.

However, given that the occlusal and skeletal characteristics of each patient are unique and individual, all cases should not be finished in the same manner. Thus, some adjustments in the original Straight-Wire concept became necessary. Since this realization, many orthodontists have begun to customize brackets according to their clinical experience in view of the morphological diversity inherent in the dentofacial complex. Most of these changes were introduced without any scientific support.

Even Andrews<sup>3</sup> incorporated some changes into the torque of incisor brackets to compensate for the skeletal discrepancies that had not been addressed in their entirety during orthodontic treatment. In the case of Class III malocclusion, more buccal torque was applied on maxillary incisors and more lingual torque on

mandibular incisors. Based on Andrews<sup>3</sup> ideas, other authors<sup>5</sup> have advocated brackets with different angles and inclinations for Class I, II and III malocclusions. These brackets appeared after changes were made to Andrews<sup>3</sup> brackets. The main variations to the original model relate to canine angulations to facilitate the torque compensation applied to the central incisors while keeping incisor torque compensations.

Class III malocclusion is significantly different from sagittal malocclusions to the extent that in most cases patients present a natural dental compensation. Thus, in cases of Class III malocclusion, maxillary incisors are more angulated than in Class I malocclusion. Class III malocclusion brackets were therefore prescribed whenever this problem proved amenable to being solved by means of dental compensation, through orthodontic treatment alone, without the need for surgery.<sup>5</sup> For this purpose, an 11° angulation was applied to maxillary canines (three degrees above standard) and 0 degree to mandibular canines (five degrees below standard). These changes aimed to increase the perimeter of the upper arch and reduce the perimeter of the lower arch to help develop an anterior positive overjet or the maintenance of any pre-existing compensation.

The results achieved in this study disclosed that maxillary canine angulation was similar in both groups, although canine angulation was slightly increased, by nearly 2 degrees, in the Class III group (Table 2, Fig 5). The results for mandibular canines revealed statistically significant differences between the two groups, with smaller canine angulation in Class III subjects ( $p = 0.0009$  for tooth 33 and  $p = 0.0074$  for tooth 43). Therefore, the results highlighted differences in natural canine angulation in Class I vs. Class III individuals, thereby lending support to the prescription advanced by Capelloza Filho et al<sup>5</sup> while confirming the finding that the incisor compensation seen in

cephalometric studies of Class III patients described in the literature<sup>1,7,11</sup> appear to be accompanied by changes in canine angulation.

This study found a mean angulation of 10.03° for maxillary canines and -1.75° for mandibular canines in the Class III group. These measures are very close to the measures suggested for use in compensatory brackets recently introduced<sup>5</sup> for Class III brackets (11 degrees for upper and 0 degree for lower canines). The Class I group displayed a mean angulation of 8.02° for maxillary and 3.5° for mandibular canines, whereas Capelloza et al<sup>5</sup> prescribes a mean angulation of 8° for upper and 5° for lower canines. It should be noted, however, that the measurements obtained in this study were taken from individuals with malocclusion, although every effort was made to avoid interference from other confounding factors such as crowding, bimaxillary protrusion and tooth loss, while seeking to deal with incipient Class I malocclusions.

Even individuals with normal occlusion failed to exhibit all mesial angulations, as described in the original study.<sup>2</sup> A recently published study<sup>12</sup> found that only 27.9% of the examined models displayed correct dental crown angulations. This means that tooth positioning changes depending on the type of malocclusion and that this factor is very important when orthodontic treatment is aimed at correcting skeletal errors by way of dental compensation. In these cases, special attention should be paid to canine angulation because if such angulation proves beneficial for treatment it should be maintained or even enhanced.

The mean angulations found in this study support the idea of inserting modifications in the slot angulation of canine brackets. However, analysis of data dispersion revealed a significant standard deviation (Table 2) and wide total range (minimum and maximum values) (Figs 5 and 6), which justified the need for customizing canine angulation even before the orthodontic

appliance had been installed. The wide variability found in this study can be ascribed, among other factors, to a heterogeneous canine crown morphology.<sup>8</sup> Clinically, brackets with compensatory prescriptions may be used but orthodontists should customize each clinical case, increasing or reducing these offsets accordingly. For cases where the need arises to measure pre-existing tooth angulations, it is believed that the method described in this article provides sufficient reliability to justify its use.

## CONCLUSIONS

Based on the data described above it can be concluded that:

1. The method showed excellent repeatability, with no differences between the two measurements, and relatively small random error ( $<2^\circ$ ).
2. Statistically significant differences were found in the angulation of permanent canines between individuals with Class I and Class III malocclusions, especially in mandibular canines. Such differences are in line with natural compensations for Class III incisor inclination, widely described in literature.

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# Assessment of tooth inclination in the compensatory treatment of pattern II using computed tomography

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## Abstract

**Objective:** To evaluate changes in the inclination of anterior teeth caused by orthodontic treatment using a Straight-Wire appliance (Capelozza's prescription II), before and after the leveling phase with rectangular stainless steel archwires. **Methods:** Seventeen adult subjects were selected who presented with facial pattern II, Class II malocclusion, referred for compensatory orthodontic treatment. Inclinations of anterior teeth were clinically assessed using CT scans at three different times, i.e., after the use of 0.020-in (T1), 0.019 X 0.025-in (T2) and 0.021 X 0.025-in (T3) archwires. Friedman's analysis of variance was applied with 5% significance level to compare the three assessments (T1, T2 and T3). **Results:** It was noted that the rectangular wires were unable to produce any significant changes in inclination medians, except for a slight change in mandibular lateral incisors ( $p < 0.05$ ). On the other hand, variations in inclination were smaller when 0.021 X 0.025-in archwires were employed, particularly in maxillary incisors ( $P < 0.001$ ). **Conclusion:** The use of rectangular 0.021 X 0.025-in archwires produces more homogeneous variations in the inclination of maxillary incisors, but no significant median changes.

**Keywords:** Computed Tomography. Orthodontic treatment. Tooth inclination.

## INTRODUCTION

The aim of the Straight-Wire technique is to ensure that teeth are optimally positioned by the end of treatment while reducing the need for bending orthodontic archwires. Since its inception, several authors have suggested changes to the original prescription values.<sup>5</sup> These changes yielded new, unique prescriptions in the search for one that would fit all or most cases.

In the following years—before this technique became the most widely used worldwide—several authors claimed that most orthodontists had embraced this technique because they did not use larger-caliber archwires to finish their cases.<sup>12,13</sup> Nonetheless, discussions were already under way about the need for adjustments to compensate for the slack between archwire and bracket slot, even when thicker archwires were

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used, in order to move teeth to their planned position. Thus, when evaluating an orthodontic appliance, one should not just consider its prescription but also the archwire progression protocol being employed. Moreover, professionals need to tailor the orthodontic treatment for each patient individually if satisfactory aesthetic and functional outcome are to be achieved.<sup>11</sup>

After assessing the inclinations of teeth of treated and untreated groups who had normal occlusion, Vardimon and Lambertz<sup>29</sup> noted a standard deviation of  $\pm 5^\circ$ , indicating a considerable dispersion of inclination means in all teeth. There was no statistically significant difference between the two groups, except in the second mandibular molar. In contrast with the original Straight-Wire prescription, this study showed different values for maxillary incisors,  $+1^\circ$  for central incisors and  $-1^\circ$  for lateral incisors.

Any ideal preadjusted appliance featuring identical torques and angulations for all patients seems to be unacceptable. This conclusion was confirmed after examining the buccal surface of the teeth, determining the extent and frequency of changes in their contour and assessing inclination when brackets were bonded more incisally or gingivally on their buccal axis.<sup>13</sup> As the more posterior teeth were examined, wider variations were noted on their buccal surface both in the maxilla and mandible, however, all the teeth of the same individual presented homogeneous variation.

In a comparison between the inclination of anterior teeth in cases treated with fixed edgewise, Straight-Wire, Roth prescription appliances and normal occlusion cases, the upper anterior teeth of the latter individuals exhibited negative values, whereas the former displayed positive, or buccal inclinations.<sup>28</sup> Inclinations found in subjects treated with MBT<sup>TM</sup> prescription were statistically different when compared with the "Six Keys to Normal Occlusion".<sup>5</sup> Significant individual variations were also observed.<sup>6</sup> When Brazilians with

normal occlusion were compared with the original Straight-Wire<sup>5</sup> values, the inclinations of the vast majority were negative, with the sole exception of the maxillary incisors.<sup>30</sup>

For compensatory treatment of patients with facial patterns whose basal bones present with acceptable discrepancies, attention is paid to the position that the teeth should occupy by the end of treatment. The focus point is the direction of the dental compensation based on malocclusion features, treatment goal and treatment prognosis.<sup>5,8</sup> Three sets of prescriptions have been described,<sup>8</sup> one geared to the treatment of cases with normal maxillomandibular relationship (pattern I), and two other prescriptions aimed at cases of maxillomandibular discrepancies (pattern II or III), where the anterior teeth require compensatory torque and angulation to achieve an optimal occlusion, despite the skeletal condition.

Dental compensation of maxillary and mandibular incisors related to the anteroposterior relationship of the basal bones was evaluated in young Brazilians treated with standard Straight-Wire appliances, with orthodontic treatment without extractions and cases finished according to the Six Keys of Occlusion Normal.<sup>5</sup> The values found for the upper incisors were close to Andrews' sample ( $+7.96^\circ$  to  $+7^\circ$ , respectively), but highly discrepant in mandibular incisors ( $+5.03^\circ$  to  $-1^\circ$ ). Moreover, it was observed that as the basal bones extend positively (maxilla ahead of the mandible) maxillary incisors vary their inclinations lingually while mandibular incisors vary their inclinations buccally, suggesting that orthodontic treatment could be performed with fewer extractions since it allows a significant buccoversion of mandibular incisors.<sup>7</sup>

The use of prescriptions built into the brackets and their proper utilization in treatment individualization are compromised as these pre-adjustments are not fully expressed due to the slack between bracket slot and archwire. This is

especially limiting in terms of inclination, when archwire progression stops before maximum caliber archwires are inserted, thereby preventing the features of a particular prescription from being fully expressed.

For this reason, it seems important to assess whether inclinations produced in the anterior teeth during the final stages of orthodontic leveling reflect the prescription values described by the bracket manufacturer.

Thanks to advances in dental imaging technology, more accurate diagnoses are now possible that boast a high degree of reliability while providing detailed images of structures in three-dimensional tests with less radiation exposure.<sup>21,26,27</sup> Computed tomography (CT) allows the reconstruction and visualization of anatomical areas in three dimensions, revealing information about size, shape and texture and has become an important tool for all areas of dentistry, providing reliable linear<sup>15,18,20,23</sup> and angular<sup>22,23</sup> measurements.

A method for evaluating torques and angulations by means of computed tomography has been described,<sup>10</sup> which faithfully depicts dental structures and allows professionals to measure each individual tooth, in addition to facilitating the study of dental positioning<sup>15</sup> and inclinations, instrumental in the diagnosis, prognosis and analysis of finished orthodontic cases.<sup>16</sup>

## MATERIAL AND METHODS

### Sample selection

The sample for this prospective study comprised individuals selected for orthodontic treatment in the department of graduate studies and met the following requirements: Permanent dentition, presenting with Angle Class II malocclusion without significant crowding (>2 mm); facial pattern II,<sup>9</sup> but with enough facial pleasantness<sup>24</sup> as to contraindicate orthodontic-surgical treatment. A group of 17 individuals was selected, 10 males and 7 females, aged between 16 years and 5 months, and 52 years and 11 months; 16 Caucasians and 1

Afro-descendant. Nine patients had Class II, division 1 malocclusion and 8 had Class II, division 2 malocclusion. Volumetric Computed Tomography (VCT) examinations were performed to obtain the proposed measurements. VCT was preferred as it allows measurements of each individual tooth<sup>10</sup> without superimposing images while providing images without magnification.<sup>20,22</sup>

## Methods

### Orthodontic treatment protocol

Patients were subjected to compensatory orthodontic treatment using Capelozza's<sup>8</sup> prescription II brackets with 0.022 X 0.028-in slots (Abzil, São José do Rio Preto, Brazil). Treatment was provided by a single specialist from start (bonding) to finish. Bonding was performed by implementing Andrews' bracket placement technique<sup>2</sup>, i.e., using the center of the clinical crown as reference. Subsequently, a strict archwire progression protocol (Table 1) was performed ensuring that alignment and leveling occurred gradually without the intervention or use of any additional mechanical resources. Therefore, any changes in tooth position would be directly related to the gradual increase in size of the leveling archwires.

| Archwire            | Replacement(days) |
|---------------------|-------------------|
| 0.014-in NiTi       | 30                |
| 0.016-in NiTi       | 30                |
| 0.016-in SS         | 30                |
| 0.018-in SS         | 30                |
| 0.020-in SS         | 30                |
| 0.019 X 0.025-in SS | 40                |
| 0.021 X 0.025-in SS | 40                |

TABLE 1 - Protocol used for orthodontic archwire progression.

### CT image scanning

In order to perform the dental measurements, all sample patients were subjected to VCT scanning at three different times during the protocol described above:

» T1 - At the end of the leveling phase, using 0.020-in stainless steel (SS) archwire.

» T2 - At the end of the rectangular 0.019 X 0.025-in SS archwire period.

» T3 - At the end of the rectangular 0.021 X 0.025-in SS archwire period.

NewTom DVT-9000 Computed tomography equipment (NIM - Verona - Italy) was used to acquire the images. QR-DVT 9000 software was used for reformatting the images and measuring tooth inclinations.

### Tooth inclination measurement

The method described by Capellozza, Fattori and Maltagliati<sup>10</sup> was implemented.

To be considered optimal for this sample tooth inclination values (Figs 1 and 2) had to be close to those of the prescription described by the manufacturer, taking into account a maximum allowed

slack of  $\pm 3.9^\circ$ .<sup>11</sup> Therefore, the value of each inclination angle was analyzed in each subject at the three study times by adding or subtracting the value of the slack. Thus, each tooth was classified into one of three categories, within, above or below prescription values.

### Statistical analysis

Analysis of systematic error was performed by paired t-test and random error was examined using Dahlberg's formula for all measurements, in 23.5% of the sample (n=4), 90 days after the first measurement. For random error, values above  $1.5^\circ$  were regarded as significant in terms of angular measurements, as suggested by Houston.<sup>19</sup>

Data normality was examined using the Shapiro-Wilk test (Table 2). Friedman's analysis of variance was used to compare data between the different times (T1, T2 and T3) due to the fact that some data exhibited abnormal distribution or unequal variances (Figs 3 - 8). Coefficient of variation was used to examine the variation between T1, T2 and T3.

A significance level of 5% was set for all statistical tests employed in this study.



FIGURE 1 - Positive inclination.

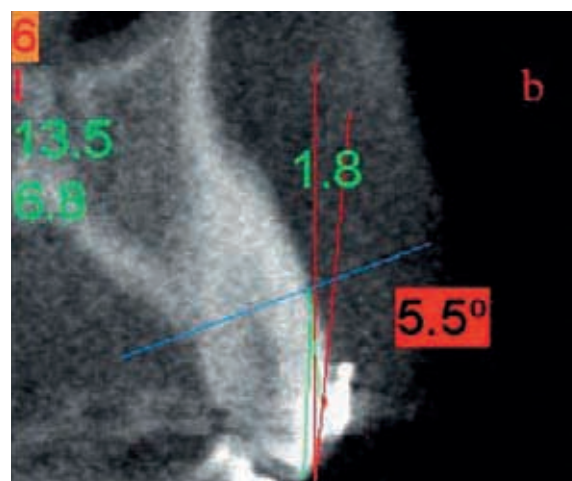


FIGURE 2 - Negative inclination.

TABLE 2 - Median (Med), Interquartile Deviation (IQD) and p value for the analysis of normality (Shapiro-Wilk) and for Friedman's analysis at T1, T2 and T3.

|                    | T1<br>(0.020-in) |      |                   | T2<br>(0.019 X 0.025-in) |      |                   | T3<br>(0.021 X 0.025-in) |      |                   | Capelozza<br>Prescription | Friedman<br>(P)<br>T1XT2XT3 |
|--------------------|------------------|------|-------------------|--------------------------|------|-------------------|--------------------------|------|-------------------|---------------------------|-----------------------------|
|                    | Med              | IQD  | p (SW)            | Med                      | IQD  | p (SW)            | Med                      | IQD  | p (SW)            |                           |                             |
| Maxill. Canine     | -1.80            | 3.40 | 0.08              | -2.75                    | 4.63 | 0.44              | -2.45                    | 4.05 | 0.61              | -5                        | 0.99 (ns)                   |
| Maxill. Lat. Inc.  | 7.00             | 3.40 | <b>&lt;0.01**</b> | 7.20                     | 4.75 | <b>&lt;0.01**</b> | 7.05                     | 4.63 | <b>&lt;0.01**</b> | 3                         | 0.13 (ns)                   |
| Maxill. Cent. Inc. | 5.75             | 5.73 | <b>0.03*</b>      | 6.20                     | 6.15 | <b>0.02*</b>      | 6.65                     | 4.93 | <b>0.04*</b>      | 7                         | 0.07 (ns)                   |
| Mand. Canine       | -4.95            | 8.03 | <b>0.04*</b>      | -6.10                    | 5.48 | 0.09              | -5.15                    | 6.35 | 0.53              | -11                       | 0.44 (ns)                   |
| Mand. Lat. Inc.    | 4.70             | 4.08 | 0.05              | 5.60                     | 3.00 | <b>0.02*</b>      | 4.85                     | 3.00 | <b>0.01*</b>      | 4                         | <b>0.013*</b><br>(T1=T2)#T3 |
| Mand. Cent. Inc.   | 6.00             | 5.15 | 0.19              | 7.50                     | 4.68 | <b>0.02*</b>      | 6.60                     | 3.05 | <b>0.04*</b>      | 4                         | 0.15 (ns)                   |

\*p<0.05/ \*\*, p<0.01; SW= Shapiro-Wilk.

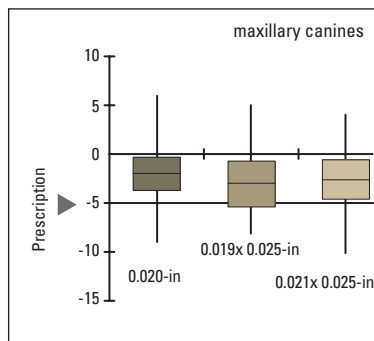


FIGURE 3 - Boxplot for maxillary canines (teeth 13 and 23). The solid line corresponds to Capelozza's Prescription value (-5°). Median values and coefficient of variation between the groups were similar between the three times (T1=T2=T3).

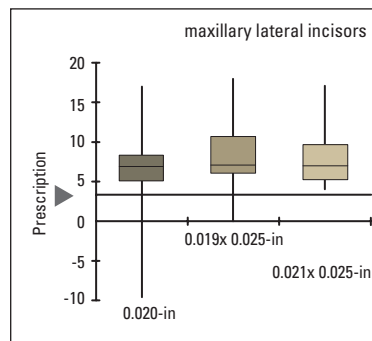


FIGURE 4 - Boxplot for maxillary lateral incisors (teeth 12 and 22). The solid line corresponds to Capelozza's Prescription value (+3°). Median values were similar between groups (T1=T2=T3). However the range of values obtained at T1 was significantly wider compared to the T3 group (p<0.01).

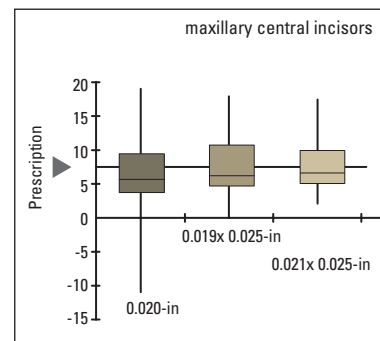


FIGURE 5 - Boxplot for maxillary central incisors (teeth 11 and 21). The solid line corresponds to Capelozza's Prescription value (+7°). Median values were similar between groups (T1=T2=T3). However the range of values obtained at T1 was significantly wider compared to the T3 group (p<0.01).

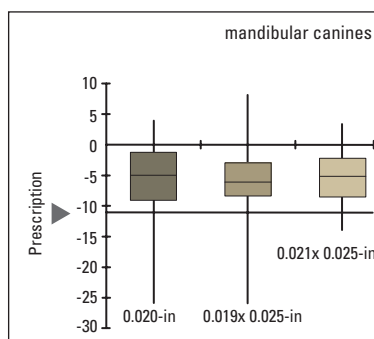


FIGURE 6 - Boxplot for mandibular canines (teeth 33 and 43). The solid line corresponds to Capelozza's Prescription value (-11°). Median values were similar between groups (T1=T2=T3). Although the range of values obtained at T1 seems wider, no significant difference was found.

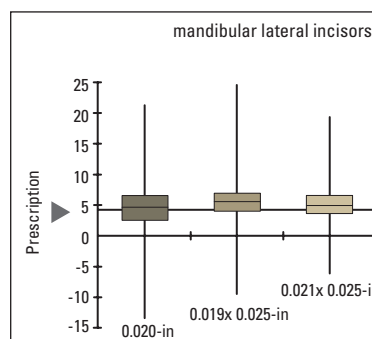


FIGURE 7 - Boxplot for mandibular lateral incisors (teeth 32 and 42). The solid line corresponds to Capelozza's Prescription value (+4°). Median differences between groups T1=T2 and T2=T3. Variation between the groups was similar.

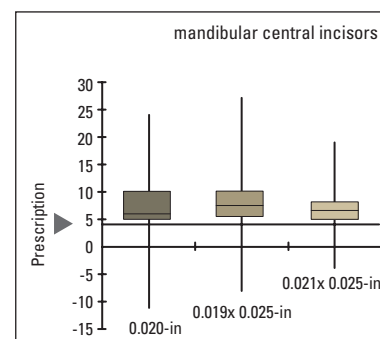


FIGURE 8 - Boxplot for mandibular central incisors (teeth 31 and 41). The solid line corresponds to Capelozza's Prescription value (+4°). Median values and coefficient of variation between the groups were similar between the three times (T1=T2=T3).

## RESULTS

The systematic error test showed no statistically significant differences in none of the teeth at the three different times, with the sole exception of tooth 32, which showed a value of  $p=0.043$  when the 0.021 0.025-in (T3) archwire was examined. No representative value ( $> 1.5^\circ$ ) was found for random error.

### Normality values (Shapiro-Wilk)

T1 (0.020-in archwire) and  
Capelloza's Class II Prescription

Comparing tooth inclination values at T1 with the prescription, a prevalence of individual patient values was noted due to different measurements among individuals. This result was expected, since it referred to a phase of round wire use, and little changes in inclination were expected, as round archwires cannot express torque. Therefore, any change in inclination at this stage can be attributed to adjustments in alignment and as a result of angular values built into lower anterior brackets. It should be noted, however, that both maxillary and mandibular central incisors exhibited median torque values that were close to the prescription used in the study. This finding suggests that in the presence of skeletal discrepancy, like that of the individuals in this sample, a natural compensation takes place, especially in mandibular teeth, which showed positive values close to the prescription, although such values were different from standard prescriptions, applicable to individuals with proportionate basal bones ( $-1^\circ$ ). Furthermore, maxillary teeth displayed values close to normal since prescription II features values that are identical with those of standard prescriptions, confirming that in pattern II malocclusions, increased compensation also occurs in the lower arch.<sup>8</sup>

T2 (0.019 X 0.025-in archwire) and  
Capelloza's Class II Prescription

This detachment of prescription values from the median, observed during the first use of a rectangular wire, means that 0.019 X 0.025-in

archwires did not express the inclinations incorporated into the preadjusted brackets but, on the contrary, yielded even higher values. This behavior may result from a greater vertical filling of the bracket slot by the archwire responsible for finishing alignment. The dental crowns are therefore moved to a more buccal position (Fig 9) by a lack of available spaces but without expressing the torque values built into the prescription due to the amount of slack, which is enough to compromise torque efficiency. Thus, one can assume that the main function of rectangular 0.019 X 0.025-in archwires is to finish leveling, and not to express numerically the angular inclination values present in the prescription, as previously believed. Therefore, if the expression of these torques in anterior teeth is desired, this archwire does not seem to be the most appropriate choice.

T3 (0.021 X 0.025-in archwire) and  
Capelloza's Class II Prescription

When this archwire was in use, many teeth still showed values that were different from the prescription. However, median inclination values were harmonized for all teeth, causing them to exhibit more similar values between the teeth of the same group, but in opposing quadrants. This fact is clinically significant because it represents movement toward symmetry.

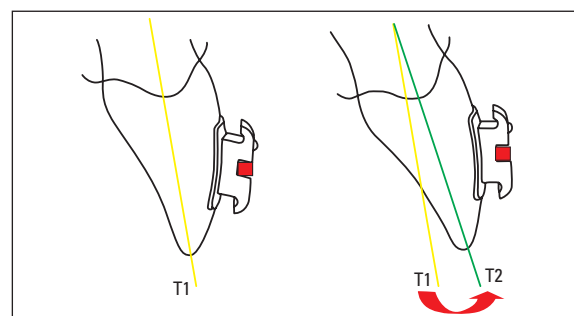


FIGURE 9 - Effect on tooth inclination at T2. Unaffected by the inclination provided in the prescription, the rectangular 0.019 X 0.025-in archwire caused labial inclination in order to finish leveling.

Statistical analysis between the values found at each of the three times showed no statistically significant difference during the test between T1 and T2 (0.020 and 0.019 X 0.025-in) and between T2 and T3 (0.019 X 0.025-in and 0.021 X 0.025-in). Statistically significant differences were found only between T1 and T3 (0.020-in and 0.021 X 0.025-in) for the following groups of teeth: maxillary central incisors ( $p=0.0023$ ) and maxillary lateral incisors ( $p=0.0055$ ).

### Slack between bracket slot and archwire

Taking into account the maximum slack for the 0.021 X 0.025-in archwire ( $\pm 3.9^\circ$ ),<sup>11</sup> it was found that after this archwire had done its job, the inclination values of all teeth examined began to approach the torque values built into Class II brackets. It can be asserted that the prescription values tended to be expressed at this time. It was also found that, in terms of the slack between archwire and bracket slot, the percentage of teeth whose torque values approached the prescription values increased between times (Table 3).

Of the 204 teeth examined at T1, 52.9% (108 teeth) were within the prescription range, 13.2% (27 teeth) had values below the prescription and 33.8%, i.e., 69 teeth were above prescription. At T2, the values remained unchanged when compared with those that were above or below the prescription. As at T1, the same 52.9% (108 teeth) were found to be within the prescription range, with 38.7% above prescription values (79 teeth), while 17 teeth, i.e., 8.3% displayed lower values. At T3, however, a tendency was noted whereby the number of teeth within the prescription range rose to 59.8% (122 teeth). Those above prescription declined to 35.8% (73 teeth), and those below prescription decreased to 4.4% or 9 teeth.

The results displayed in Table 3 allow the following explanation. At T2 the number of teeth within the prescription was found to be

the same as at T1, which confirms the finding that smaller-caliber rectangular archwires are unable to fully express the torque values built into the bracket prescription. Nevertheless, there was an increase in the number of teeth whose values were above prescription, which can be explained by the action of leveling, as it causes greater proclination of anterior teeth by increasing the perimeter of the dental arches. These data confirm that 0.019 X 0.025-in archwires work primarily for leveling.

The values found at T3 indicate that 0.021 X 0.025-in archwires successfully express the bracket prescription. The number of teeth that reached the torque values built into the brackets increased from 52.9% at T1 and T2, to 59.8%, or 122 teeth, at T3. These data clearly confirm that 0.021 X 0.025-in archwires are the only ones capable of adequately expressing inclination values, leading to a decrease in the number of teeth whose values were above and below the prescription (Fig 10).

Nonetheless, some teeth failed to exhibit inclination values within the prescription's range of tolerance which—for 0.021 X 0.025-in archwires—would be  $+4^\circ$  of torque in the mandibular incisors,  $\pm 3.9^\circ$  slack between bracket slot and archwire (Fig 11).

### DISCUSSION

The theme of tooth inclination has been extensively debated in orthodontics as it is part and parcel of daily orthodontic practice since the advent of preadjusted brackets. However, oddly enough, there are no published studies on the behavior of this feature, which is present in these orthodontic appliances. Nor has there been any research on how these preprogrammed brackets affect different individuals and different techniques, or the magnitude of changes in each tooth when different archwire calibers are employed. The most reasonable explanation for this gap is that the findings would probably dispel

TABLE 3 - Number of teeth whose inclination values were within the prescription, considering a  $\pm 3.9^\circ$  slack, according to Creekmore<sup>11</sup>.

|                   | T1                  |              |              | T2                  |              |             | T3                  |              |             |
|-------------------|---------------------|--------------|--------------|---------------------|--------------|-------------|---------------------|--------------|-------------|
|                   | within prescription | above        | below        | within prescription | above        | below       | within prescription | above        | below       |
| 13                | 14                  | 3            | 0            | 12                  | 5            | 0           | 11                  | 5            | 1           |
| 12                | 5                   | 10           | 2            | 6                   | 11           | 0           | 7                   | 10           | 0           |
| 11                | 9                   | 4            | 4            | 11                  | 4            | 2           | 12                  | 4            | 1           |
| 21                | 13                  | 2            | 2            | 12                  | 4            | 1           | 13                  | 4            | 0           |
| 22                | 10                  | 6            | 1            | 11                  | 6            | 0           | 9                   | 8            | 0           |
| 23                | 9                   | 8            | 0            | 12                  | 5            | 0           | 11                  | 5            | 1           |
| 43                | 3                   | 10           | 4            | 3                   | 10           | 4           | 7                   | 10           | 0           |
| 42                | 12                  | 2            | 3            | 11                  | 3            | 3           | 13                  | 3            | 1           |
| 41                | 9                   | 5            | 3            | 7                   | 8            | 2           | 11                  | 4            | 2           |
| 31                | 7                   | 7            | 3            | 7                   | 8            | 2           | 10                  | 5            | 2           |
| 32                | 10                  | 3            | 4            | 9                   | 5            | 3           | 13                  | 3            | 1           |
| 33                | 7                   | 9            | 1            | 7                   | 10           | 0           | 5                   | 12           | 0           |
| <b>Total</b>      | <b>108</b>          | <b>69</b>    | <b>27</b>    | <b>108</b>          | <b>79</b>    | <b>17</b>   | <b>122</b>          | <b>73</b>    | <b>9</b>    |
| <b>Percentage</b> | <b>52.9%</b>        | <b>33.8%</b> | <b>13.2%</b> | <b>52.9%</b>        | <b>38.7%</b> | <b>8.3%</b> | <b>59.8%</b>        | <b>35.8%</b> | <b>4.4%</b> |

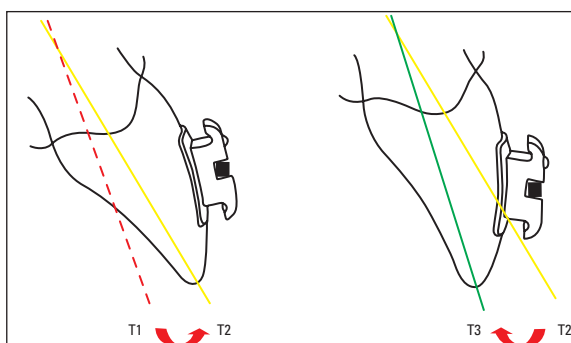


FIGURE 10 - Effect on tooth inclination from T1 to T2 and from T2 to T3. The inclination prescription influenced the effect of the 0.021 X 0.025-in archwire on the position of the teeth.

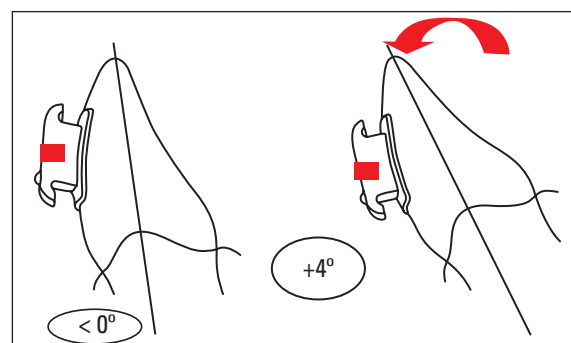


FIGURE 11 - Effect at T3 on the teeth whose values were below the prescription.

the misconception that 'one prescription fits all cases' and lay bare the need for bracket individualization and a selective use of archwires and even so, the difficulties in controlling the results expressed in the final position of the teeth would not be easily surmounted.

Most orthodontists use a single prescription because they do not use larger-caliber archwires to finish their cases, which results in loss of control over the full expression of prescription,

especially in terms of inclination. This allows similar brackets to be used in different patients with distinct therapeutic goals.<sup>12</sup>

Andrews'<sup>5</sup> standard prescription, however, emerged from measuring the crowns of teeth on normal occlusion models. Variation in incisor inclination was wider than that of other teeth, a characteristic attributed to different skeletal patterns present even in patients with optimal occlusion. For this reason, Andrews has suggested

since the introduction of Straight-Wire that individual prescriptions be employed using three torque values for the incisors in order to accommodate compensable inter-maxillary Class I, II or III relationships. Interestingly, this concept has aroused very little attention in the vast universe of those who routinely use this technique.

In this study, assessment of inclinations in anterior teeth was performed as of the stage when round the 0.020-in stainless steel archwire stopped being used. The results were used as inclination reference for comparison with the effects produced by rectangular 0.019 X 0.025-in and 0.021 X 0.025-in archwires. The use of rectangular wires aimed to induce the highest possible expression of the inclinations built into the brackets and, therefore, they were kept inserted for longer than the round wires, 40 and 30 days, respectively. It was only after this period that CT images were acquired.

It is important to stress that the slack between a 0.019 X 0.025-in archwire and the bracket slot is  $10.5^\circ$ .<sup>11</sup> Theoretically, this is a very high value and a significant expression of the prescription can be therefore expected in the anterior teeth in terms of inclination. From this perspective, the 0.021 X 0.025-in archwire was the last to be used, with a  $3.9^\circ$  slack<sup>11</sup> since it is potentially better able to express the prescription. It was thus possible to assess and compare the behavior of all archwires and brackets, always taking into consideration the slack between archwire and bracket slot.

The absence of statistically significant differences in the values of tooth inclination between the three times (T1, T2 and T3) for most teeth analyzed in this study can be attributed to the similarity between the torque values in the prescription and those found in the first phase, when the round 0.020-in archwire was used. This fact has a direct bearing on the means and statistical results. Some individuals showed little difference between the three moments

(T1, T2 and T3) and others showed great differences, which caused an increase in result variability.

For both lateral and central maxillary incisors, the statistical differences found between the round archwire and the rectangular archwires that filled the bracket slot maximally can be ascribed to the fact that the prescription reading was based on these teeth, for most individuals examined in this sample. In the Class II sample, the selection was made for both those subjects whose anterior teeth had buccal (Class II, division 1) and lingual (Class II, division 2) inclinations. By using rectangular 0.021 X 0.025-in archwires, these teeth reached values that differed from their initial values, as well as, from the values found when round archwires were used. This effect did not occur with any other tooth examined in this study.

## CLINICAL CONSIDERATIONS

At this point in this article it seems important to highlight the clinical insights that can be inferred from the results. Much has been said about the individualization of orthodontic treatment by means of an accurate, differential and individualized diagnosis with a view to determining the best treatment plan for each individual. This concept encompasses the choice of orthodontic brackets, a key issue often neglected by users of the Straight-Wire technique. This technique requires that brackets be chosen according to the final position of the teeth, which varies from patient to patient.

The sample selected for this clinical research was conducted in a judicious manner on individuals with an indication for Capellozza's prescription II. Despite such stringent selection, different inclinations were observed between individuals with identical facial pattern and malocclusion. This is perfectly natural as it represents the universe of patients expected in routine clinical practice. Although the median values found in this study are close to the

prescription values, inclinations varied widely between individuals, even at the three different assessment times.

Some teeth displayed a unique behavior, such as the maxillary central incisors. Inclination values varied little at each time, regardless of archwire size and its effect on anterior teeth. Despite the proclination tendency shown by 0.019 X 0.025-in archwires, torque values for these teeth remained at around  $+7^\circ$ , a value suggested by Andrews<sup>5</sup> as ideal and used in Capelozza's prescription II. This finding regarding the central incisors is also corroborated by another study in which, although the value ( $0.96^\circ$ ) was higher than the one found by Andrews, it is not clinically significant.<sup>7</sup>

This information reinforces the recommendation that a  $+7^\circ$  torque be built into the Class II prescription for central incisors which, unlike the  $+2^\circ$  prescription suggested by Andrews,<sup>5</sup> do not have their inclination values decreased. The argument in favor of maintaining  $+7^\circ$  in maxillary incisor inclination, even in brackets designed for compensatory treatment of Pattern II malocclusions, stems from the need to give resistance to these teeth in the face of other mechanical resources used to treat this malocclusion, such as headgear and Class II elastics, thereby minimizing the tendency towards a more vertical position. Thus, any compensation for tooth inclinations occurs in the lower arch in order to prevent the negative aesthetic impact that takes place when maxillary teeth are inclined in an attempt to compensate for the facial pattern.<sup>8</sup>

A unique behavior was also noted in maxillary lateral incisors, which exhibited values well above those found in the sample of normal occlusions suggested by Andrews<sup>5</sup> and above Class II prescription values.<sup>8</sup> This seems due to the fact that the means were influenced by individuals who presented with Class II, division 2 malocclusion.

In the maxillary canines a behavior was noted which differs from that found in other teeth during the transition of T1, T2 and T3. Clinically, it was observed that in each individual, the initial position of the canines tended to remain unchanged. Thus, if one of the teeth exhibited an inclination that was altogether different from its analogue in the opposite quadrant, such difference in position was maintained despite the use of rectangular wires. This finding attests that the importance of canine position, and the impact it exerts on other teeth, especially in terms of inclination, cannot be overemphasized. The size of the root may have been the main obstacle to the full expression of the prescription inclination, despite the use of larger-caliber rectangular archwires.

Also based on the results of this study, but now seen from a clinical perspective, it seems reasonable to emphasize that the 0.019 X 0.025-in archwire should be primarily regarded as a leveling archwire, since its major effect is to procline incisors (Fig 12), irrespective of the prescription built into the bracket.

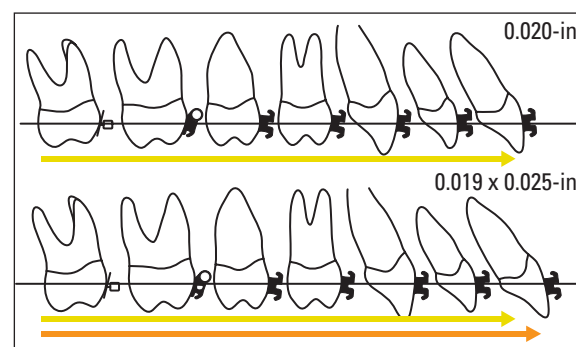


FIGURE 12 - Proclination effect and increase in arch perimeter in the transition from T1 to T2.

Therefore, to ensure that the inclination values of a given prescription are fully expressed, it is advisable to use larger-caliber rectangular archwires, e.g., 0.021 X 0.025-in in a 0.022-in slot. It would also be reasonable to assume that this wire should be maintained for a longer period of time to produce a more effective prescription expression.<sup>11</sup>

As for the orthodontic treatment of the sample, it must be emphasized that there was a reduction, if not a complete correction, of overjet in these individuals, even without the use of any additional mechanical resources. This probably occurred in a compensatory manner, through changes in their inclinations.

The use of individualized prescriptions can be helpful in creating or maintaining the inclinations and angulations necessary to achieve the planned movements, which ultimately compensate for pattern II malocclusions by facilitating, and not hindering, these movements.

When planning an orthodontic case, orthodontists envision the positioning of teeth, in terms of the desired inclinations and movements, with the purpose of attaining an interincisor relationship that is acceptable both esthetically and functionally. As regards the individuals selected for this scientific research, it is expected that the mandibular incisors will remain or become proclined, i.e., with a positive

inclination value. Upper incisors should also undergo proclination, in line with dental and facial esthetics. Values, however, should not be too high but nominally equivalent to the values built into the prescription.

The use of the prescription can still be advocated given the increased value used in the mandibular canine angulation. This angulation makes for lower incisor proclination. It should be emphasized once again that in the absence of mandibular canine proclination, which should be expected as compensation for Pattern II, the prescription would help achieve the best possible positioning. On the other hand, in the presence of an increased angular value, the prescription would ensure its maintenance.

## CONCLUSIONS

Based on the methodology used in this investigation and the results it achieved, it seems reasonable to state that:

- » The median inclinations found at T1, T2 and T3 were similar. Statistical significance was found only for mandibular lateral incisors.

- » The use of rectangular 0.021 X 0.025-in archwires reduces inclination variation, mainly in maxillary incisors, thereby increasing the number of teeth whose values come close to the prescription built into the bracket.

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# Computed Tomographic evaluation of a young adult treated with the Herbst appliance

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## Abstract

**Introduction:** The key feature of the Herbst appliance lies in keeping the mandible continuously advanced. **Objective:** To monitor and study the treatment of a patient wearing a Herbst appliance by means of Cone-Beam Computed Tomography (CBCT) images for 8 months after pubertal growth spurt. The subject was aged 16 years and 3 months and presented with a Class II, Division 1 malocclusion associated with mandibular retrognathia. **Results:** The CBCT images of the temporomandibular joints suggest that the treatment resulted in the remodeling of the condyle and glenoid fossa and widening of the airway. **Conclusions:** The Herbst appliance constitutes a good option for treating Class II malocclusion in young adults as it provides patients with malocclusion correction and improves their aesthetic profile.

**Keywords:** Temporomandibular joint. Computed Tomography. Orthopedic appliances.

## INTRODUCTION

Despite the availability of a wide range of Class II malocclusion treatment options, the actual action mechanism behind these orthopedic devices remains controversial. The effectiveness of the Herbst appliance in treating Class II malocclusions has been studied for decades. However, despite the obvious effectiveness of this therapy, the possibility of manipulating mandibular growth potential beyond what is genetically determined still fuels the debate between proponents and opponents of dentofacial orthopedics.<sup>1</sup> Some researchers, grounded in Functional Matrix theory, believe that local environmental factors ultimately determine the final size of the craniofacial skeleton, which

could therefore be subjected to some regulation by changing its functional pattern.<sup>1</sup> Opponents of this view advocate that control is predominantly genetic, alterations are restricted to the dentoalveolar component and do not affect basal bone growth. It is suggested that the use of functional appliances for stimulating mandibular growth would have only a temporary impact on the dentofacial pattern and that over the long term the morphogenetic pattern would prevail.<sup>1,2</sup>

Nevertheless, the primary issue remains controversial: Do functional appliances cause significant changes in mandibular growth? Although these appliances have been in use for over a hundred years little is known about how they work,

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which tissue systems are affected, to what extent and how stable these effects really are.<sup>1,2,3</sup>

However, recent studies using computed tomography (CT)—which allows the reconstruction of anatomical areas and their display in three dimensions, revealing information about size, shape and texture—show tissue response in patients treated after pubertal growth spurt<sup>3,4</sup> as well as remodeling of the glenoid fossa and condyle, and TMJ adaptation.<sup>5,6,7,8</sup>

Some studies<sup>9,10,11</sup> assessed the response of the condyle, glenoid cavity and posterior mandibular ramus in adult rhesus monkeys. The results showed adaptation of the condyle and glenoid fossa during treatment with the Herbst appliance.

Advances in Imaging Technology in Dentistry and the advent of Computed Tomography (CT) scans ensure accurate diagnoses with great reliability, enabling the three-dimensional analysis of structures. As well as specific CT software, which allows measurements to be carried out in tomographic slices, a new methodology has emerged which makes for the assessment of inclinations and angulations of individual teeth, and bone remodeling, accurately reproducing the various structures.

Computed Tomography is the exam of choice for analyzing bone components and dental structures.<sup>12</sup> The development of this new technology has provided dentistry with the reproduction of three-dimensional images of mineralized maxillofacial tissues with minimal distortion and significantly reduced radiation doses.<sup>13</sup>

Its diagnostic reliability is due to the accuracy of the measurements used in different methods, which is of great importance to orthodontists since orthodontic treatment diagnosis, prognosis and planning, among other factors, depend on such measurements.

## CLINICAL CASE REPORT

The case described in this article is part of a re-

search sample collected at the Araraquara School of Dentistry, Paulista State University, aimed at evaluating and comparing orthodontic and orthopedic effects on subjects treated with tooth supported Herbst appliances using CT. This clinical case report is part of a research project approved by FOAr's Ethics in Research Committee (Protocol No. 26/06), with the support of the São Paulo Research Foundation (FAPESP).

## Initial diagnosis

A Brazilian patient, male, 16.3 years old, sought orthodontic treatment at the Araraquara School of Dentistry (UNESP) complaining that his chin was positioned backwards. Front view facial analysis showed a mesofacial pattern and absence of lip seal. Lateral view analysis disclosed a convex profile associated with mandibular retrognathia (observed clinically), and a short chin-neck line (Fig 1).

Intraoral examination showed that the patient presented permanent dentition, a Class II malocclusion and 7.3 mm overjet (Fig 3). At diagnosis, functional changes were noted in swallowing. Morphological analysis of the cephalometric radiograph confirmed a convex facial pattern (Fig 2).

Skeletal age was verified by means of carpal X-ray using skeletal maturation indicators according to the Greulich and Pyle atlas.<sup>16</sup> The patient was nearing the end of the descending growth curve (FPut – Complete epiphyseal union in the proximal phalanx of the 3<sup>rd</sup> finger; FMut – Complete epiphyseal union in the middle phalanx of 3<sup>rd</sup> finger; and/or Rut - Complete epiphyseal union of the radius bone), i.e., at the end of pubertal growth.

## Using the Herbst appliance

The patient was treated orthopedically with a banded Herbst appliance for a period of eight months. To evaluate dental and skeletal changes the patient underwent two lateral cephalometric radiographs and CBCT scans in maximal



FIGURE 1 - Initial extraoral photographs profile (A) and front (B) views.



FIGURE 2 - Initial lateral cephalometric radiograph.



FIGURE 3 - Initial intraoral photographs right (A), front (B) and left (C) views.

habitual intercuspation (MHI): At T1, beginning of treatment, and T2, eight months after treatment. The Cone-Beam CT scans were performed at the beginning of treatment and after removal of the Herbst appliance, and analyzed using specific software (Dolphin 10.5, Dolphin Imaging & Management Solutions, USA).

The anchorage system used in the upper and lower arches was a banded Herbst (Figs 4, 5 and 6). To cement the anchorage structures we used light cure glass ionomer cement (3M Unitek).

A telescopic mechanism was used (Flip-Lock - TP Orthodontics), composed of the following accessories: a) Tube, determines the amount of mandibular advancement, b) Piston, adapted to the length of the tube, c) Connectors, with a spherical shape.

### CT examination and measurements

The CT scans were obtained with an i-CAT scanner with the patient's mouth shut and in maximal intercuspation (MHI). Scanners provide standardized images in a single 360-degree rotation, 20-second scan. It reconstructs the data in real time, automatically and immediately, yielding 460 individual 0.5 mm slices in each orthogonal plane. Data were exported in DICOM format and evaluated using Dolphin software.®

It is very important to standardize head position in the software during CT examination. 3D views of the axial, coronal and sagittal planes are used. In the front view CT scan, the sagittal midline is standardized in the vertical plane. The Frankfort plane provides guidance in the horizontal plane. In lateral view CT scans, the vertical



FIGURE 4 - Intraoral photograph showing the banded Herbst appliance without piston assembly.



FIGURE 5 - Intraoral photograph showing lower Herbst anchorage.

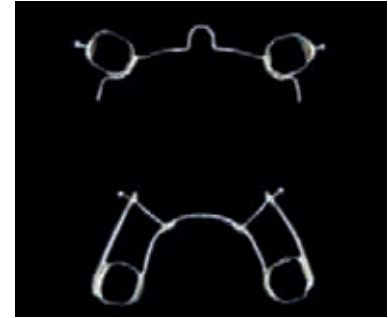


FIGURE 6 - Upper and lower banded Herbst anchorage.

plane comprises the line where the Porion crosses the Frankfort horizontal plane.

#### CT scan image assessment

The CT scans revealed a 0.8 mm increase in condyle diameter on the right side and 0.7 mm on the left side (Figs 7, 8 and 9). The subjective analysis of the region suggests that the area of the glenoid fossa and condyle experienced remodeling. However, analysis of a single case does not allow meaningful assessment.

Studies<sup>14</sup> report this change and show, by means of magnetic resonance imaging in patients treated with Herbst appliance, an adaptation of the temporomandibular joint, concluding that such remodeling of the glenoid fossa and condyle does take place. Another investigation,<sup>7</sup> this time using MRI in 20 adolescent patients treated with Herbst, pointed out changes in TMJ disc position and concluded that during treatment with Herbst there is an alteration in the position of the articular disc, but within normal limits. Treatment with Herbst in young adults provides bone remodeling and formation of new condylar bone. Furthermore, this newly formed bone has been shown to be stable.<sup>3,6</sup>

CT examinations allow anatomical areas to be reconstructed and viewed in three dimensions, disclosing information about size, shape

and texture of the area under analysis. CT scanners capture body images in slices using radiation and export them to a dedicated software. Given its accuracy, CBCT contributes to scientific investigations of remodeling in the TMJ region through the use of orthopedic appliances. Studies conducted in adult monkeys treated with the Herbst appliance showed by means of histological sections that the treatment produces significant bone formation in the glenoid fossa or remodeling in the area of the fossa and condyle.

In assessing an individual's airway, the initial volumetric value of 4324.5 mm<sup>3</sup> can be found, whereas after treatment with Herbst, such value rises to 5108.5 mm<sup>3</sup> (Fig 9), indicating an increase in the nasopharyngeal region after treatment. A study<sup>15</sup> conducted with 26 individuals who presented with constriction of the upper airways and were treated with mandibular advancement devices, upon examination of the airways using CT scans in the Dolphin software version 11, found a significant increase in the mean oropharyngeal volume. Recent advances in software technology allow these volumetric data to be used in research. In its latest version, Dolphin shows the volumetric analysis of the airway. These technological advances allow an increase in resolution and can attest to the effectiveness

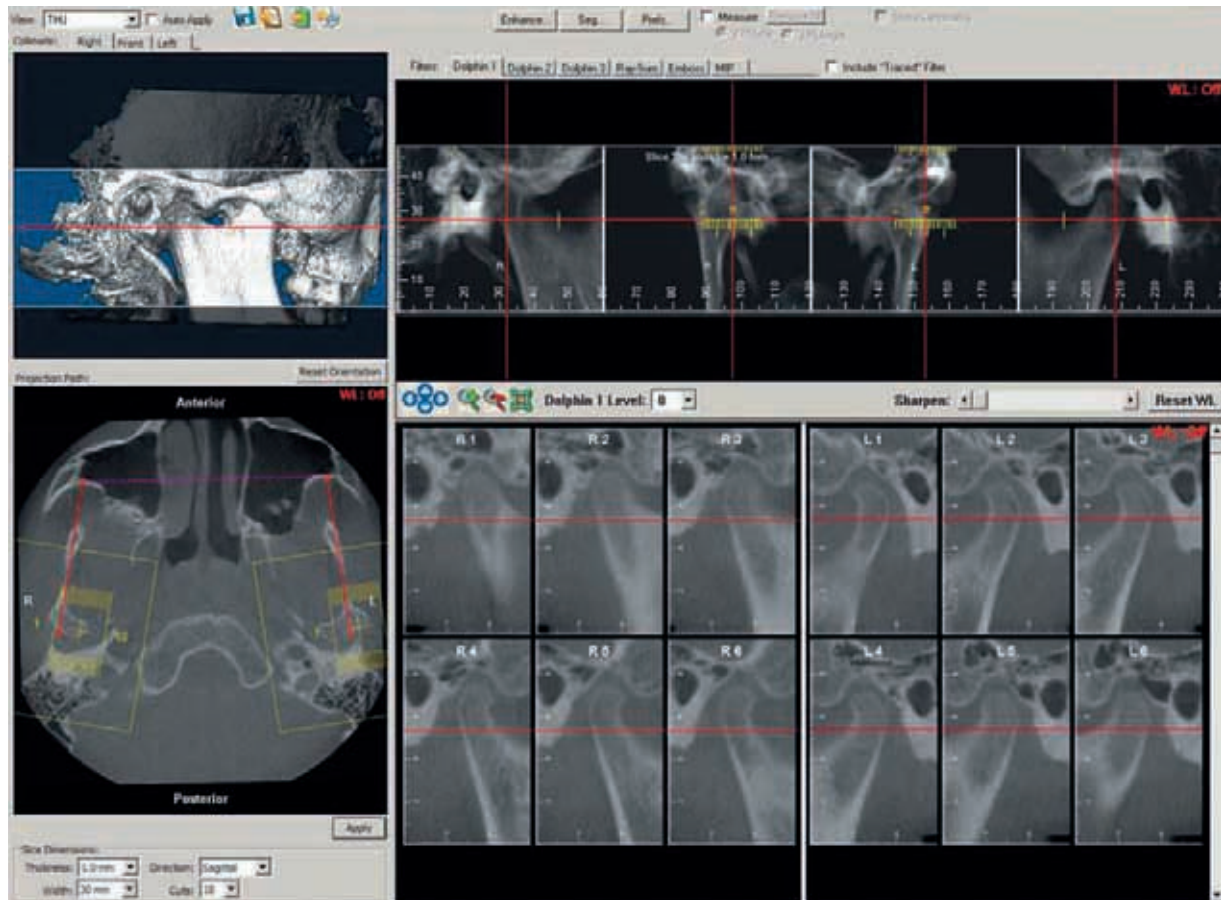


FIGURE 7 - TMJ examination method using Dolphin software.

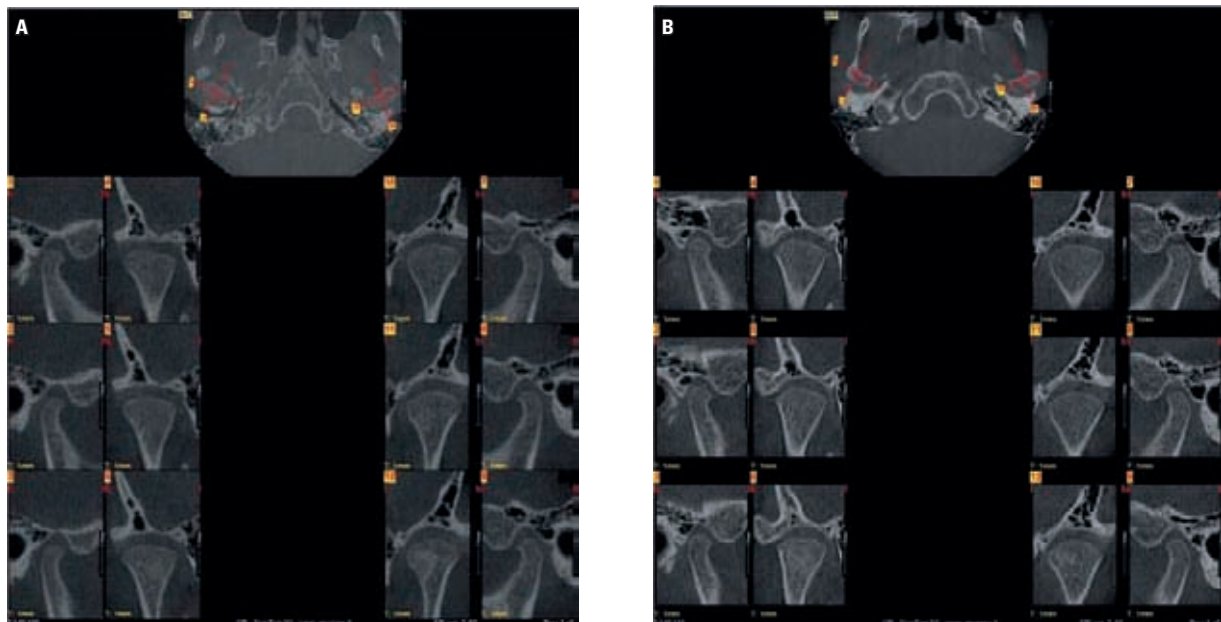


FIGURE 8 - A) Initial CT scan of TMJ regions. B) Final CT scan of TMJ regions.

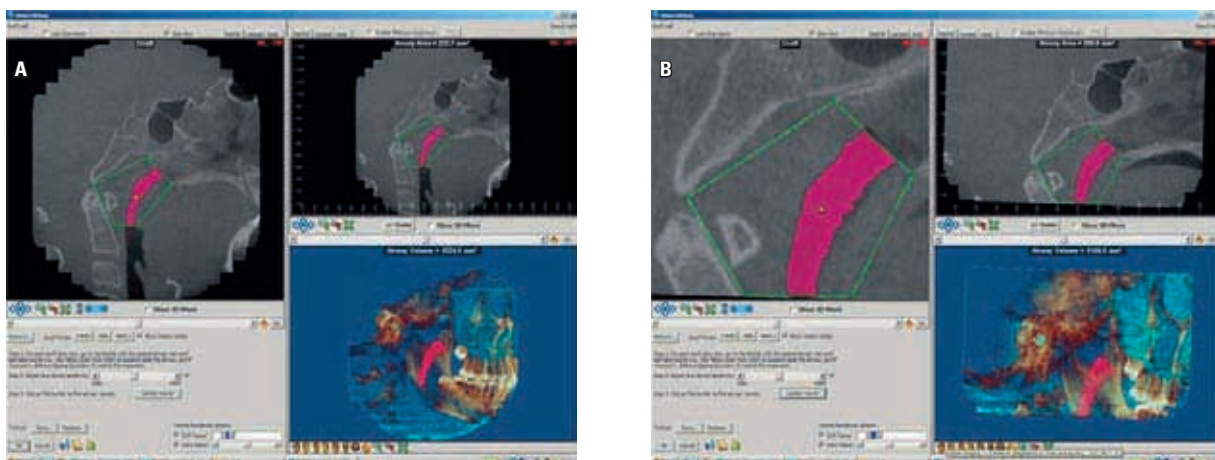


FIGURE 9 - Airway tomogram analysis: **A)** initial and **B)** final.

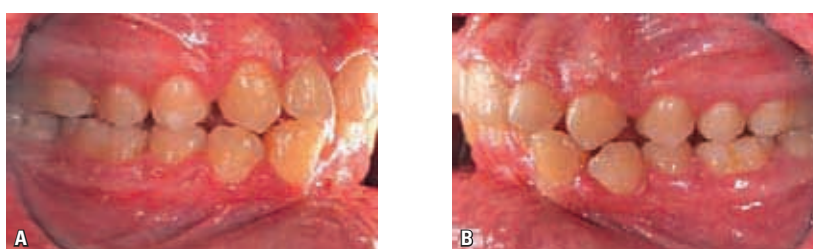


FIGURE 10 - Final intraoral photographs: Right side **(A)** and left side **(B)** views.



FIGURE 11 - Extraoral photographs after treatment with Herbst: profile **(A)** and front **(B)** views.



FIGURE 12 - Final lateral cephalogram.

of mandibular advancement devices, as in the treatment presented in this study.

After eight months of treatment with Herbst the results show (Fig 10) correction of Class II and Class I malocclusion as well as improved facial aesthetics (Figs 11 and 12) with no changes

in muscles and joints.

CT studies on the influence of Herbst in the TMJ region and airways are scarce. The findings show assessments made using resonance and disc positioning since CT examinations are a more recent phenomenon.<sup>7</sup>

## CONCLUSIONS

CT scans provide better diagnosis and orthodontic treatment planning, making it possible to view the problem in three dimensions in space. Furthermore, CBCT allows structures such as the condyle and glenoid fossa to be analyzed while enabling the evaluation of remodeling in this region

after treatment with orthopedic appliances. Treatment with the Herbst appliance produces satisfactory results, providing patients with malocclusion correction and improving their aesthetic profile. After treatment with the Herbst appliance CT evaluation is suggestive of remodeling in the TMJ region and condyle, and a widened airway.

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# Assessment of condylar growth by skeletal scintigraphy in patients with posterior functional crossbite

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## Abstract

**Objectives:** This study evaluates the condylar growth activity in 10 patients with functional posterior crossbite before and after correction, using the mandibular bone skeletal scintigraphy. **Methods:** Patients received endovenous injection of radioactive contrast (Technesium-99m labeling, sodium methylene diphosphate). After two hours, planar scintigraphic images were taken by means of a Gamma camera. Lateral images of the closed mouth, showing the right and left condyles, were used. An image of the 4<sup>th</sup> lumbar vertebra was also used as reference. **Results:** Statistically significant differences were not found in the uptake rate values, on both sides when pre-treatment and post-treatment periods were analyzed separately and also when pre-treatment and post-treatment periods were analyzed in the same side. No differences were found in the condylar growth activity, in patients with functional posterior crossbite.

**Keywords:** Functional posterior crossbite. Condilar growth. Skeletal scintigraphy.

## INTRODUCTION

In dentistry and particularly orthodontics, the understanding of growth and craniofacial development, have always been of extreme importance due to the direct influence on diagnosis and prediction of treatment. As the knowledge of these events improves, it is also possible to im-

prove treatment planning because most attempts to prevent, intercept and correct malocclusions take place during growth.<sup>1-5</sup>

The dynamic growth assessment by means of conventional methods is quite limited, as this is based, either on the growth that occurred in the past (serial observation and serial cephalograms)

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or due to the craniofacial assessment based on general skeletal maturation (hand and wrist radiographs and vertebra maturation). Thus, a dynamic method to specifically assess craniofacial growth, such as skeletal scintigraphy would enhance diagnosis and treatment planning, especially in cases of craniofacial deformities or mandibular alterations.<sup>6,7,8</sup>

Skeletal scintigraphy is an imaging method that has the sensitivity to reflect skeletal metabolic activity.<sup>9</sup> It involves the administration of a bone-seeking radiopharmaceutical preparation, which is then absorbed by the blood flow. Bone formation and remodeling can thus be observed through this technique as osteogenesis is detected by means of bone scans carried out with a gamma camera.<sup>6,7,8</sup>

The radioisotope used, <sup>99m</sup>Tc, is coupled to phosphates and phosphonates which are incorporated to the bone matrix, where bone formation and resorption take place. Thus, bone scintigraphy is considered an efficient technique that can be indicated for the assessment of dynamic craniofacial growth, with only one exam.<sup>6,7,8</sup> Because of its ability to detect functional change, a bone scan can be informative before visible structural changes occur on radiographs.<sup>9,10</sup>

Functional posterior crossbite is a lateral deviation of the mandible due to occlusal interference. Authors report that, in children with this malocclusion, the condyles on the crossbite side are positioned relatively more superiorly and posteriorly in the glenoid fossa than those on the non-crossbite side.<sup>11</sup> In such cases the neuromuscular activity is altered, thus, a skeletal remodeling of the temporomandibular joint can occur over time, generating asymmetries in the condylar and mandibular growth, which will result in true dentofacial asymmetries in adult stage. Several studies, using radiographs, report that when this malocclusion is corrected, and the functional deviation eliminated, condyles will take a symmetric position, which will allow a more harmonic mandibular growth.<sup>12,13,14</sup>

The aim of this study was to evaluate the condylar growth activity in patients with functional posterior crossbite, through mandibular skeletal scintigraphy.

## MATERIAL AND METHODS

Ten patients were selected (mean age 9yr±4mo) presenting posterior functional crossbite and chosen to be treated in the Orthodontic Clinic at the State University of Rio de Janeiro. Specific criteria were: Crossbite should involve, at least, two teeth, including the first permanent molar plus a deciduous molar, and a midline deviation of 1 mm or more in the intercuspal position. The patient should not have midline deviation in centric relation and, when requested to occlude, should present occlusal interferences that cause lateral deviation of the mandible. Consent was obtained and this study was previously submitted and authorized by the ethical committee of the State University of Rio de Janeiro.

A removable Porter appliance (W arch) was used for crossbite correction. Activations were carried out with a six-week interval, and continued until the overcorrection of the crossbite. Once the overcorrection had been achieved, the appliance remained passive for a six-week retention period.<sup>14</sup> Mandibular skeletal scintigraphy examination was carried out before treatment and then repeated after the retention period (mean, 5.1 months).

To perform mandibular skeletal scintigraphy, patients were sent to the Nuclear Medicine Service of the State University of Rio de Janeiro Hospital, where a radioactive contrast was injected intravenously (cubital vein), using the Technesium-99m Radionucleid composite, labeling methylene diphosphonate sodium (Tc 99m – MDP), in saline solution (0.9%). Dose used was 300 microcuries (300μCi) for each kilogram.<sup>7,8</sup>

After two-hours, the patients were positioned in front of the Gamma camera (Siemens™ E-CAN model), with a wide range of vision using

a parallel hole collimator for low energy and high resolution. Static (planar) projections of the head were taken, considering the lateral direction (right and left) with closed mouth, having 400.000 counts per image. An image of the lumbo-sacral spine was also taken using the same technique. Hyperextension of the neck was carried out on the lateral shots, to increase space between the cervical spine and the mandible region and help the observation of the condyles.<sup>7,8</sup>

Images were processed on the ICON/Siemens system. Regions of Interest (ROIs) were selected in the right and left projections of the condyles and in the 4<sup>th</sup> lumbar vertebra (Fig 1). Considering the selected regions, mean counts per pixel were calculated on each one of the ROIs. Uptake ratio between counts of each condyle and the fourth vertebra was calculated as follows: UR (uptake ratio) is equal to mandible ROIs count divided by 4<sup>th</sup> lumbar vertebra ROIs count. The fourth lumbar vertebra uptake was used as a control and reference for the other selected areas, as it had an even skeletal uptake, compensating possible errors resulting from skeletal overposition of the condylar regions.<sup>7,8</sup>

Before final results were obtained, the same evaluator, trained for the method, carried out the ROIs markings on all projections. Exams were evaluated three times and intra-observer error was 6.5%.

Pre-treatment and post-treatment UR values were compared for the same side and each side UR value (crossbite and non-crossbite sides) was

also compared for the same period. Wilcoxon test was used to verify the differences. Significance would be accepted for a level of 5%.

## RESULTS

No statistically significant differences were found in the condylar growth activity, on both sides when pre-treatment and post-treatment periods were analyzed separately and also, when pre-treatment and post-treatment periods were analyzed in the same side (Tables 1 and 2).

In Figures 2 and 3, it can be observed that the dispersion found was greater in the pre-treatment than in the post-treatment period. This suggests that the UR values of the altered and non-altered sides presented closer values in the post-treatment period.

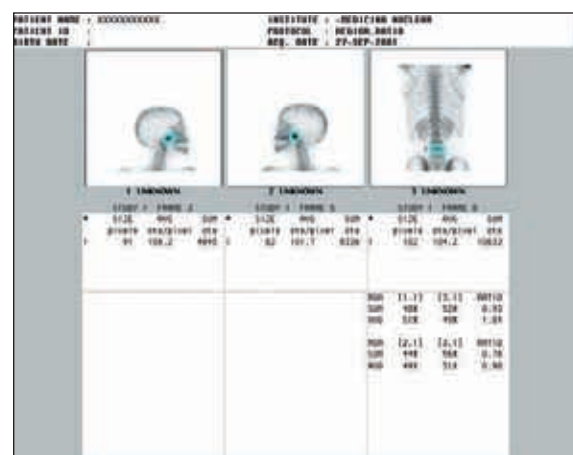


FIGURE 1 - Patient with functional posterior crossbite (scintigraphy images processing): lateral images X fourth lumbar vertebra image, with selected regions of interest (ROIs) and calculated ratio of uptake (RU).

TABLE 1 - Uptake ratios (UR) comparisons between the condylar sides treated.

|      | Altered side<br>Pre-treatment | Altered side<br>Post-treatment | Non-altered side<br>Pre-treatment | Non-altered side<br>Post-treatment |
|------|-------------------------------|--------------------------------|-----------------------------------|------------------------------------|
| Mean | 1.152                         | 1.035                          | 1.169                             | 1.023                              |
| SD   | 0.144                         | 0.238                          | 0.152                             | 0.242                              |
| p    | 0.575                         |                                | 0.475                             |                                    |

(Wilcoxon test for significance level of 5%).

TABLE 2 - Uptake ratios (UR) comparisons between treatment periods.

|      | Altered side<br>Pre-treatment | Non-altered side<br>Pre-treatment | Altered side<br>Post-treatment | Non-altered side<br>Post-treatment |
|------|-------------------------------|-----------------------------------|--------------------------------|------------------------------------|
| Mean | 1.152                         | 1.169                             | 1.035                          | 1.023                              |
| SD   | 0.144                         | 0.152                             | 0.238                          | 0.242                              |
| p    | 0.574                         |                                   | 0.540                          |                                    |

(Wilcoxon test for significance level of 5%).

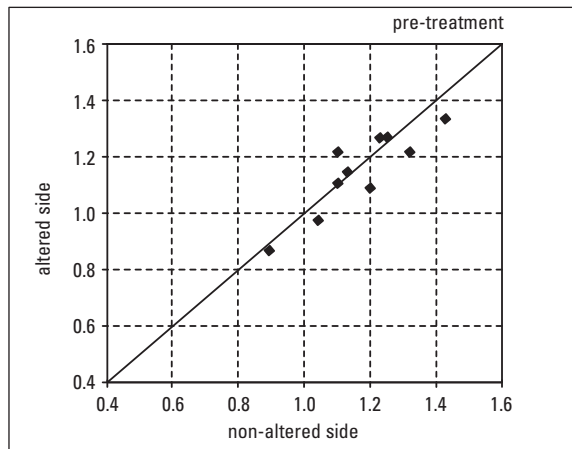


FIGURE 2 - Dispersion between the uptake ratios (UR) of the altered and non-altered condylar sides in the pre-treatment in the lateral scintigraphy projections.

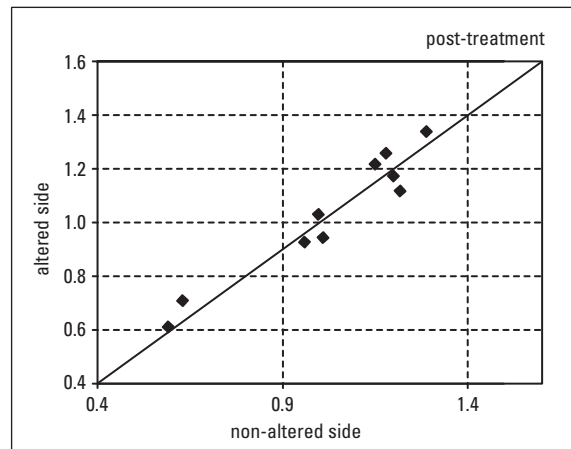


FIGURE 3 - Dispersion between the uptake ratios (UR) of the altered and non-altered condylar sides, in the post-treatment, in the lateral scintigraphy projections.

## DISCUSSION

There are evidences that condylar position in patients presenting functional posterior crossbite may appear altered.<sup>10</sup> Previous studies have found that the condyle, on the crossbite side, became higher and posteriorly positioned in the glenoid fossa,<sup>11-16</sup> while the condyle on the non-crossbite side would present a more anterior and lower position.<sup>12,14</sup> When the condyles presented such excentric position, some altered neuromuscular activity might exist in these patients. This may cause asymmetries in the condylar development, as well as in mandibular growth.<sup>12-17</sup>

It has been observed in some studies that once malocclusion has been corrected, the functional deviation is usually eliminated. Thus, condyles that were mal-positioned before treatment can take a more symmetrical bilateral position, which, as a consequence, may allow for a more harmonic condylar and mandibular growth.<sup>12,13,14</sup> In the present study, even though no statistical differences were observed, the

tendency for a greater uptake of the altered condylar side, in the pre-treatment, may suggest agreement with the previously referred studies on condylar positioning.<sup>12,13,14</sup> Due to the altered condylar position, these authors suggest an increased condylar skeletal uptake on the altered condylar side, before crossbite correction.

Interestingly, the results of the present study may also raise some questions about the condylar growth changes. As we could not find statistically significant differences between crossbite and non-crossbite sides using a very sensitive technique, the altered positioning of the condyles may not actually lead to significant changes in condylar growth but some TMJ soft tissue adaptations and remodeling of the glenoid fossa.

It is also important to consider that maybe changes do not occur immediately after crossbite correction, and that possibly a retention period greater than six weeks is necessary to observe significant differences.

On the other hand, as both sides of the mandible work on a correlated function basis, an altered

growth condition, on one side, may generate considerable effects in the function and growth of the opposite, biasing the results.<sup>6</sup> Further studies with a longer retention period and larger sample, may enhance the knowledge about this important clinical issue.

The similar post-treatment condylar uptake values, suggested, in agreement to previous studies, that concentric position of the condyles may represent a more balanced growth and development of such condyles, when the functional posterior crossbite is corrected.<sup>11-14</sup>

The dispersion analysis for condylar uptake suggests that in the pre-treatment (Fig 2) period the UR values presented a greater difference between the crossbite and non-crossbite sides than in the post-treatment (Fig 3), where smaller dispersion suggests closer UR values between the two condylar sides.<sup>11-14</sup>

Although no statistically significant difference was found in the present study, a decrease tendency in the condylar uptake was observed, on both sides, after the crossbite correction.

Some studies suggest that the condylar position becomes more concentric after the crossbite correction.<sup>11,12,13</sup> According to those authors, the altered condylar side may have more growth stimulus due to the condylar displacement, caused by the malocclusion. Once this stimulus

is eliminated, by the treatment and a greater concentricity of the condylar position is obtained, a smaller or more balanced condylar growth can be achieved.<sup>11,12,13</sup>

Variation in the uptake values in the post-treatment period might suggest that patients respond differently to the treatment, although they keep the same tendency. Different reactions to crossbite correction have been also cited, according to their characteristics (number of patients, individual characteristics, re-assessment period) and the nature of treatment (appliance design, period of treatment).<sup>16,17</sup>

This study introduces an important mechanism of evaluation of the influence of orthodontic treatment upon growth during crossbite correction. Further researches will be able to clarify the questions raised as they become more specific in their analysis strategies. In this way, resources for the skeletal scintigraphy examination could be used to optimize diagnostic routine in clinical orthodontics.

## CONCLUSION

No statistically significant differences were observed in the condylar growth activity in individuals with functional posterior crossbite, when ipsilateral and contralateral sides are compared before and after treatment.

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# Reproducibility of bone plate thickness measurements with Cone-Beam Computed Tomography using different image acquisition protocols

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## Abstract

**Introduction:** A smaller voxel dimension leads to greater resolution of Cone-Beam Computed Tomography (CBCT), but a greater dosage of radiation is emitted. **Objective:** Assess and compare the reproducibility of buccal and lingual bone plate thickness measurements in CBCT images using different image acquisition protocols, with variations in the voxel dimension. **Methods:** CBCT exams were taken of 12 dried human mandibles with voxel dimensions of 0.2, 0.3 and 0.4 mm using the i-CAT Cone-Beam 3-D Dental Imaging System. The thickness of the buccal and lingual bone plates was measured, with the i-CAT Vision software, on an axial section passing 12 mm above the right mental foramen. Intra-examiner and inter-examiner reproducibility was assessed using the paired t-test and independent t-test, respectively, with the level of significance set at 5%. **Results:** Excellent inter-examiner reproducibility was observed for the three protocols analyzed. Intra-examiner reproducibility was very good, with the exception of some regions of the anterior teeth, which exhibited statistically significant differences regardless of the voxel dimensions. **Conclusion:** The measurement of buccal and lingual bone plate thickness on CBCT images demonstrated good precision for voxel dimensions of 0.2, 0.3 and 0.4 mm. The reproducibility of the measurements of the anterior region of the mandible was more critical than that of the posterior region.

**Keywords:** Cone-Beam Computed Tomography. Alveolar bone. Reproducibility.

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## INTRODUCTION

A correct and precise diagnosis and treatment plan are fundamental for the success of orthodontic treatment. With the advent of Cone-Beam Computed Tomography (CBCT), orthodontists are able to obtain all the two-dimensional images (2D) that compose the orthodontic documentation during a single exam with the same precision of conventional radiographs, along with a detailed view of dentofacial structures.<sup>1,8,9</sup>

CBCT offers images of the labial/buccal and lingual bone plates, which are not apparent in conventional two-dimensional x-rays due to image superimposition.<sup>4</sup> Tooth movements in the buccolingual direction may cause bone dehiscence, as documented in studies involving animals and humans.<sup>17,18</sup> That constitutes a concern regarding the long-term periodontal integrity. Moreover, many patients, especially adults, may exhibit bone dehiscence prior to orthodontic treatment, which requires the orthodontist to plan more parsimonious dental movements.<sup>6,19</sup> Facial type has an effect on the thickness of the alveolar bone. Patients with a horizontal growth pattern have a greater buccolingual dimension of the alveolar ridge in comparison to hyperdivergent patients.<sup>6</sup> Thus, the morphology of the alveolar bone is one of the limiting factors of orthodontic movements.<sup>6</sup>

Previous studies have validated CBCT for quantitative analyses, demonstrating its highly precise measurements.<sup>2</sup> Measurement precision is related to the resolution of the image.<sup>11</sup> The spatial resolution of CBCT, in turn, depends upon the voxel dimension, which is the lowest image unit. A smaller voxel dimension leads to greater image resolution,<sup>14</sup> but also a higher dose of radiation.<sup>3</sup>

A number of studies have demonstrated the precision of linear measurements performed on CBCT images.<sup>7,10,11,12,15</sup> However, the influence of the voxel dimension on measurement precision of delicate structures, such as the buccal

and lingual bone plates, has yet to be demonstrated. Thus, the aim of the present study was to assess and compare the reproducibility of buccal and lingual bone plate thickness measurements in CBCT images using different image acquisition protocols with variations in the voxel dimension.

## MATERIALS AND METHODS

Twelve dried human mandibles with permanent dentition were selected from the Anatomy Department of the Bauru Dental School, Universidade de São Paulo, Brazil. CBCT scans were performed on each specimen using the i-CAT Cone-Beam 3-D Dental Imaging System (USA). Each mandible was embedded in a cube of no. 7 dental wax with water and detergent in order to simulate the density of the soft tissue. The base of the mandible was directly supported on the floor of the box and parallel to the ground. The following image acquisition protocols were used for each specimen:

1. Protocol 1: Field of view (FOV) of 8 cm, 120 kVp, 36.12 mAs, 0.2-mm voxel, 40-second scan time
2. Protocol 2: FOV of 8 cm, 120 kVp, 18.45 ma, 0.3-mm voxel, 20-second scan time
3. Protocol 3: FOV of 8 cm, 120 kVp, 18.45 ma, 0.4-mm voxel, 20-second scan time

The difference between protocols was essentially the voxel dimension, which is the smallest unit of the tomographic image. Thirty-six CBCT scans were performed, composing the overall sample.

Measurements were made using the i-CAT Viewer software. On the multiplanar reconstruction screen, the coronal section showing the right mental foramen was selected (Fig 1). On this section, the cursor representing the axial section was positioned on the superior border of the foramen. This cursor was then moved an average of 12 mm toward the occlusal direction, remaining in the level of the dentoalveolar region (Fig 1).

Due to the variation in the morphology of the mandibles analyzed, the cursor was moved more or less than 12 mm on some specimens in order to reach the region between the middle and apical thirds of the tooth roots.

On the axial section, the thickness of the labial/buccal and lingual bone plates was measured on all permanent teeth (Fig 2). The measurement extended from the external limit of the root to the external limit of the cortical bone, perpendicular to the contour of the dental arch on both sides (Fig 3).

The measurements were performed by two previously calibrated examiners. The first examiner repeated the measurements after an interval of at least 15 days. Statistical analysis involved the calculation of mean and standard deviation values of the labial/buccal and lingual bone plate thickness measurements for each tooth group (incisors, canines, premolars and molars). Paired t-tests were used for the intra-examiner comparison and the independent t-tests were used for the inter-examiner comparison, with the significance level of 5%.

## RESULTS

Table 1 displays the mean and standard deviation values for the measurements of labial/buccal and lingual bone plate thickness, along with the results of the intra-examiner comparison. There were statistically significant differences between the first and the second measurements for a single area using the 0.2-mm voxel protocol (buccal canine surface), for two areas using the 0.3-mm voxel protocol (lingual surface of incisors and canines) and for a single area using the 0.4-mm voxel protocol (lingual surface of incisors).

Table 2 shows the mean and standard deviation values for the measurements of buccal and lingual bone plate thickness, along with the results of the inter-examiner comparison. No statistically significant differences were found between the measurements of the two examiners.

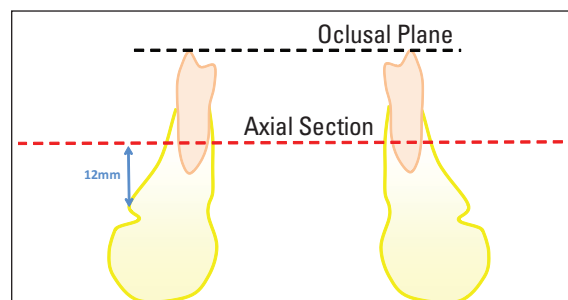


FIGURE 1 - Frontal reconstruction showing the right mental foramen used as reference to define the axial section for taking the measurements. The axial section passing an average of 12 mm above the superior border of the right mental foramen was used.

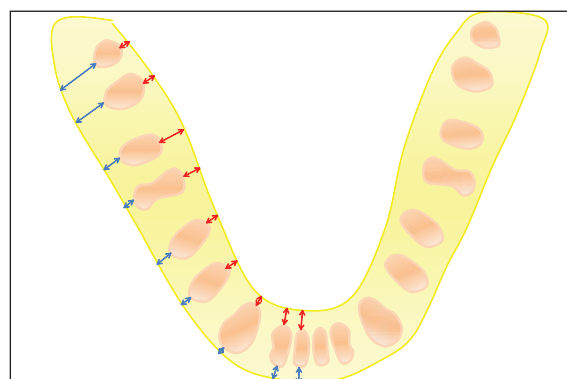


FIGURE 2 - Schematic representation of buccal and lingual bone plate thickness measurements in the selected axial section.



FIGURE 3 - Buccal and lingual bone plate thickness measurements in the axial section of one specimen (0.2-mm voxel).

TABLE 1 - Intra-examiner comparison for buccal and lingual bone plate thickness measurements (in millimeters) on CBCT images with voxel dimensions of 0.2, 0.3 and 0.4 mm.

| 0.2-MM VOXEL |   |                             |      |                             |      |            |       |       |
|--------------|---|-----------------------------|------|-----------------------------|------|------------|-------|-------|
|              |   | 1 <sup>st</sup> measurement |      | 2 <sup>st</sup> measurement |      | Difference | T     | P     |
|              |   | Mean                        | SD   | Mean                        | SD   |            |       |       |
| <b>I</b>     | B | 0.72                        | 0.38 | 0.73                        | 0.37 | 0.01       | 0.50  | 0.61  |
|              | L | 1.13                        | 0.48 | 1.00                        | 0.42 | -0.13      | -1.54 | 0.13  |
| <b>C</b>     | B | 0.44                        | 0.31 | 0.51                        | 0.27 | 0.07       | 2.46  | 0.02* |
|              | L | 1.12                        | 0.56 | 1.17                        | 0.53 | 0.05       | 1.03  | 0.31  |
| <b>PM</b>    | B | 0.43                        | 0.36 | 0.42                        | 0.31 | -0.01      | -0.24 | 0.81  |
|              | L | 1.36                        | 0.92 | 1.33                        | 0.98 | -0.03      | -0.70 | 0.48  |
| <b>M</b>     | B | 0.17                        | 0.31 | 0.21                        | 0.38 | 0.04       | 0.85  | 0.40  |
|              | L | 0.13                        | 0.30 | 0.06                        | 0.18 | -0.07      | -1.74 | 0.10  |
| 0.3-MM VOXEL |   |                             |      |                             |      |            |       |       |
|              |   | 1 <sup>st</sup> measurement |      | 2 <sup>st</sup> measurement |      | Difference | T     | P     |
|              |   | Mean                        | SD   | Mean                        | SD   |            |       |       |
| <b>I</b>     | B | 0.82                        | 0.44 | 0.79                        | 0.41 | -0.03      | -0.58 | 0.56  |
|              | L | 1.17                        | 0.49 | 0.97                        | 0.48 | -0.20      | -4.52 | 0.00* |
| <b>C</b>     | B | 0.56                        | 0.31 | 0.55                        | 0.20 | -0.01      | -0.05 | 0.95  |
|              | L | 1.30                        | 0.66 | 1.07                        | 0.64 | -0.23      | -3.68 | 0.00* |
| <b>PM</b>    | B | 0.55                        | 0.41 | 0.56                        | 0.43 | 0.01       | 0.17  | 0.86  |
|              | L | 1.37                        | 1.04 | 1.38                        | 1.00 | 0.01       | 0.26  | 0.79  |
| <b>M</b>     | B | 0.05                        | 0.14 | 0.07                        | 0.23 | 0.02       | 1.00  | 0.33  |
|              | L | 0.05                        | 0.23 | 0.04                        | 0.16 | -0.01      | -1.00 | 0.33  |
| 0.4-MM VOXEL |   |                             |      |                             |      |            |       |       |
|              |   | 1 <sup>st</sup> measurement |      | 2 <sup>st</sup> measurement |      | Difference | T     | P     |
|              |   | Mean                        | SD   | Mean                        | SD   |            |       |       |
| <b>I</b>     | B | 0.84                        | 0.38 | 0.76                        | 0.33 | -0.08      | -1.21 | 0.23  |
|              | L | 1.04                        | 0.42 | 0.75                        | 0.38 | -0.29      | -4.60 | 0.00* |
| <b>C</b>     | B | 0.64                        | 0.35 | 0.62                        | 0.23 | -0.02      | -0.21 | 0.82  |
|              | L | 1.07                        | 0.50 | 1.15                        | 0.61 | 0.08       | 0.99  | 0.33  |
| <b>PM</b>    | B | 0.49                        | 0.40 | 0.46                        | 0.42 | -0.03      | 0.43  | 0.66  |
|              | L | 1.14                        | 1.14 | 1.16                        | 1.11 | 0.02       | 0.34  | 0.73  |
| <b>M</b>     | B | 0.06                        | 0.16 | 0.07                        | 0.19 | 0.01       | 1.00  | 0.33  |
|              | L | 0.13                        | 0.42 | 0.14                        | 0.34 | 0.01       | 0.22  | 0.82  |

I: incisors; C: canines; PM: premolars; M: molars; B: buccal bone plate; L: lingual bone plate; \* p < 0.05.

## DISCUSSION

Considering the increasing applicability of CBCT in Dentistry, it is very important to determine an image acquisition protocol capable of providing a three-dimensional view with the appropriate resolution to measure small structures,

such as buccal and lingual bone plates. A smaller voxel dimension leads to greater spatial resolution of the image, but also emits a greater amount of radiation.<sup>3</sup> In other words, the voxel dimension set during the exam is directly related to the radiation dose to which the patient is

TABLE 2 - Inter-examiner comparison for buccal and lingual bone plate thickness measurements (in millimeters) on CBCT images with voxel dimensions of 0.2, 0.3 and 0.4 mm.

| 0.2-MM VOXEL |   |                             |      |                             |      |            |       |      |
|--------------|---|-----------------------------|------|-----------------------------|------|------------|-------|------|
|              |   | 1 <sup>st</sup> measurement |      | 2 <sup>st</sup> measurement |      | Difference | T     | P    |
|              |   | Mean                        | SD   | Mean                        | SD   |            |       |      |
| <b>I</b>     | B | 0.72                        | 0.40 | 0.77                        | 0.40 | 0.05       | -0.53 | 0.59 |
|              | L | 1.13                        | 0.48 | 1.13                        | 0.45 | 0.00       | -0.01 | 0.98 |
| <b>C</b>     | B | 0.44                        | 0.31 | 0.57                        | 0.29 | 0.13       | -1.38 | 0.17 |
|              | L | 1.12                        | 0.56 | 1.33                        | 0.59 | 0.21       | -1.17 | 0.24 |
| <b>PM</b>    | B | 0.43                        | 0.36 | 0.54                        | 0.32 | 0.11       | -1.44 | 0.15 |
|              | L | 1.36                        | 0.92 | 1.46                        | 1.04 | 0.10       | -0.42 | 0.67 |
| <b>M</b>     | B | 0.17                        | 0.31 | 0.24                        | 0.44 | 0.07       | -0.48 | 0.62 |
|              | L | 0.13                        | 0.30 | 0.10                        | 0.29 | -0.03      | 0.26  | 0.79 |
| 0.3-MM VOXEL |   |                             |      |                             |      |            |       |      |
|              |   | 1 <sup>st</sup> measurement |      | 2 <sup>st</sup> measurement |      | Difference | T     | P    |
|              |   | Mean                        | SD   | Mean                        | SD   |            |       |      |
| <b>I</b>     | B | 0.82                        | 0.44 | 0.86                        | 0.46 | 0.04       | -0.39 | 0.69 |
|              | L | 1.17                        | 0.49 | 1.19                        | 0.54 | 0.02       | -0.17 | 0.85 |
| <b>C</b>     | B | 0.56                        | 0.31 | 0.62                        | 0.33 | 0.06       | -0.59 | 0.55 |
|              | L | 1.30                        | 0.66 | 1.33                        | 0.60 | 0.03       | -0.13 | 0.89 |
| <b>PM</b>    | B | 0.55                        | 0.41 | 0.56                        | 0.39 | 0.01       | -0.09 | 0.92 |
|              | L | 1.37                        | 1.04 | 1.55                        | 1.11 | 0.18       | -0.70 | 0.48 |
| <b>M</b>     | B | 0.05                        | 0.14 | 0.14                        | 0.41 | 0.09       | -0.85 | 0.40 |
|              | L | 0.05                        | 0.23 | 0.05                        | 0.23 | 0.00       | 0.00  | 1.00 |
| 0.4-MM VOXEL |   |                             |      |                             |      |            |       |      |
|              |   | 1 <sup>st</sup> measurement |      | 2 <sup>st</sup> measurement |      | Difference | T     | P    |
|              |   | Mean                        | SD   | Mean                        | SD   |            |       |      |
| <b>I</b>     | B | 0.84                        | 0.38 | 0.94                        | 0.37 | 0.10       | -1.10 | 0.27 |
|              | L | 1.04                        | 0.42 | 0.96                        | 0.43 | -0.08      | 0.81  | 0.41 |
| <b>C</b>     | B | 0.64                        | 0.35 | 0.68                        | 0.33 | 0.04       | -0.43 | 0.66 |
|              | L | 1.07                        | 0.50 | 1.17                        | 0.61 | 0.10       | -0.56 | 0.57 |
| <b>PM</b>    | B | 0.46                        | 0.40 | 0.43                        | 0.41 | -0.03      | 0.33  | 0.73 |
|              | L | 1.14                        | 1.14 | 1.23                        | 1.65 | 0.09       | -0.33 | 0.73 |
| <b>M</b>     | B | 0.06                        | 0.16 | 0.03                        | 0.14 | -0.03      | 0.45  | 0.65 |
|              | L | 0.13                        | 0.42 | 0.15                        | 0.44 | 0.02       | -0.14 | 0.88 |

I: incisors; C: canines; PM: premolars; M: molars; B: buccal bone plate; L: lingual bone plate; \* p < 0.05.

submitted during the procedure. Thus, before selecting the image acquisition protocol, it is necessary to determine its cost-benefit ratio based on the ALARA principle (as low as reasonably achievable dose of radiation), in which the professional chooses the scanning protocol with the

lowest possible radiation dose, but with sufficient resolution for the identification of the structures to be assessed.

CBCT technology is very recent and the literature offers few investigations for the study of its reproducibility related to the image

acquisition protocol. Thus, the aim of the present study was to compare the reproducibility of thickness measurements of the buccal and lingual bone plates of permanent teeth in CBCT images with different voxel dimensions (0.2, 0.3 and 0.4 mm). The results revealed statistically significant differences in the intra-examiner comparison in some regions of the anterior teeth (Table 1). This corroborates the findings of previous studies. Tsunori et al<sup>16</sup> have measured the buccal, lingual and basal cortical bone thickness as well as the buccolingual width and height of the alveolar ridge using CBCT of 39 dry skulls and found few significant differences between the first and second measurements by a single examiner.<sup>16</sup>

Mol and Balasundaram<sup>13</sup> analyzed the precision of measurements of bone dehiscence using CBCT on five dry skulls. The authors compared measurements performed by six examiners using CBCT, conventional radiographs and the anatomic specimens and concluded that CBCT achieved the greatest diagnostic precision of the three methods. However, the authors found that the region of the mandibular anterior teeth showed less precision in comparison to other areas and concluded that the measurement of bone dehiscence in the anterior region is more limited with the NewTom 9000 scanner.<sup>13</sup>

In the present study, significant intra-examiner differences were found in the region of the anterior teeth (incisors and canines) although the differences between the first and second measurements did not surpass 0.30 mm (Table 1). The measurements of the bone plates in the posterior region were highly precise. It is likely that the difference in the reproducibility of the measurements between anterior and posterior teeth is due to the fact that the thickness of the bone plates is thinner in the anterior region compared with the posterior region. A thinner bone plate has less image resolution, decreasing the precision of linear measurements.<sup>14</sup>

This limitation of computed tomography may be due to the property denominated “partial volume averaging”; when the limit between two tissues is in the middle of a voxel, its density corresponds to the average density of the two structures it encompasses.<sup>14</sup> These results are in agreement with those described by Mol and Balasundaram<sup>13</sup>, who found less accuracy in the measurement of buccal bone dehiscence in the anterior region of the mandible in comparison with the posterior region on images generated with the NewTom 9000 scanner. Using helical computed tomography, Fuhrman found that only bone plates with a thickness of less than 0.2 mm were not apparent on the exam.<sup>5</sup> To date, no studies have indicated the least bone plate thickness that can be identified on CBCT images.

In 2008, Loubele et al<sup>10</sup> performed linear measurements of the buccolingual diameter of the alveolar ridge at previously marked points on an human maxilla comparing CBCT with helical CT and found no significant inter-examiner differences. The present study corroborates this finding, as inter-examiner reproducibility was excellent (Table 2).

Based on the results of the present study, the measurement of bone plate thickness proved to have similar reproducibility in the different image acquisition protocols, although the 0.2 mm voxel protocol has produced sharper images than the 0.3 and 0.4 mm voxel protocols. Further studies should be carried out to determine the accuracy of bone plate thickness measurements using CBCT images.

## CONCLUSION

The measurement of buccal and lingual bone plate thickness on CBCT images demonstrated good precision for exams obtained with voxels of 0.2, 0.3 and 0.4 mm. The reproducibility of the measurements in the anterior region of the mandible was more critical than that of the posterior region.

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# Assessment of pharyngeal airway space using Cone-Beam Computed Tomography

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## Abstract

**Introduction:** Evaluation of upper airway space is a routine procedure in orthodontic diagnosis and treatment planning. Although limited insofar as they provide two dimensional images of three-dimensional structures, lateral cephalometric radiographs have been used routinely to assess airway space permeability. Cone-Beam Computed Tomography (CBCT) has contributed to orthodontics with information concerning the upper airway space. By producing three-dimensional images CBCT allows professionals to accurately determine the most constricted area, where greater resistance to air passage occurs. **Objectives:** The purpose of this article is to enlighten orthodontists on the resources provided by CBCT in the diagnosis of possible physical barriers that can reduce upper airway permeability.

**Keywords:** Cone-Beam Computed Tomography. Pharynx. Upper airway space.

## INTRODUCTION

Clinicians and researchers involved in the treatment of dentofacial deformities have sought to elucidate the determinants of facial morphology. The relationship between respiratory pattern disorders and changes in facial morphology has been extensively debated in the literature<sup>1,2</sup> and remains controversial. Conflicting opinions can be divided into two camps: One that considers breathing pattern an important etiological factor in producing the long face syndrome (LFS) and one which believes that LFS expresses an inherited pattern and breathing pattern would act only as an aggravating factor. Currently the prevailing

view is that skeletal morphology is a result of genetically determined growth superimposed by the action of its functional matrix. And, according to this view, the action of soft tissue genotype would continue during growth.

Several factors may be associated with mouth breathing, among which are constriction of the nasal passage, narrow or obstructed nasopharynx, hypertrophic nasal membranes, enlarged turbinates, hypertrophic palatine or pharyngeal tonsils, nasal septal deviation, choanal atresia and tumors in the nose or nasopharynx.

When the size of the nasopharyngeal space appears reduced—either by the presence of adenoids

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or due to the narrow anatomical structure of the nasopharynx—the resulting functional imbalance can impact craniofacial growth and development, reflected in a tendency toward vertical facial growth, which leads to the stereotype of the adenoid face or long face syndrome (LFS). This syndrome is characterized by lip incompetence, underdeveloped nostrils, maxillary atresia with the presence of deep palate and posterior crossbite, increased anterior inferior facial height, increased gonial angle and mandibular retrognathism.<sup>2,3,4</sup> Because LFS is a multifactorial syndrome it is not always easy to diagnose and, to be successful, treatment requires a multidisciplinary approach.

The upper airway space can be described in terms of height, width and depth. It is known that the limiting factor determining respiratory capacity is a reduced cross-sectional air passage area<sup>5,6</sup> anywhere in the pharyngeal path.

Over the past century extensive research<sup>1,7-10</sup> was conducted to elucidate the relationship between craniofacial morphology and breathing pattern. Most studies were based on lateral cephalometric radiographs because such radiographs are part of the records used for proper planning of orthodontic treatment. Although it can provide a wealth of information, cephalometric radiography is limited in the sense that it produces two-dimensional images (height and depth) of a three-dimensional structure, therefore hindering accurate assessment of the size and complexity of this structure.

Cone-Beam Computed Tomography has made it possible to acquire 3D image volumes of all structures in the maxillofacial complex. With the use of specific software and acquisition protocols based on individual needs, these digital volumetric scans can be turned into multiple planar view images (axial, coronal and sagittal). Software tools also allow bone structure measurements to be obtained as well as 3D assessment of soft tissues, and the shapes, volumes and features of the face and upper airways.

Currently, assessment of upper airway space is a routine procedure in orthodontic diagnosis and treatment planning. Cone-Beam CT equipment has become more efficient, reducing acquisition time and developing specific software, which provides improved image processing and analysis of three-dimensional images of the structures comprised in the maxillofacial region. This information may provide clinical benefits and a foundation for rational decision-making regarding the appropriate treatment to be administered to growing individuals with decreased pharyngeal airway space in order to minimize the etiological influence of breathing pattern on the development of malocclusion.

## ASSESSING UPPER AIRWAY SPACE

Understanding the morphology and function of the skeletal structures and soft tissue that make up the upper airway space is essential for an understanding of the physiology and pathogenesis of obstruction. Assessment is complex however because of its location, which does not allow direct visualization. Different forms of image-based exams have been used to evaluate the upper airway space, skeletal structures and adjacent soft tissues. Each method has inherent advantages and disadvantages, and there is no consensus regarding the gold standard procedure for evaluation. Among the methods used are acoustic rhinometry, fluoroscopy, nasopharyngoscopy, MRI, cephalometry and tomography.<sup>11</sup>

Over the last century a large number of tests were suggested for evaluation of upper airway space from lateral radiographs using linear and angular measurements, and sagittal areas between cephalometric landmarks.<sup>12-15</sup> These points are defined by superimposing projections of different structures.

In a comparison between CT and lateral cephalometric radiographs in assessing the pharyngeal airway space, Abouda et al<sup>16</sup> found a significant correlation between sagittal area obtained from

the radiographs and the volume obtained from CBCT, although the latter showed greater variability in patients with similar airway space in lateral cephalometric radiographs. This is expected since cephalometric analysis of conventional lateral radiographs only measures pharynx height and depth and therefore does not allow cross-sectional (i.e., width) examination.

Clinically, orthodontists can assess obstructed airway space in conventional cephalometric radiography. When this obstruction is considered severe, the patient is referred to an otolaryngologist. It is imperative that more accurate diagnostic tools be employed that inform otolaryngologists and orthodontists on the proper procedures to be adopted, thereby averting obstacles in the air passage that can affect dentition, speech, and craniofacial development.

### ACQUIRING CBCT SCANS FOR AIRWAY ASSESSMENT

CT examinations for assessing the airways have a specific image acquisition protocol. Patients must be sitting, in maximum intercuspation, with the midsagittal plane perpendicular to the horizontal plane and Frankfort plane parallel to the horizontal plane. An extended field of view (EFOV) of 17X 23 cm should be used; 0.25 mm voxel size; 40 seconds. Upon completion of the CBCT examination, some manipulations can be performed using the software provided by the scanner manufacturer. The raw image (raw data) is reconstructed to enable visualization of 3D reconstruction and multiple planar cross-sections. These two-dimensional images of the pharynx can be examined from any direction. The most commonly used are sagittal, coronal and axial (Fig 1).

Images can be better observed using specific tools. Images can be rotated and magnified to allow better assessment of a given region. Images can also be rendered from any angle, and in any scale or position. Different filters can be applied,

allowing differentiation between tissues of different densities and the use of transparency, which enables hard tissue to be viewed through soft tissue. A linear measurement tool is also available, which can measure height, width and depth of any portion of the pharynx (Fig 2).

These images can also be converted to DICOM (Digital Imaging and Communications in Medicine) files that can be exported to other 3D assessment software, which in turn enables a wider range of resources useful in airway space evaluation.

### VIEWING THE UPPER AIRWAY SPACE USING CONE-BEAM COMPUTED TOMOGRAPHY

Software is available for assessment of the upper airway space, such as InVivoDental, 3dMD-vultus and Dolphin Imaging.<sup>17</sup>

Dolphin Imaging program version 11.0 is an airway space analysis tool that not only enables the evaluation of the shape and contour of the upper airway space in three dimensions, but also calculates volume, sagittal area and the smallest predefined cross-sectional area in the airway space. It provides segmentation of the upper airway space through images that can be rotated and magnified. The program features two threshold filters: For hard tissue and soft tissue, displaying the airway space together with skeletal tissue or separately.

To assess images in the program, one must first import the files in DICOM single-file format from CBCT images. Once imported, the three-dimensional image of the patient's head must be oriented in the virtual space in like manner as in the cephalostat, i.e., so that the Frankfort horizontal plane is parallel to the axial plane, the midsagittal plane coincides with the midline of the individual, and the coronal plane is oriented in such a way that it crosses beyond the inferior border of the left and right orbits (Figs 3 and 4). In asymmetry cases, orientation should be as close as possible to these reference planes. This virtual orientation allows the head to be properly rotated so that bilateral structures are coincident.<sup>17</sup>



FIGURE 1 - Opening screen of the XoranCat software provided by the manufacturer of the i-CAT scanner, showing the multiple planar views (MPV) (sagittal, coronal and axial) obtained from volumetric reconstruction. The cursor, represented by two intersecting lines, indicates the precise location in virtual space, making it possible to go through these two-dimensional images of the pharynx in any direction.



FIGURE 2 - XoranCat software screen, where anatomy can be evaluated and measurements of the pharyngeal structure performed in any slice.

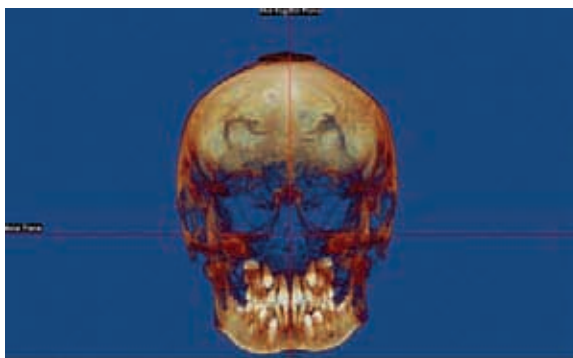


FIGURE 3 - Dolphin 3D software object orientation screen. In frontal view, the midsagittal plane should coincide with the individual's median plane, and the axial plane must be tangent to the infraorbital rim.

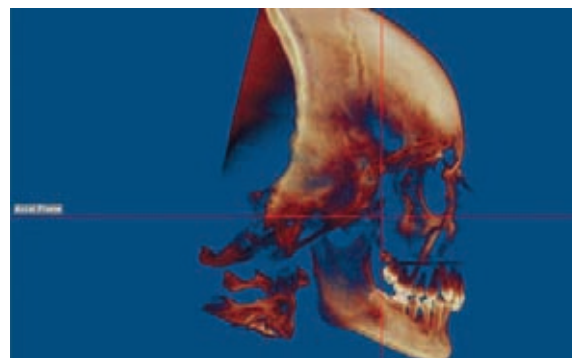


FIGURE 4 - Dolphin 3D software object orientation screen. In the lateral view of reconstruction orientation, the axial plane must coincide with the Frankfort plane.

Once a tool is selected for evaluating the airway space it is necessary to define, in the sagittal cross-section, the area of interest in the airway space. The program automatically provides the area and total volume of any predefined region as well as location and dimensions of the most constricted airway space area (Fig 5).

### CREATING TWO-DIMENSIONAL PROJECTIONS FROM A THREE-DIMENSIONAL IMAGE

Most of these cephalometric landmarks created for two-dimensional images cannot be viewed or are difficult to trace on the curved surface of three-

dimensional images. Currently, for ethical reasons, longitudinal growth records are forbidden, and there are as yet no normative standards for these three-dimensional dimensions. However, the parameters established for two-dimensional images can be compared with three-dimensional records.<sup>18,19</sup> Softwares have been developed using algorithms that allow projections to be generated similarly to radiographs. These projections can show morphological changes in maxillofacial structures in the 3 orthogonal planes, which might contribute to air passage obstruction.

To create these radiographic projections from a volumetric CT using Dolphin 3D Imaging program version 11.0 (Dolphin Imaging and

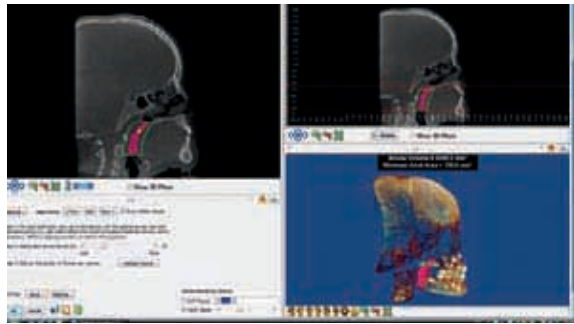


FIGURE 5 - Using Dolphin Imaging Program version 11.0 airway space assessment tool one can obtain the sagittal area, volume and smallest cross-sectional area of a predefined pharyngeal airway space. To this end, one must choose the area of interest by moving the markers that define the green line, starting from the sagittal cross-section.. The yellow marker is then placed within the airway space, and the program performs the calculation of sagittal area and volume. In order to obtain the smallest cross-sectional area, one should drag the red reference lines delimiting the area to be evaluated.

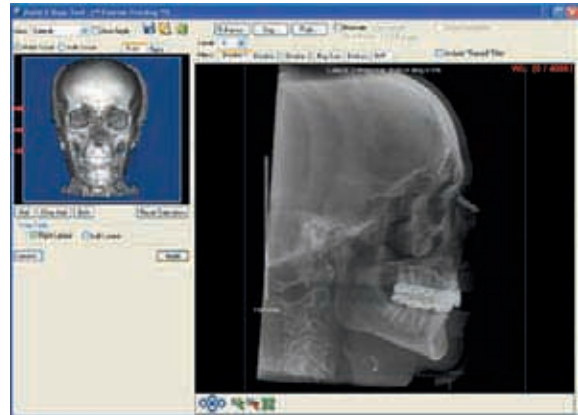


FIGURE 6 - Dolphin Imaging program's radiograph creation tool. One must choose the type of projection desired. In this case, a right lateral projection was selected with the application of Dolphin filter 1, which allows better definition of skeletal structures.



FIGURE 7 - Two different types of filters available in version 11.0 of Dolphin Imaging program, used to obtain lateral projections (A) Dolphin Filter 1 provides better visualization of skeletal structures, ideal for use in cephalometric analysis of skeletal tissue (B) Ray-sum filter, ideal for disclosure of the upper airway space.

Management Solutions, Chatsworth, CA), it is first necessary that the image be properly oriented. In the radiographic projection construction module, the program lets one choose an orthogonal projection or perspective. The upper and lower limits of the image must be set, as well as its thickness. Once the projection has been created, different types of display filters can be applied. Ray-sum is the filter that provides the best visualization of upper airway space (Figs 6 and 7).

The program also features a measurement tool and cephalometric analysis tool, providing

linear and angular measurements in these two-dimensional images, which enable the evaluation of craniofacial factors that may contribute to the obstruction of the upper airway space (retrognathism, crossbite, asymmetries, hypertrophic tonsils).

## ASSESSING MORPHOLOGY IN 3D RECONSTRUCTIONS

3D reconstructions also allow assessment of airway space morphology. Resistance to air flow is related to airway space size and shape. Airway

space can be large, but a winding path can offer considerable effective resistance to air flow and affect respiratory function. Studies using CBCT have established a correlation between airway space and facial pattern. The oropharyngeal airway space of individuals with Class III anteroposterior skeletal pattern appears to be wider and more flattened,<sup>20</sup> displaying a more vertical orientation relative to the sagittal plane.<sup>17</sup> Individuals with Class II anteroposterior skeletal pattern, on the other hand, showed a more anterior superior airspace.<sup>17</sup> Abransom et al<sup>21</sup> also evaluated changes in the shape of the pharynx and argued that with age the airway space becomes wider in the transverse direction and therefore more elliptical. Ogawa et al<sup>23</sup> associated the shape of the airway space with Obstructive Sleep Apnea Syndrome (OSAS). OSAS patients had a more elliptical or concave air space, unlike non-OSAS individuals, who exhibited a more rounded or square shape.

#### UPPER AIRWAY SPACE ASSESSMENT AND OSAS

Obstructive Sleep Apnea Syndrome (OSAS) is a disease characterized by the collapse of the pharyngeal airway space resulting in repeated

episodes of air passage obstruction, decreased oxygen saturation and sleep disruption. The anatomy of the upper airway space seems to play a critical role in the pathogenesis responsible for upper airway space collapse in OSAS patients. Collapse may occur at different spots in the upper airway space of OSAS patients. The retroglossal and retropalatal regions are most frequently involved.<sup>22</sup> It is known that the pharynx is bounded by a musculomembranous wall supported by a skeletal framework, so that the location of the most constricted area depends on the relationship between craniofacial skeletal structures and surrounding soft tissue. Therefore, the tonsils and adenoids, soft palate, uvula, tongue and lateral pharyngeal walls are soft tissue structures crucial in defining the upper airway space. Moreover, the mandible and hyoid bone are the major skeletal determinants of the airway space. Any abnormality in these structures can affect the airway space and cause SAOS.<sup>22</sup>

SOAS has a multifactorial etiology involving among others a reduced upper airway space, nasal cavity obstruction, distributed body fat mass and muscle tone. The upper airway space is significantly constricted in OSAS compared with non-OSAS

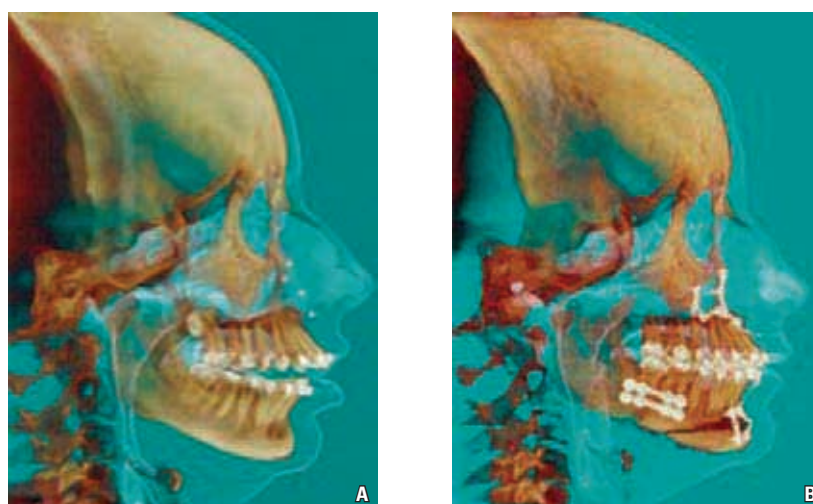


FIGURE 8 - CT images obtained before (A) and after surgery (B) showing changes made in the airway space (available at [www.dolphinimaging.com](http://www.dolphinimaging.com)).

patients, although the most constricted region varies from OSAS patient to OSAS patient.

Treatment of OSAS is primarily geared towards airway space maintenance, which is achieved with the use of a ventilation therapy device named CPAP—continuous positive airway pressure—which provides a constant air flow while keeping the airways open.

Secondarily, treatment seeks to make the airway space less likely to collapse. Increased pharyngeal airway space can be obtained in a reversible manner, with the use of removable appliances, or permanently, with surgery. When secondary treatments are needed, the most constricted oropharyngeal area must be identified in order to determine an appropriate treatment solution. To be able to assess upper airway space morphology, determine the degree and location of constriction and evaluate the effectiveness of treatment, examinations such as nasopharyngoscopy with Muller maneuver, fluoroscopy, cephalometry, rhinomanometry, MRI and CT have been employed.

Cephalometric studies have shown that individuals with OSAS have smaller, retruded mandibles, narrowing of the posterior airway space, larger tongues, more inferiorly positioned hyoid bone and repositioned maxilla when compared with non-OSAS individuals<sup>23</sup>. Although this information is valuable, it does not enable clinicians to have access to the complex morphology of the upper airway space.

Because CBCT is three-dimensional, it allows clinicians to assess the airway space and surrounding structures, and determine three-dimensional naso-, oro- and hypopharyngeal measurements, such as the most constricted area, volume and the smallest anteroposterior and lateral pharyngeal dimensions in OSAS patients. One can also evaluate changes that might potentially be induced by the treatment modality itself, and identify which patients would benefit from such treatment (Fig 9). Haskell et al<sup>24</sup> asserted that it was possible to predict the amount of increase in total volume and

in the cross-sectional area of the oropharynx obtained through appliance-induced mandibular advancement, since the most constricted area could move to any higher or lower point in the pharynx. They argued therefore that CT evaluation would be necessary prior to installing the appliance to determine whether the patient would benefit from its use. They further stressed that, in treating OSAS, it is more important to achieve improvement in the most constricted area than to increase the volume of the pharynx as a whole.

#### CLINICAL IMPLICATIONS AND LIMITATIONS OF CBCT IN ASSESSING THE UPPER AIRWAY SPACE

Besides the anatomy of the skeletal and soft tissue, airway space depends on some dynamic variables such as lung volume, intraluminal and extraluminal pressure, muscle tone and head position.<sup>21</sup> Since the soft palate and the tongue are structures composed of soft tissue with no rigid support, they are greatly affected by gravitational forces. Therefore, in CT scans and other examinations performed in the supine position, these structures move further toward the posterior pharyngeal wall, which results in changes in the dimensional measurements of the upper airway space, as demonstrated by Lowe et al,<sup>25</sup> Huang et al,<sup>26</sup> Abramson et al<sup>21</sup> and Ono et al.<sup>27</sup> Thus, scan results obtained with the patient sitting cannot be extrapolated or even directly compared to those obtained with the individual in the supine position. The latter position is recommended for individuals with OSAS. Lohse et al<sup>28</sup> suggest that in assessing OSAS patients a modification be made to the CBCT acquisition technique, namely, removing the chin positioner so that the patient can hold their head in a natural position.

Airway space size and morphology vary when the patient inhales or exhales.<sup>11</sup> CT scan acquisition time is around 20-40 seconds, too long for the individual to control their respiratory movements. Hopefully, in the near future CBCT acquisition



FIGURE 9 - CT images obtained with i-CAT software, illustrating the increased air space obtained using a mandibular advancement device in the treatment of OSAS.

time will be faster in order to prevent patient movements (breathing, swallowing and involuntary movements) from interfering with the results.

## CONCLUSIONS

Although no normative data are available regarding information gained through CBCT, a

host of scientific studies have been conducted for this purpose, which leads us to believe that soon CBCT will be able to guide orthodontic diagnosis and planning by enlightening clinicians about the effects caused by mechanotherapy applied to the airway space and the consequences of these effects.

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# Mixed-dentition analysis: Tomography versus radiographic prediction and measurement

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## Abstract

**Objective:** The aim of this study was to evaluate the method for mixed-dentition analysis using Cone-Beam Computed Tomography for assessing the diameter of intra-osseous teeth and compare the results with those obtained by Moyers, Tanaka-Johnston, and 45-degree oblique radiographs. **Methods:** Measurements of mesial-distal diameters of erupted lower permanent incisors were made on plaster cast models by using a digital calliper, whereas assessment of the size of non-erupted permanent pre-molars and canines was performed by using Moyer's table and Tanaka-Johnston's prediction formula. For 45-degree oblique radiographs, both canines and pre-molars were measured by using the same instrument. For tomographs, the same dental units were gauged by means of Dolphin software resources. **Results:** Statistic analysis revealed high agreement between tomographic and radiographic methods, and low agreement between tomographs and other methods being evaluated. **Conclusion:** Cone-Beam Computed Tomography was accurate for mixed-dentition analysis in addition to presenting some advantages over compared measurement methods: observation and measurement of intra-osseous teeth individually with the possibility, however, to view them from different prospects and without superimposition of anatomical structures.

**Keywords:** Mixed dentition. Cone-Beam Computed Tomography. 45-degree oblique radiograph. Plaster cast.

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## INTRODUCTION

The majority of malocclusions involve problems related to an imbalance between the dimensions of teeth and bone base.<sup>1</sup> However, there is a short period of dentition development in which lower arch crowding is considered acceptable. When the lower permanent lateral incisor erupts into the oral cavity, an additional space of 1.6 mm, on average, is needed to allow correct alignment of all anterior teeth.<sup>2,3</sup> In many cases, this dental crowding is transient and tends to resolve spontaneously due to an increase in intercanine distance, migration of deciduous canines towards primate spaces, and a more labial position of permanent incisors in relation to their deciduous antecessors.<sup>4</sup> During this phase, it is important to analyse the mixed dentition to estimate the diameter of non-erupted permanent teeth and to assess whether dental volume is in accordance with the bone base size.

Several methods have been developed aiming for this goal, and they can be briefly grouped into three categories: Those based on regression equations, those using radiographs, and those combining these both methods.<sup>5</sup>

Among them, Moyers' analysis has been largely used because of its simplicity.<sup>6</sup> Based on the fact that permanent teeth have highly proportional dimensions in a same individual, Moyers<sup>4</sup> proposes a table with values for permanent canines and pre-molars not yet erupted, using as reference the diameter of permanent lower incisors.

Tanaka-Johnston's formula is a practical manner of obtaining the same information, since no table is needed. The values for pre-molars and canines of an hemi-arch are defined by adding one-half of the mesial-distal diameter of the permanent lower incisors to a pre-determined value regarding both lower and upper hemi-arches, respectively, 10.5 mm and 11.0 mm.<sup>7</sup>

Oblique radiographs at 45-degree angle have been cited as one of the most reliable methods

for obtaining diameters of non-erupted teeth because it allows unilateral identification and clear visualization of posterior teeth.<sup>8-13</sup> This method has a small magnification factor, little distortion compared to the lateral cephalometric radiograph<sup>10</sup> and tooth size is effectively measured and not estimated.

One of the possibilities of using computed tomography in orthodontics is the exact measurement of the mesial-distal diameter of teeth for evaluation of tooth-bone discrepancies<sup>14</sup>. Three-dimensional views generated by computed tomographs allow rapid and efficient occlusion analysis, particularly in patients with mixed dentition as such images show erupted teeth as well as those erupting or developing. In addition, their relative position and root formation are also provided.<sup>15</sup>

Due to the decrease in arch length, particularly the lower one, during transition from mixed to permanent dentition, the mixed-dentition analysis is usually applied to the mandible.<sup>16</sup>

In the present study, the main objective was to compare a new method for mixed-dentition analysis, which was based on computed tomographic measurements, to those traditionally employed such as Moyers' analysis, Tanaka-Johnston prediction table and 45-degree oblique radiography.

## MATERIALS AND METHODS

The sample consisted of 30 healthy patients of both genders coming from different ethnic and social backgrounds who had been enrolled in the post-graduation orthodontics program for dental treatment at the Federal University of Rio de Janeiro Dental Faculty. On clinical examination, all presented erupted permanent incisors and first molars, deciduous canines, deciduous first and second molars. These teeth had no clinically observed caries, no restorations, no loss of interproximal dental substance, no coronal fracture, and no other anomaly.



FIGURE 1 - Image of digital calliper used for measurements in plaster cast models, with its tips made of acrylic and stainless steel wire.

Plaster cast models were made from alginate impressions and the diameters of lower permanent incisors were obtained by using a digital calliper with precision of 0.02 mm and repetition precision of 0.01 mm (Starrett, Itu, SP, Brazil). A device was made using acrylic resin and stainless steel wire and then adapted onto the tips of the digital calliper (Fig 1) to facilitate the measurement of tooth size. The maximum dental mesial-distal width was achieved by positioning the tips of calliper at the regions of contact point, parallel to occlusal or incisal surfaces and perpendicular to the tooth long axis. The values regarding the four incisors were added so that Moyers' table could be used at 75% probability level and Tanaka-Johnston's prediction formula applied, whereas the values regarding non-erupted permanent canines and pre-molars were used for prediction.

Oblique radiographs were taken at 45-degree angle during the Dental Radiology and Imaging Specialization Course at the Federal University of Rio de Janeiro (UFRJ). The radiographs of right and left sides of the same patient were taken by using an orthopantomography unit (Rotograph Plus, Villa Sistemi Midicali, Buccinasco MI, Italy). The diameters of intra-osseous teeth appearing on the 45-degree oblique radiographs were also obtained by using a digital calliper. The greatest mesial-distal width of the teeth was determined visually.

Computed tomographs performed with i-CAT scan equipment were imported under DICOM file format by using Dolphin 3D V.11



FIGURE 2 - **A, B**) Tomographic images whose segmentation and translucence were changed, showing **(B)** the possibility of visualization of intra-osseous teeth.

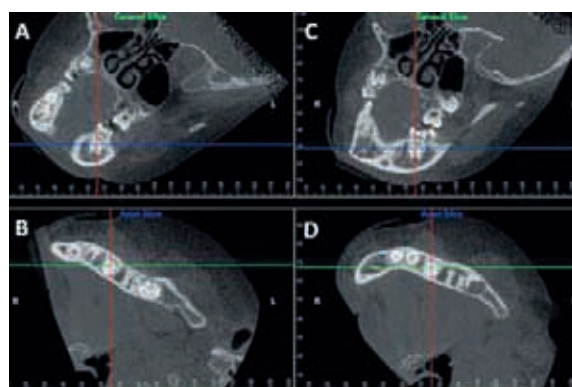


FIGURE 3 - Image of tooth 35 presenting rotation and incorrect long axis in relation to blue and green lines, which represent axial and coronal sections, respectively (**A, B**), and after correction of tooth position in relation to such lines (**C, D**).

software. The measurements of both erupted tooth diameter and arch perimeter were obtained by using tools of this software. Therefore, the long axis of each tooth was corrected in the three planes—axial, coronal, and sagittal (Figs 2 and 3). The technique employed in the measurement of intra-bony teeth in this study had been previously tested to evaluate erupted teeth and was very appropriate. The method using Cone-Beam Computed Tomography to measure tooth diameter could be considered valid.

The research project was reviewed and approved by the Ethic Commission of Institute for Studies in Public Health of the Federal University of Rio de Janeiro.

## RESULTS

In order to determine precision, reliability, and capacity of measurement repetition, ten pairs of plaster cast models, ten 45-degree radiographs, and ten tomographs were randomly selected and then measured twice by the same investigator, with a 10-day interval between both measurements. The intra-class correlation rate was as high as 0.98 for plaster cast models, 0.97 for radiographs, and 0.99 for tomographs, thus indicating reliability of the measurements performed by the investigator.

The descriptive statistics containing mean, standard deviation, minimum and maximum values for the sum of right and left permanent canines and premolars in Cone-Beam Computed Tomography (CBCT), in 45-degree radiographs, in 45-degree radiographs with correction of magnification and derived from Moyers' table and Tanaka-Johnston's formula are represented in Table 1.

The agreement between measurements of non-erupted teeth regarding tomography and those predicted by Moyers' table and Tanaka-Johnston's formula, including the 45-degree oblique radiographs, was evaluated by using both intra-class correlation rate and paired Student's t test at 95% confidence interval ( $p < 0.05$ ). The results revealed high agreement between tomographic and radiographic methods as well as low agreement between tomographs and other methods studied (Table 2).

## DISCUSSION

Imaging diagnosis and study models are very important resources available in orthodontics. Within the context of conventional radiographic techniques, a varied number of exams (periapical, panoramic, telerradiographic, profile, posterior-anterior, occlusal, and 45-degree oblique) are routinely employed for orthodontic evaluation of the craniofacial region. Nevertheless, the conventional radiography is a two-dimensional

TABLE 1 - Descriptive statistical analysis of linear measurements (mm) representing the sum of permanent canines and premolars for right and left sides, performed with Cone-Beam Computed Tomography (CBCT), 45 degree radiographs and 45 degree radiographs with magnification correction and derived from the Moyers table and from Tanaka-Johnston's formula, including mean, standard deviation and minimum and maximum values.

|                           | n  | Mean  | SD   | Minimum | Maximum |
|---------------------------|----|-------|------|---------|---------|
| CBCT                      | 30 | 46.44 | 2.57 | 39.40   | 52.90   |
| Moyers' table             | 28 | 44.62 | 1.42 | 44.62   | 48.60   |
| Tanaka-Johnston's Formula | 29 | 44.07 | 1.47 | 44.07   | 47.62   |
| 45° X-ray                 | 30 | 46.27 | 2.75 | 39.15   | 52.65   |
| 45° X-ray x 0.928         | 30 | 42.93 | 2.58 | 36.26   | 48.83   |

n = size of sample, SD = standard deviation.

TABLE 2 - Results of the statistical analysis used to evaluate agreement between measurements performed with Cone-Beam Computed Tomography, and those derived from the Moyers table and from Tanaka-Johnston's formula, and 45 degree oblique radiographs.

|                           | n  | ICC  | Paired t-test            |                      |
|---------------------------|----|------|--------------------------|----------------------|
|                           |    |      | p value ( $p < 0.05^*$ ) | Mean Difference (mm) |
| Moyers' table             | 28 | 0.35 | 0.000*                   | 2.00                 |
| Tanaka-Johnston's Formula | 29 | 0.41 | 0.008*                   | 1.81                 |
| 45° X-ray                 | 30 | 0.97 | 0.273                    | 0.25                 |
| 45° X-ray x 0.928         | 30 | 0.82 | 0.000*                   | 3.54                 |

n = size of sample.

representation of three-dimensional structures and therefore there are some drawbacks in terms of precision and spatial orientation, size, shape, and relationship between anatomical structures regarding this method.<sup>18</sup> Differently from the radiography, which projects the X-ray exposed objects into one plane, the Cone-Beam Computed Tomography shows the relationships between structures in depth.<sup>14</sup>

Plaster cast models have limitations as well, since they have been traditionally measured manually by means of a calliper. Alternatively, measurements can be made on photocopies, photographs, holograms, and virtual models.<sup>19</sup>

Among some advantages regarding the digital methods in relation to the manual measurement, one can cite shorter procedure time, no need to store study models, and easy access to diagnostic records from anywhere.<sup>6</sup>

The use of Cone-Beam Computed Tomography to evaluate tooth diameter has not been tested. Despite this, other studies<sup>20-24</sup> pointed out such a possibility as quantitative analyses using computed tomography were found to have high accuracy and precision. Measurements made directly on skull and on the tomographic image of the same skull were entirely similar. Precision and reproducibility of the method were confirmed by the presence of very few errors in the measurement repetitions, regardless of intra- and inter-examiner variability.<sup>14</sup>

In the evaluation of values regarding the sum of diameters of intra-osseous teeth, permanent pre-molars, and permanent canines measured on tomographic images and those measured using Moyers' table and Tanaka-Johnston's formula, statistical analysis showed low agreement between both methods. However, studies on medical tomographs of craniofacial region indicated that measurements up to 5% are clinically acceptable,<sup>22</sup> and this figure is higher than that observed in the present study.

In the orthodontic treatment planning, individual variation represents an important factor.<sup>2</sup> All methods for predicting mesial-distal diameter of canine and pre-molars, such as the Moyers' and Tanaka-Johnston's analyses, do not take into account the individuality and then under or over-estimate actual dental dimensions.<sup>16</sup> With the use of Cone-Beam Computed Tomography, teeth are measured instead of being estimated. Tomographic exam of one of the patients revealed the presence of macrodontia and abnormal shape of the second pre-molars. By consulting the Moyers' table or Tanaka-Johnston's formula only, such information would not be taken into account

and the space needed for the patient would be mistakenly predicted as being smaller. In another case, agenesis of second pre-molars was also observed on tomographs during the mixed-dentition analysis. For this patient, with absence of the second premolar, the Moyers' table and Tanaka-Johnston's formula could not be applied for purposes of comparison with the tomographic measurements, because it yields the sum of the canines and first and second premolars. For another, whose sum of measurements of lower incisors was so low that the Moyers' table could not be used, the comparison with the tomographic measurements was also not possible. The sample, therefore, consisted of 29 and 28 patients for the evaluation of tomography measurements with those suggested by the Tanaka-Johnston's formula and Moyers' table, respectively.

In turn, both radiographic and tomographic methods took into account individual variation (each tooth is measured during both exams), and a high agreement between them was observed. With regard to radiography, most cases (29.21%) involved rotated teeth. In this way, Cone-Beam Computed Tomography has some advantages in relation to the 45-degree oblique radiograph. The authors of the present study agree that three-dimensional imaging offers greater potential for quantitative evaluation of the skull and face because points are easily identified and structures are not overlapped. There is also the possibility of moving the image three-dimensionally, which allows visualization of the object at different angles.

Lima and Monnerat<sup>25</sup> in 1992, have proposed correction of the 45-degree oblique teleradiography in order to determine the size of intra-osseous permanent canines and pre-molars. They suggested that measurements of teeth on radiographs should be multiplied by 0.928, thus resulting in high fidelity compared to real measurements.

Interestingly, the radiographic method having image magnification correction did not yield better results than the tomography (Table 2). The teeth measured on tomographs were often greater than those measured on oblique radiographs, and the radiographic magnification correction indeed enhanced such a difference.

According to Bernabé and Flores-Mir<sup>5</sup>, in 2005, the mixed-dentition analysis should present a minimum and known systematic error, allow easy replication by any basically trained operator, be quickly conducted, not require very sophisticated equipment, be directly applied to the mouth, and available for both dental arches. It is also important to emphasize that errors and time regarding the evaluation of the new method tend to be greater during this process of method change. As the examiner proceeds with the procedures and has the opportunity to evaluate more tomographs, less variations between the methods are observed, a finding also reported by Rheude et al<sup>17</sup> in 2005.

The radiation dose of this imaging modality is equivalent to approximately one sixth of that necessary for a medical tomography. In addition, Cone-Beam Computed Tomography is very similar to dental radiographs, providing more reliable and extensive information<sup>14,19,20,21,26-30</sup>. Its modest application is due mainly to the high cost of softwares that allow viewing and editing images, since their acquisition, given the cost of dental radiographs, is financially attractive because the cost of the tomographic scan is equivalent to that of conventional orthodontic documentation<sup>14</sup>. Through the years, the likelihood is

that such softwares become more accessible. The availability of such technology will undoubtedly extend the use and application of 3D images in orthodontics for clinical purposes<sup>23</sup>.

It is difficult to work with probabilities requiring accuracy, since human anatomy has inherent variations. There are several methods aimed to estimate the mesial-distal diameter of canines and pre-molars by means of tables, equations, and radiographs. Obtaining such values as closer to reality as possible by using these measurements is a challenge, since all may fail. The evaluation of the effectiveness of such methods is not meant to approve or reprove them, but to serve as a mechanism to assess how they can produce a reliable diagnosis. Therefore, allied to the prediction methods, a good professional sense should exist in order to elaborate diagnosis more effectively<sup>7</sup>.

## CONCLUSION

Mixed-dentition analysis by the tomographic method is accurate and has some advantages in relation to other evaluated methods. It considers individual variations of dental anatomy, easy identification of points, no superposition of structures, and three-dimensional movement of image, which allows visualization at different angles.

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# Increase in upper airway volume in patients with obstructive sleep apnea using a mandibular advancement device

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## Abstract

**Introduction:** Diagnosis, treatment and monitoring of patients with obstructive sleep apnea syndrome (OSAS) are crucial because this disorder can cause systemic changes. The effectiveness of OSAS treatment with intraoral devices has been demonstrated through cephalometric studies. **Objective:** The purpose of this study was to evaluate the effect of a mandibular advancement device (Twin Block, TB) on the volume of the upper airways by means of Cone-Beam Computed Tomography (CBCT). Sixteen patients (6 men and 10 women) with mild to moderate OSAS, mean age 47.06 years, wore a mandibular advancement device and were followed up for seven months on average. **Methods:** Two CBCT scans were obtained: one with and one without the device in place. Upper airway volumes were segmented and obtained using Student's paired t-tests for statistical analysis with 5% significance level. **Results:** TB use increased the volume of the upper airways when compared with the volume attained without TB ( $p < 0.05$ ). **Conclusion:** It can be concluded that this increased upper airway volume is associated with the use of the TB mandibular advancement device.

**Keywords:** Obstructive sleep apnea syndrome. Mandibular advancement device. Cone-Beam Computed Tomography.

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## INTRODUCTION

With the increase in respiratory sleep disorders, such as snoring, upper airway resistance syndrome (UARS) and obstructive sleep apnea syndrome (OSAS), the need for better diagnostics and treatment of these disorders became apparent.<sup>4,11</sup> Treatment of OSAS is important<sup>11,15,21,25</sup> as it is considered a high morbidity, progressive disease.<sup>11,28</sup>

The effectiveness of mandibular protrusion appliances has been demonstrated in several studies.<sup>13,25</sup> Although cephalometric radiography is a simple method, widely used in dentistry and in studies of obstructive sleep apnea,<sup>2,3,4,5,10,13,25,26</sup> this method generates two-dimensional images of three-dimensional structures, which limits the validity and reproducibility of airway measurements.<sup>14,16,24</sup>

Three-dimensional studies<sup>14,21</sup> to determine the effectiveness and action mechanism of oral appliances have shown that such appliances can modify pharyngeal geometry,<sup>21</sup> significantly enlarging the minimum pharyngeal area.<sup>14</sup>

The aim of this study was to evaluate, using Cone-Beam Computed Tomography (CBCT), the effects of mandibular advancement, performed with a modified Twin Block type appliance, on the volume of OSAS patients' upper airways.

## MATERIAL AND METHODS

This research was submitted to the Ethics Committee of Pedro Ernesto University Hospital and approved under number 1366-CEP/HUPE.

Patients were referred to the Orthodontics postgraduate clinic, School of Dentistry, Rio de Janeiro State University (FO-UERJ) by specialists in Sleep Medicine after undergoing a nocturnal polysomnography examination and being diagnosed with mild to moderate OSAS (AHI<30).

Other inclusion criteria were used: Only patients with a body mass index (BMI) of less than 27; having at least ten teeth in each arch to ensure adequate device retention; having an overjet of at least 4 mm so as to enable mandibular advancement.

Sixteen patients, 6 men and 10 women, mean age of 47.06 years, received modified Twin Block (TB) type oral appliances for mandibular advancement (Fig 1). They were instructed to wear the appliance at night and were monitored for an average period of seven months. The mandibular advancement achieved with TB was approximately 75% of maximum protrusion.<sup>12</sup> To participate in the sample the patients signed a form of free and informed consent after being given information about the research.

At the end of the follow up period each patient underwent two CBCT scans (NewTom 3G, Verona, Italy) with field of view of 9 inches and slice thickness of 0.2 mm. Both scans were performed on the same day, one without and one with the mandibular advancement appliance in place. The patients were awake, lying supine, with the Frankfort plane perpendicular to the floor.<sup>24</sup>

The scanning method was standardized with the aid of an acrylic positioner (Fig 2) and the



FIGURE 1 - Modified Twin Block appliance in place: **A)** right lateral view, **B)** front view and **C)** left lateral view.

NewTom 3G laser beam itself, to position the facial midline. Moreover, the distances between patient and scanner, and the height of the stretcher were recorded in the first examination to ensure that the two scans were as similar as possible. This position was verified on the computer with the aid of a scanogram before the start of the second examination.

After the primary reconstruction of the projections in the three orthogonal planes (axial, coronal and sagittal) and images of the entire craniofacial complex volume were obtained in DICOM format (Digital Imaging Communications in Medicine), the images were manipulated with

ITK SNAP 1.8.0<sup>30</sup> software to obtain volumetric reconstructions of the relevant structures. The software allows semiautomatic segmentation<sup>6,7</sup> of the area of interest, which was limited in the anterior and superior regions by the posterior nasal spine (PNS)<sup>24,27</sup> while in the inferior region, the limits were the anterior-most and inferior-most regions of the third cervical vertebra (C3)<sup>13</sup> (Fig 3). The volume in mm<sup>3</sup> of the three-dimensional model of the upper airway (Fig 4) was obtained with the software.

The statistical data were tabulated in a statistical program (Biostat 2.0, Belém, Pará State, Brazil). Method error was used only to



FIGURE 2 - Cone-Beam Computer Tomography scans: **A)** Patient positioned at NewTom 3G with acrylic positioner and Frankfort horizontal plane perpendicular to the floor; **B)** Using the laser beam to position the facial midline.

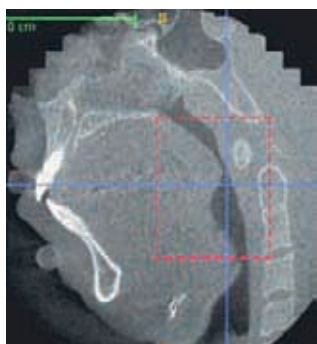


FIGURE 3 - Points used to determine upper airway volume. PNS (posterior nasal spine), C3 (anterior-most and inferior-most portions of the third vertebra).

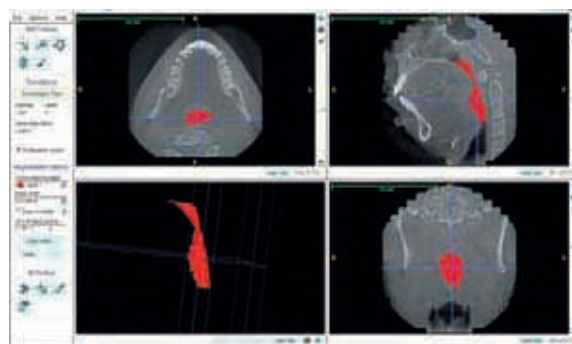


FIGURE 4 - Segmentation of a three-dimensional model. The upper airways are in red. The segmented areas are shown both in CT slices and in the three-dimensional model.

circumscribe the structure because it is a semi-automatic method. Two examiners delimited the area of interest twice at intervals of two days, and the intraclass correlation coefficient (ICC) for nominal or quantitative variables was utilized to assess the correlation between repeated measurements in the same patient. The ICC showed excellent intra and interexaminer repeatability, which allows the authors to assert that the method used to segment and obtain upper airway volume is reliable ( $p < 0.0001$ ).

After using the Shapiro-Wilk normality test, the paired t-test was applied to compare the volumes with and without TB. To be considered significant, p value was set at 0.05.

## RESULTS

The mean airway volumes with and without TB were  $8710 \pm 2813 \text{ mm}^3$  and  $7601 \pm 2659 \text{ mm}^3$ , respectively (Fig 5). There was a statistically significant difference ( $p = 0.0494$ ) in airway volume between patients with and without TB (Table 1), demonstrating that TB was successful in increasing upper airway volume in the TB patients.

## DISCUSSION

Upper airway three-dimensional assessment was performed using CBCT given its low radiation dose.<sup>16,27</sup> According to Aboudara et al,<sup>1</sup> although CBCT is not usually indicated for evaluating soft tissues the contrast between the airway lumen and the soft and hard tissue enhances segmentation accuracy when quantifying airway volume. The NewTom 3G scanner used in this study enabled the assessment of the upper airways while the patient was lying down and, although it failed to reproduce the exact sleeping position, positioning the pharyngeal tissues is important in determining the severity of the syndrome.<sup>18</sup> How to position the patient during follow-up examinations is a much debated issue, since air flow is influenced by changes in head position,<sup>8,29</sup> which

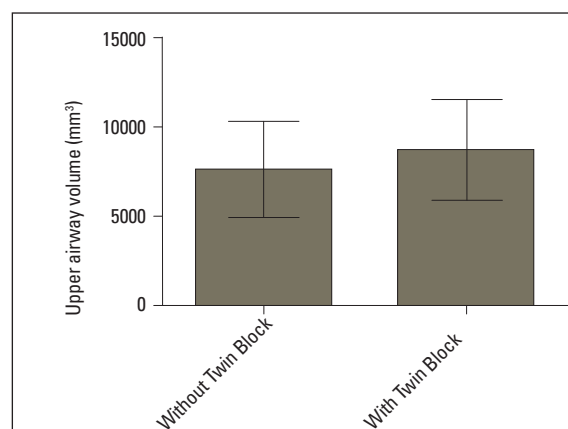


FIGURE 5 - Volume values of upper airway ( $\text{mm}^3$ ) of patients without and with TB.

TABLE 1 - Mean, standard deviation and p value for comparing airway volume (in  $\text{mm}^3$ ) between patients with and without TB.

|                   | Mean | Standard deviation | P value      |
|-------------------|------|--------------------|--------------|
| Volume without TB | 7601 | 2659               | $p = 0.0494$ |
| Volume with TB    | 8710 | 2813               |              |

may result from the reduced dimensions of the upper airways in the retropalatal region.<sup>1</sup>

While assessing the images in the three planes of space with ITK-SNAP software reference points were selected for defining the area of interest according to previous studies.<sup>24,27</sup> The reference points used in this study were the ENP<sup>1,4,13,24,27</sup> and the most anterior and inferior point of the third cervical vertebra.<sup>13</sup>

The statistically significant difference found in this study between patients with and without TB in place ( $p < 0.05$ ) shows that the upper airways expanded as a result of the mandibular advancement caused by the TB. This mechanism is still under debate. It is believed, however, that the more anterior position of the mandible and hyoid bone and the consequent stimulation of the pharyngeal muscles and tongue are responsible

for increasing airway volume.<sup>30</sup> According to the cephalometric study by Fransson et al<sup>13</sup>, the increase in pharyngeal area occurred because of the more anterior position of the hyoid bone as a result of increased activity in the genioglossus and lateral pterygoid muscles.

Only two patients had lower airway volume with TB than without TB, which may be explained by the amount of mandibular advancement in these patients or the width of their soft palate. The amount of mandibular advancement varies widely between different studies, ranging from 2.0 mm<sup>20</sup> to 9.5 mm.<sup>12,13</sup> Despite the differences, a protrusion of 75% of each patient's maximum capacity is very often used by researchers.<sup>9,10,13,14,15,17,19,22,23,25</sup> This advancement yields adequate success rates and can usually be endured by most patients.

CBCT comparison between healthy patients and patients presenting with OSAS has shown that the anteroposterior dimensions and minimum oropharyngeal dimensions of patients with OSAS were significantly lower compared to patients who did not have this syndrome.<sup>24</sup>

Three-dimensional studies in patients with SAOS<sup>14,21,30</sup> have shown increased upper airways, predominantly in the oropharyngeal<sup>21</sup> and velopharyngeal<sup>30</sup> regions. However, most of these studies<sup>21,30</sup> assessed the airways using linear measurements only, i.e., using two-dimensional data obtained through three-dimensional examinations.

According to Zhao, Liu, Gao<sup>30</sup> and Kyung, Park, Pae,<sup>21</sup> airway augmentation is achieved at the expense of an increase in transverse diameter. Gale et al<sup>14</sup> found an increase in the pharyngeal area using a mandibular advancement device but with substantial individual variability.

In the present study, preference was given to conducting two CBCT scans on the same day after the monitoring period due to image acquisition standardization, since each patient's ideal position is unique. Moreover, there could be changes in patients' BMI and health status during follow-up, as well as climate changes. These factors would render impracticable any comparisons between soft tissues and upper airway volumes at different times.

OSAS studies using Cone-Beam Computed Tomography and three-dimensional models require further research and improved standardization of assessment methods, in addition to a better understanding of the action mechanisms underlying mandibular advancement devices and their results, if these devices are to become the treatment of choice for OSAS patients.

## CONCLUSIONS

Based on the results of upper airway volume comparisons (in mm<sup>3</sup>) of OSAS patients treated with a mandibular advancement device, the authors have grounds to conclude that the TB significantly changed upper airway volume.

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# Mandibular condyle dimensional changes in subjects from 3 to 20 years of age using Cone-Beam Computed Tomography: A preliminary study

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## Abstract

**Introduction:** Cone-Beam Computed Tomography (CBCT) imaging provides an excellent representation of the temporomandibular joint bone tissues. **Objective:** The aim of this study was to investigate morphological changes of the mandibular condyle from childhood to adulthood using CBCT. **Methods:** A cross-sectional study was conducted in 36 condyles of 18 subjects from 3 to 20 years of age. Condyles were scanned with the i-CAT Cone-Beam 3D imaging system and linear dimensions were measured with a specific i-CAT software function for temporomandibular joint, which permitted slices perpendicular to the condylar head, with individual correction in function of angular differences for each condyle. The greatest distances in lateral and frontal sections were considered on both left and right mandibular condyles. **Results:** The linear dimension of the mandibular condyle on the lateral section varied little with growth and seemed to be established early, while the dimension of the frontal section increased. Small asymmetries between left and right condyles were common but without statistical significance for both lateral ( $P=0.815$ ) and frontal ( $P=0.374$ ) dimensions. **Conclusions:** The condyles were symmetric in size and only the frontal dimension enlarged during growth. These preliminary data suggest that CBCT is a useful tool to measure and evaluate the condylar dimensions.

**Keywords:** Mandibular condyle. Cone-Beam Computed Tomography. Morphology. Temporomandibular joint.

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## INTRODUCTION

The mandibular condyle (or head), besides joint function, acts as a site of regional adaptive growth even under functional load supported by its cartilage.<sup>8</sup> Mandibular condyle morphology is characterized by a rounded bone projection with an upper biconvex and oval surface in axial plane.<sup>24</sup> Typically, the antero-posterior dimension (or lateral) is shorter than the medial-lateral (or frontal), whose ends are called medial and lateral poles.

A normal variation of the condylar morphology occurs with age,<sup>13,24</sup> gender,<sup>24</sup> facial type,<sup>5</sup> functional load,<sup>7</sup> occlusal force,<sup>16</sup> malocclusion type<sup>14</sup> and between right and left sides.<sup>5,7,16,24</sup> The most prevalent morphologic changes are detected in the temporomandibular joints (TMJ) of elderly persons<sup>20</sup> due to the onset of joint degeneration, and that is probably the reason of greater focused study.<sup>2,13,20</sup>

TMJ morphology has been studied on dry and autopsy human skulls,<sup>13</sup> histology,<sup>13</sup> radiographic exams,<sup>12,13</sup> magnetic resonance<sup>1</sup>, traditional computed tomography<sup>12</sup> and Cone-Beam Computed Tomography (CBCT)<sup>12,18</sup> methods. Although the panoramic radiograph has been widely employed in clinical environment, it has limitation to evaluate the accuracy of condylar morphology and to reveal minor osseous change<sup>4</sup>. For this reason panoramic radiographs should be used with caution when performing linear measurements.<sup>12,17</sup> CBCT images provide an excellent representation of TMJ bone tissues, despite the variation in bone density and composition. Studies have shown that CT images can be remarkably accurate for linear,<sup>3,18,19</sup> geometric,<sup>19</sup> and volumetric<sup>22</sup> measurements within the maxillofacial complex. The high potential for clinical application and the accuracy of CBCT compared to other radiologic techniques have contributed in treatment planning, diagnosis, therapeutic and prognosis of different diseases.<sup>2,9-12</sup>

The aims of the present study were to investigate dimensional changes in the mandibular

condyle presenting normal growth from infancy to adulthood in different subjects, and to evaluate possible asymmetries in size between right and left sides using CBCT images.

## MATERIAL AND METHODS

### Imaging Selection

This study was developed with the data of private radiology clinics (CIRO, Goiânia, GO, Brazil, RIO, Brasília, DF, Brazil, CROIF, Cuiabá, MT, Brazil) based on dentomaxillofacial records selected from 18 subjects, one of each age (13 males and 5 females, with ages between 3 and 20 years old, 18 right and left mandibular condyles) between May 2007 and May 2010. The subjects were referred to the dental radiology service for different diagnosis purpose. The involved sample had essentially normal condylar morphology with preserved cortical bone. The exclusion criteria included images where the patients had: condylar fracture, TMJ ankylosis, tumors, hyperplasia, condylar resorption and absence of posterior teeth.

The study design was approved by the Local Ethics Research Committee of Federal University of Goiás (Proc.#169/2008).

### Imaging Methods

All subjects were seated during the exam and were oriented to have their heads positioned with the Frankfurt horizontal plane parallel to the floor.

The CBCT scans were taken with an i-CAT Cone-Beam 3D Imaging System (Imaging Sciences International, Hatfield, PA, USA) Volumes were reconstructed with a 0.2 mm isometric voxel size, tube voltage was 120 kVp and the tube current 3.8 mA. The exposure time was 40 seconds. Images were examined with the scanner's proprietary software (Xoran version 3.1.62; Xoran Technologies, Ann Arbor, MI, USA) in a PC workstation running Microsoft Windows XP professional SP-2 (Microsoft Corp, Redmond, WA, USA) with an Intel (R) Core 2 Duo 1.86Ghz-6300 processor (Intel Corporation, USA), a NVIDIA GeForce

6200 turbo cache video board (NVIDIA Corporation, USA) and an EIZO – Flexscan S2000 monitor with a 1600x1200 pixels resolution (EIZO NANO Corporation Hakusan, Japan).

### Imaging Measurements

Images of the temporomandibular region were adjusted considering the inclination and position of the central region of the mandibular condyle in lateral and frontal sections. Measurements with a specific TMJ tool were made, which permitted slices perpendicular to the condylar head, with individual correction in function of condyle angulation.

The method used to assess condylar morphology was based on the delimitation and measurement of the distance between anatomical landmarks, considering the greatest distances in the lateral and frontal views of condylar images. The anatomic landmark definitions and linear measurements were similar as proposed by Schlueter et al,<sup>22</sup> criteria and were defined as follows (Fig 1):

» **M** (medial condylar surface): most medial point of the mandibular condyle on the frontal view.

» **L** (lateral condylar surface): most lateral point of the mandibular condyle on the frontal view.

» **A** (anterior condylar surface): most anterior point of the mandibular condyle on lateral view.

» **P** (posterior condylar surface): most posterior point of the mandibular condyle on lateral view.

» **M-L** (condylar width): the distance between M and L landmarks, corresponding to the largest dimension of the mandibular condyle on frontal view.

» **A-P** (condylar length): the distance between A and P landmarks, corresponding to the largest dimension of the mandibular condyle on lateral view.

A specific function of the i-CAT software (Xoran version 3.1.62; Xoran Technologies, Ann Arbor, MI, USA) was used to measure these distances in millimeters. The measurements were made by the same radiologist.

### Method Error

In order to determine the intra-operator measurement reliability for condylar dimensions, these were measured twice with a two-week interval by the same radiologist. Significance testing for linear measurement differences was accomplished using paired Student t-test.

### Statistical Analysis

All data were entered into Excel 2003 (Microsoft, Redmond, WA, USA). The statistical analyses were carried out with SPSS (version 15.0, SPSS, Chicago, IL, USA) for Windows. Average values and standard deviations were computed

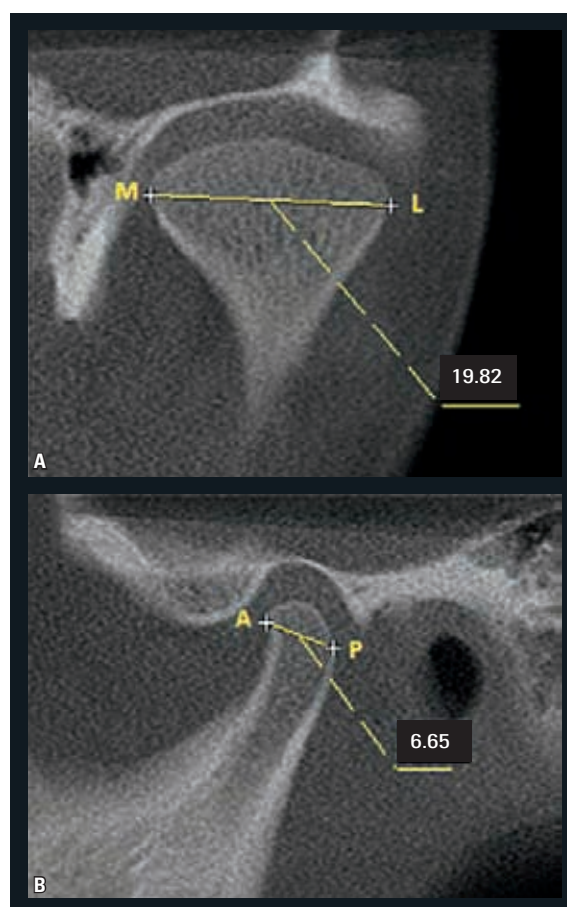


FIGURE 1 - Anatomic landmarks and linear measurements on frontal (A) and lateral (B) views of the left mandibular condyle (M: medial; L: lateral; A: anterior; P: posterior).

separately for right and left condyles in lateral and frontal sections. Differences for right and left condyles in lateral dimensions were tested using Mann-Whitney test and for frontal dimension a non-paired Student t-test.

## RESULTS

Linear measurements of the mandibular condyles on lateral and frontal sections are presented in Table 1. The values for intra-operator reliability were similar with no statistical difference, indicating agreement for the lateral (right,  $P=0.322$ ; left,  $P=0.294$ ) and the frontal (right,  $P=0.909$ ; left,  $P=0.856$ ) duplicated measurements.

There were no significant differences between right and left mandibular condyles for lateral ( $P=0.815$ ) and frontal ( $P=0.374$ ) sections. Figures 2 and 3 show mandibular condyle sequences on CBCT imaging between 3 to 20 years of age and the behavior of morphological changes with time is presented on Figure 4.

## DISCUSSION

The mandibular condyle is one of the main sites of facial growth, which is expressed in an upward and backward direction.<sup>8</sup> The present study did not aim to quantify the participation of condylar growth on total mandibular growth but, instead, assess in a cross-sectional study the local morphological changes of the mandibular condyle during growth using CBCT images. The results showed that the lateral dimension (A-P) seemed to be established early and to vary a little with age, while the frontal dimension (M-L) increases (Fig 4). Therefore, the mandibular condyle develops by a remodeling process and replaces itself by preserving its lateral dimension and enlarging laterally.

Rodrigues et al<sup>21</sup> investigated the diameter of the right and left condyles in subjects aged 13 to 30 years old. All subjects presented Class I malocclusion and were evaluated by computed tomography. Mean sagittal (lateral) dimensions for right and left condyles were, respectively, 9.39 mm and

TABLE 1 - Condylar linear measurements (mm) in relation to age.

| Age      | Right Condyle (RC) |       | Left Condyle (LC) |       |
|----------|--------------------|-------|-------------------|-------|
|          | A-P                | M-L   | A-P               | M-L   |
| 3 years  | 7.52               | 12.60 | 7.50              | 12.61 |
| 4 years  | 7.06               | 13.77 | 7.25              | 13.68 |
| 5 years  | 7.03               | 15.58 | 6.79              | 14.49 |
| 6 years  | 8.73               | 13.65 | 9.22              | 13.82 |
| 7 years  | 8.54               | 17.69 | 8.99              | 16.45 |
| 8 years  | 8.36               | 19.43 | 8.77              | 19.85 |
| 9 years  | 7.47               | 18.64 | 7.47              | 18.45 |
| 10 years | 8.83               | 16.88 | 8.94              | 15.48 |
| 11 years | 9.22               | 17.84 | 8.94              | 16.48 |
| 12 years | 7.72               | 20.25 | 6.84              | 19.80 |
| 13 years | 7.82               | 17.89 | 7.20              | 15.01 |
| 14 years | 9.06               | 17.42 | 9.04              | 16.42 |
| 15 years | 6.62               | 19.27 | 6.46              | 18.49 |
| 16 years | 8.68               | 20.54 | 8.81              | 21.16 |
| 17 years | 7.42               | 20.08 | 6.85              | 17.60 |
| 18 years | 6.83               | 21.42 | 6.61              | 19.55 |
| 19 years | 8.29               | 21.00 | 8.22              | 20.28 |
| 20 years | 9.18               | 20.81 | 8.94              | 20.67 |

Lateral: (RC)  $P=0.322$ ; (LC)  $P=0.294$  / Frontal: (RC)  $P=0.909$ ; (LC)  $P=0.856$ .

9.30 mm, and for mediolateral (frontal) 20.62 mm and 20.57 mm with no statistically significant differences between right and left condyles. The lateral dimensions were slightly larger for the same age group when compared to the present study, but the measurements were done on the axial plane.

The basic morphology of mandibular condyle is thought to be established early, and modified throughout life according to functional load.<sup>6</sup> Small asymmetries are expected to develop during normal condylar growth, but the manner in which this asymmetry occurs has to be differentiated. Asymmetries in size differs from shape, volume or position asymmetries. Conventional linear and angular measurements provide quantitative information about size and position, and fail to define features such as shape and volume of the condyles. The present study found symmetric condyle sizes on lateral and frontal sections using CBCT and did not consider the occlusion. Several other studies have used

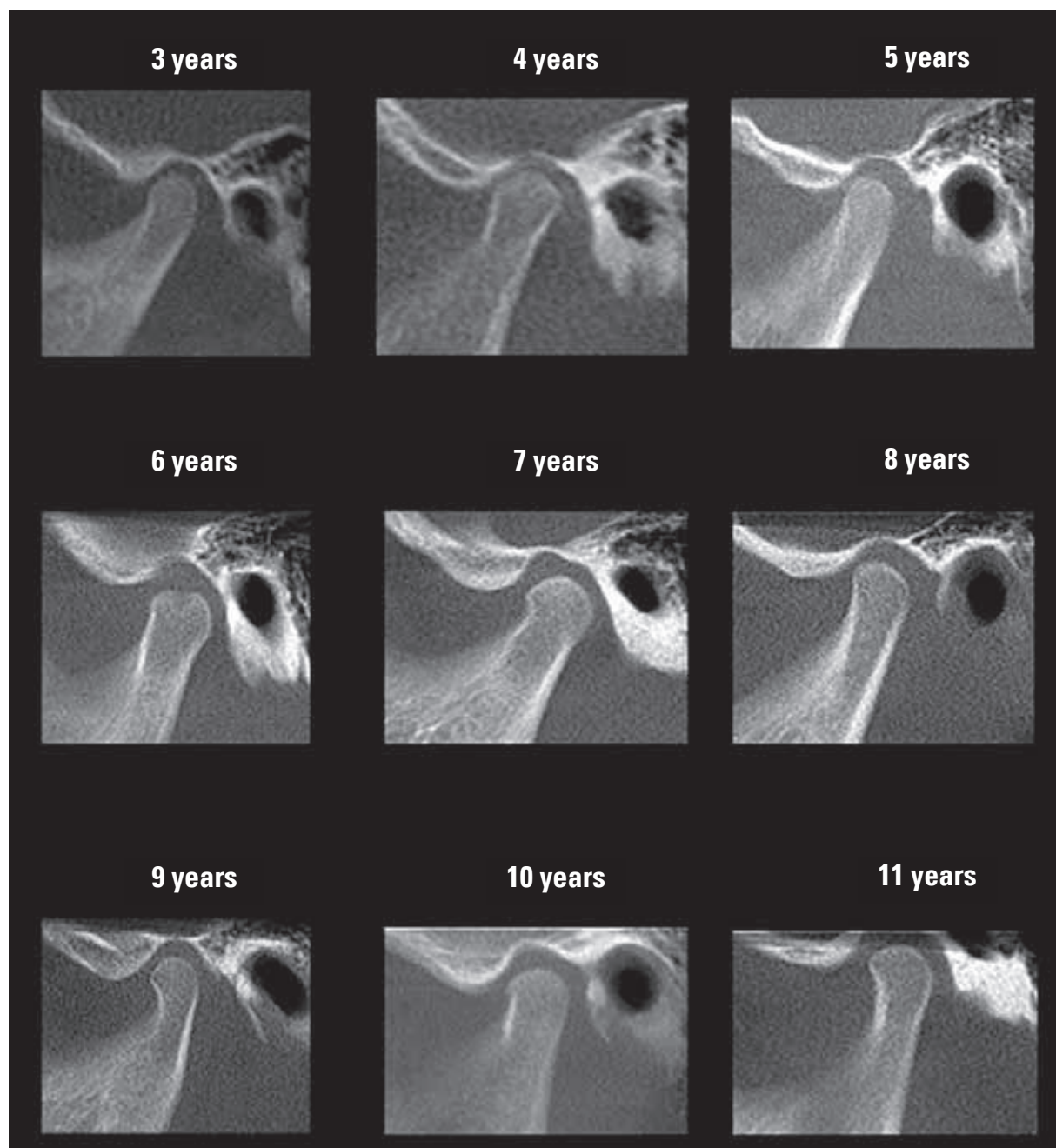


FIGURE 2 - Sequence of morphological variation of the mandibular condyle in lateral view according to age (3 to 20 years old) (continue).

panoramic radiography to evaluate the purpose of symmetry with contrasting results.<sup>15,23</sup> It is known that panoramic radiography is not the most appropriate method since it produces magnification and distortion in the vertical and horizontal directions.<sup>17</sup>

Similar studies should be performed with a larger sample to confirm the present data and to correlate them to gender, facial patterns and condyle types. The vertical dimensions, shape of mandibular fossae, articular eminence, and degree of

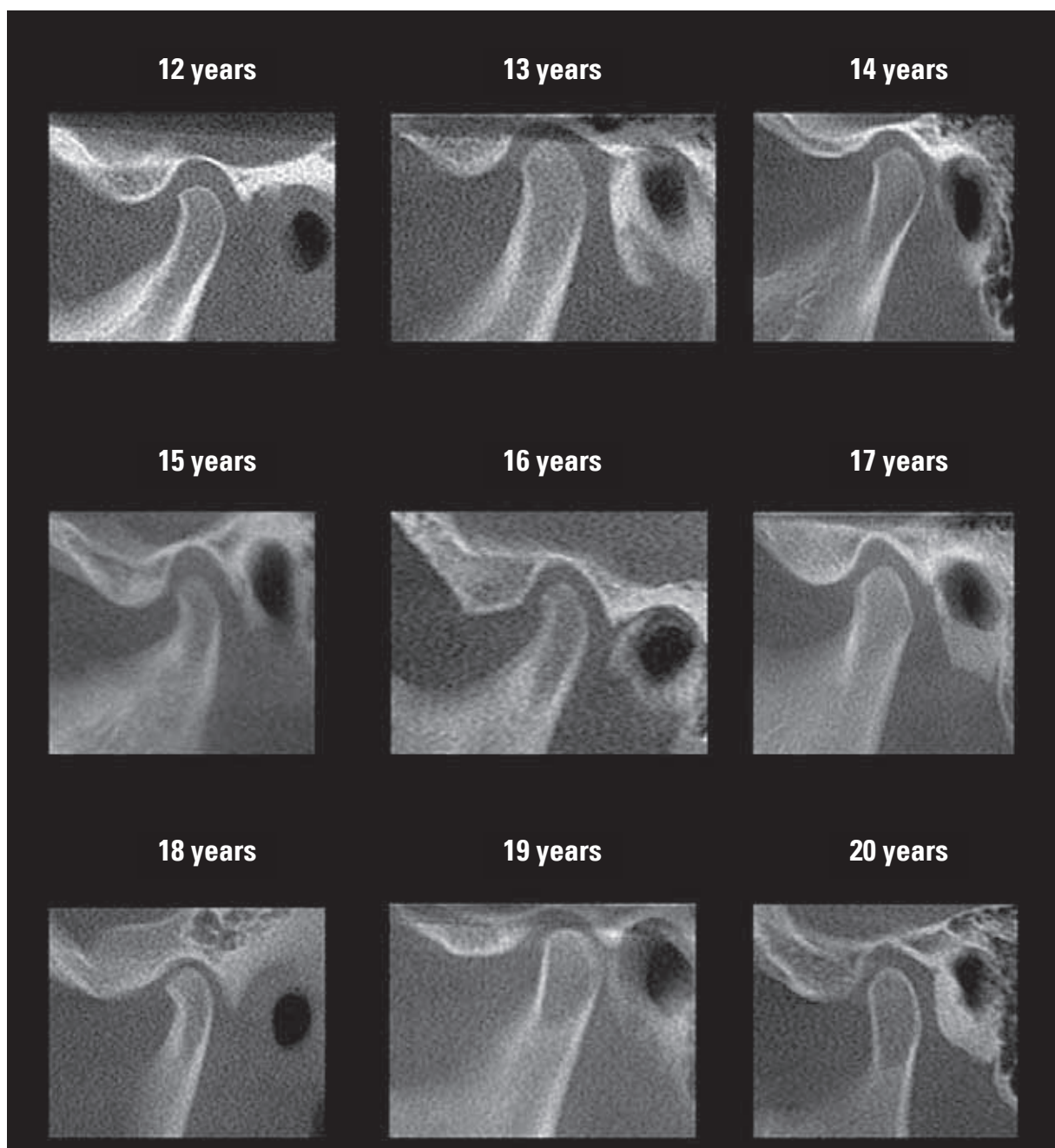


FIGURE 2 - Sequence of morphological variation of the mandibular condyle in lateral view according to age (3 to 20 years old).

inclination of the condyle should be also included with a specific methodology.

CBCT is becoming an important tool in modern dental practice and provides excellent imaging of the osseous components of the TMJ with less radiation

exposure compared to other techniques.<sup>1,12</sup> The developed technique showed promising results for condyle measurement and to detect morphological changes during the growth phase in a non-invasive manner using CBCT images in living individuals.

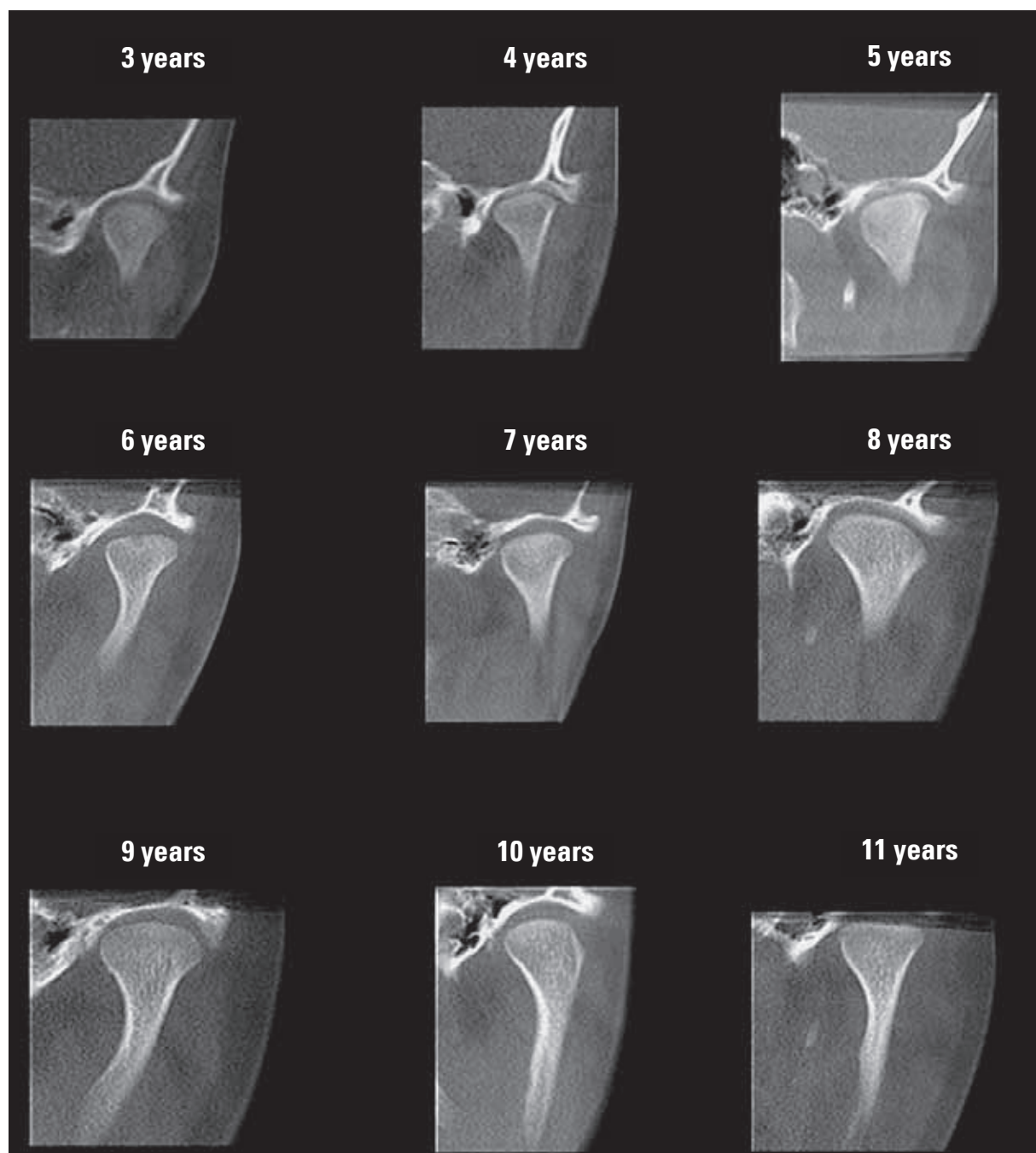


FIGURE 3 - Sequence of morphological variation of the mandibular condyle in frontal view according to age (3 to 20 years old) (continue).

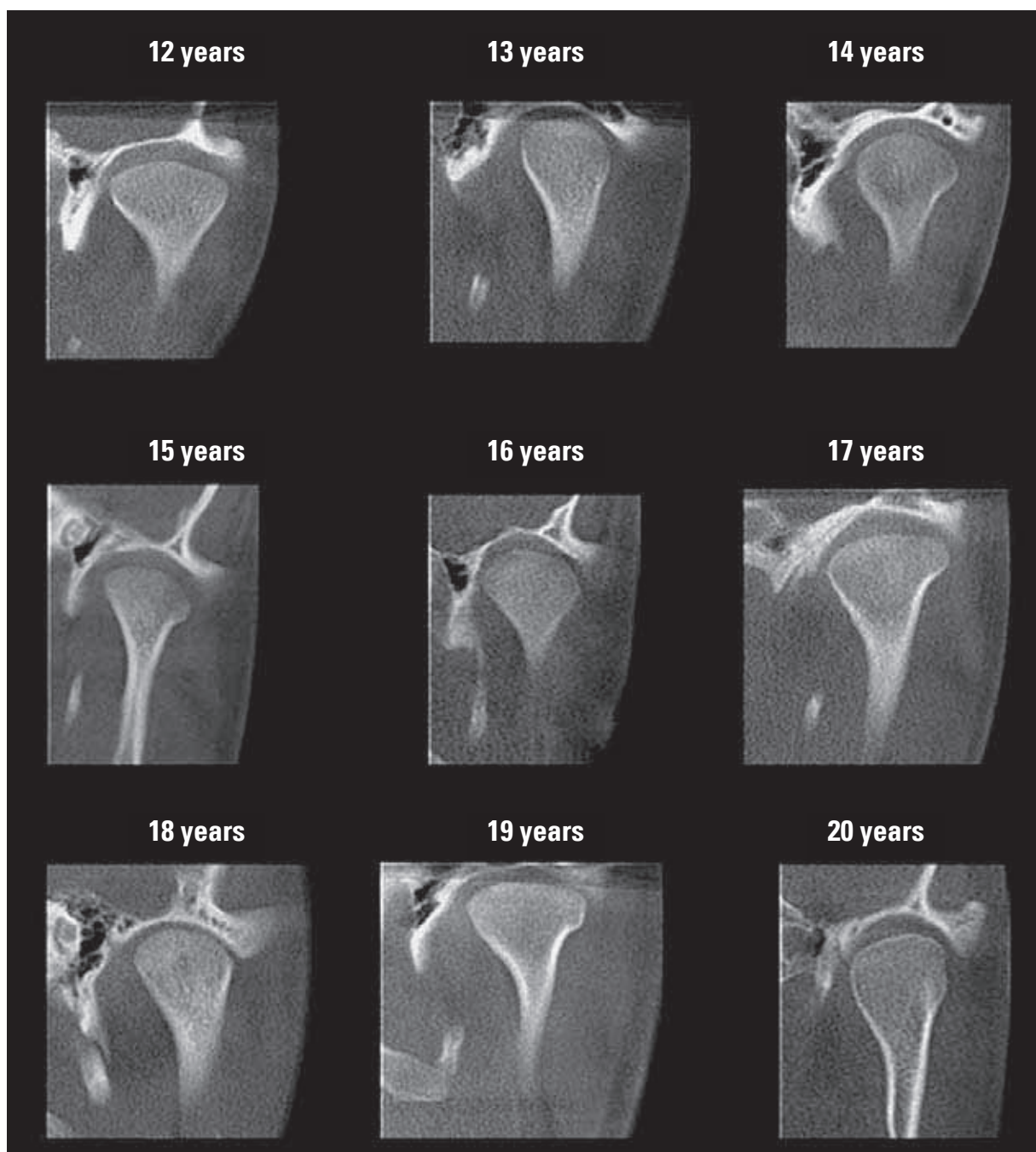


FIGURE 3 - Sequence of morphological variation of the mandibular condyle in frontal view according to age (3 to 20 years old).

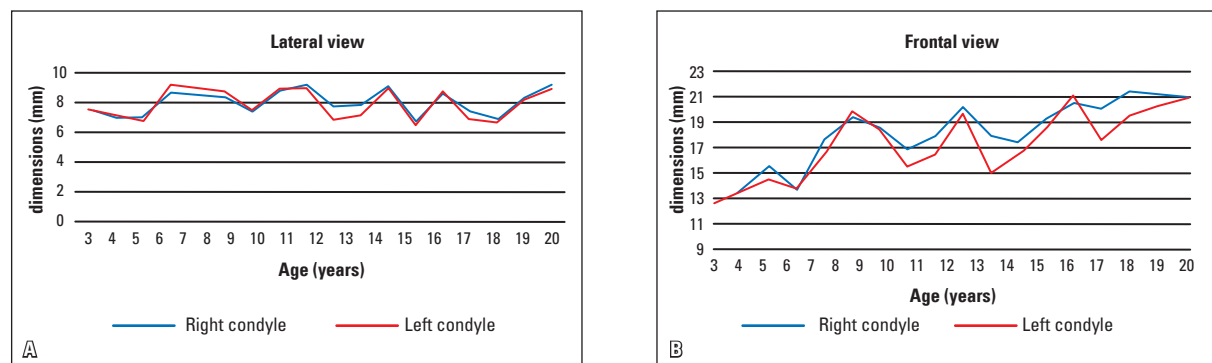


FIGURE 4 - Behavior of mandibular condyle dimensions (in mm) between 3 to 20 years old: Lateral (A) and frontal (B) view.

## CONCLUSION

The lateral dimension of the mandibular condyle seems to establish itself early because it varied very little with age, while the frontal dimension increased. Small asymmetries between left and right condyles seem to be common, but with no statistical significance. These preliminary data suggested that CBCT is an useful tool

to measure and to evaluate condylar morphology during growth.

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# Class III malocclusion with unilateral posterior crossbite and facial asymmetry\*

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## Abstract

This article reports on the orthodontic treatment performed on a 36-year-old female patient with skeletal and dental Class III pattern, presenting with a left unilateral posterior crossbite and mandibular asymmetry, and a relatively significant difference between maximum intercuspation (MIC) and centric relation (CR). The treatment was performed with maxillary dental expansion, mandibular dental contraction and anterior crossbite correction, eliminating the difference between MIC and CR. Results were based on careful diagnosis and planning of orthodontic compensation without surgical intervention in the maxilla, at the request of the patient. This case was presented to the Brazilian Board of Orthodontics and Facial Orthopedics (BBO) as representative of Category 5, i.e., malocclusion with a transverse problem, presenting with a crossbite in at least one of the quadrants, as part of the requirements for obtaining the BBO Certificate.

**Keywords:** Angle Class III. Crossbite. Facial asymmetry. Adult patient. Corrective Orthodontics.

## HISTORY AND ETIOLOGY

The patient sought orthodontic treatment at 36 years of age, in good general health and without significant medical history. Her chief complaint concerned anterior and posterior crossbites and chronic pain in the left temporomandibular joint. She showed good oral hygiene, overall healthy-looking gingiva and some poorly fitting amalgam restorations.<sup>2</sup> She had no history of orthodontic intervention. When orthognathic surgery was suggested the patient expressed her unwillingness to undergo surgery to correct the malocclusion.

## DIAGNOSIS

As regards dental pattern (Figs 1 and 2), she presented with an Angle Class III, subdivision left malocclusion, no mandibular dentoalveolar discrepancy, 3 mm overbite, 2 mm overjet, crowding in the upper anterior region, U-shaped maxillary arch, contracted on the right side, lower arch slightly expanded on the right side, posterior crossbite on the left<sup>5</sup>, less than 3 mm lower midline shift to the left and inclined lower occlusal plane.

Facial analysis revealed a concave profile with upper lip retrusion and mandibular deviation to the left side (Fig 1).

\* Case report, Category 5 - approved by the Brazilian Board of Orthodontics and Facial Orthopedics (BBO).

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FIGURE 1 - Initial facial and intraoral photographs.

Regarding functional occlusion, at MIC she presented with a 5 mm mandibular deviation to the left side (Fig 5) and a 2 mm difference between MIC and CR. At CR, contact existed only between tooth 23 (left upper canine) and tooth 33 (left lower canine) with reduced mandibular deviation.

On clinical examination, bilateral clicks were observed in the TMJ with mandibular deviations on opening and closing movements and no crepitation or mandibular deflection at maximum opening. Palpation examination showed more intense pain in the left than in the right TMJ, regardless

of whether the mouth was open or closed.<sup>3,6</sup> A maximum opening of 52 mm was recorded.

The analysis of panoramic and periapical radiographs (Fig 3) showed that the patient did not present with any condition that might compromise her orthodontic treatment.

She had a Class III skeletal pattern, ANB equal to  $-2.5^\circ$  ( $SNA=80^\circ$  and  $SNB=82.5^\circ$ ),  $-8^\circ$  convexity angle and retrusion of the maxilla. This information is depicted in Figure 4 and Table 1. Frontal analysis showed mandibular asymmetry and a 5mm deviation to the left (Fig 5).

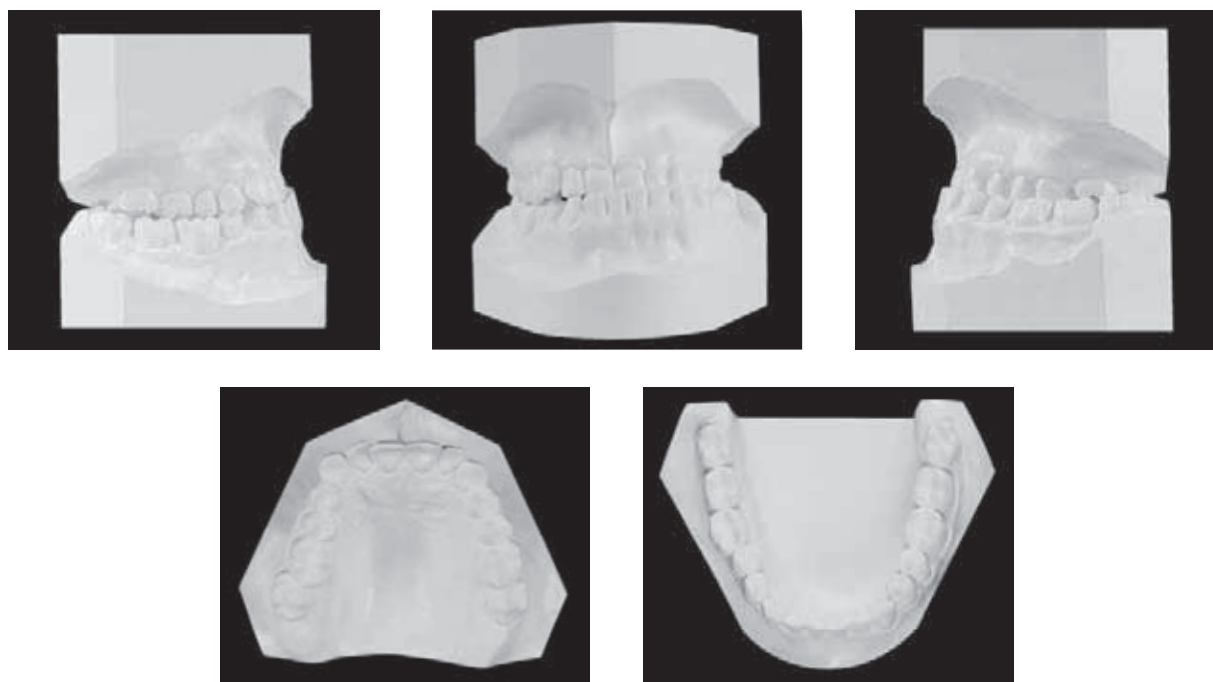


FIGURE 2 - Initial plaster models.

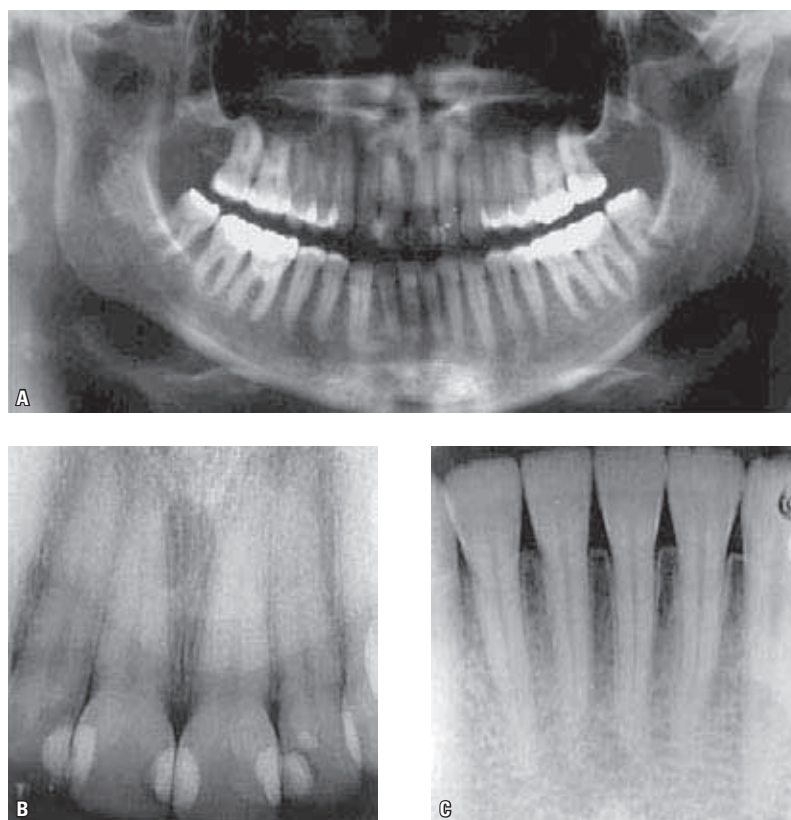


FIGURE 3 - Initial radiographs: **A)** Panoramic and **B, C)** incisor periapical.

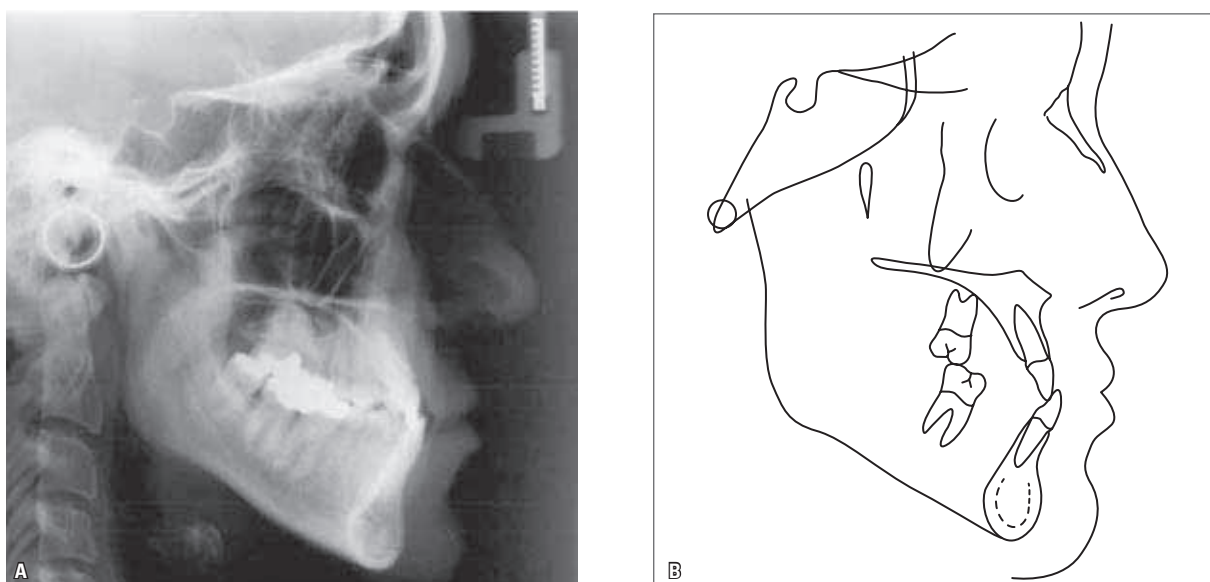


FIGURE 4 - Initial lateral cephalogram (A) and cephalometric tracing (B).

### TREATMENT GOALS

The initial goal was to control chronic pain in the left TMJ by referring the patient to a specialist in temporomandibular disorders (TMD).<sup>2,3,6</sup> After this issue had been successfully addressed, orthodontic treatment was administered with the consent of the specialist. At the patient's request, combined surgical-orthodontic treatment was ruled out.

Thus, to correct the anterior crossbite, the difference between MIC and CR<sup>6</sup> had to be addressed through axial protrusion of the maxillary incisors and retroclination of the mandibular incisors, thereby achieving normal occlusion and slightly improving the profile.<sup>1</sup>

The transverse problem was resolved by correcting the left posterior crossbite, which required expanding the upper dental arch<sup>4,7</sup> and contracting the lower. Moreover, the purpose of eliminating the difference between MIC and CR was to correct the lower midline and reduce mandibular deviation.

### TREATMENT PLAN

The first step would be to refer the patient to a TMD specialist<sup>2,3,6</sup> and then have her third molars (38 and 48) extracted, since these teeth were extruded (Figs 1 and 3A).

After TMD treatment a Hyrax-type palatal expansion appliance would be installed (for six months) with bands on all maxillary molars and premolars (eight bands) to expand the upper arch and increase intermolar width.<sup>4,7</sup> After expander removal, a palatal bar fabricated from 0.032-in stainless steel would be inserted, with bands on the first molars and palatal extension as far as the first premolars. In the lower arch, a 0.032-in stainless steel lingual arch would be placed, with bands on the lower first molars.

In the following step, fixed 0.022 X 0.028-in orthodontic appliances would be set up and stainless steel 0.014 X 0.020-in archwires inserted for alignment and leveling. Next, stainless steel 0.019 X 0.025-in archwires would be used to increase upper incisor axial inclination,

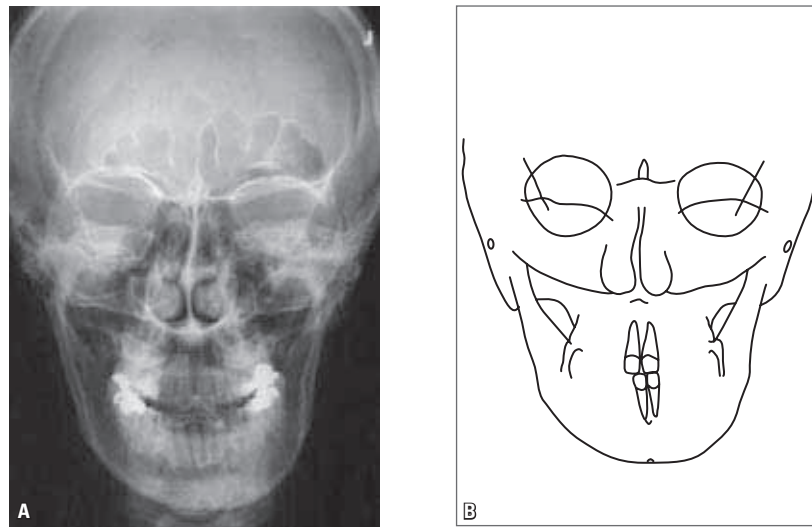


FIGURE 5 - Initial posteroanterior cephalometric radiograph (A) and cephalometric tracing (B).

induce retroclination of lower incisors and finish the case. In the phase of anterior crossbite correction it would be necessary to use Class III intermaxillary elastic mechanics.

During the finishing stage, the patient would be referred to a speech therapist for evaluation of her oral functions.

After the active treatment phase, an upper wraparound-type retention plate would be used, and on the lower arch a stainless steel 0.028-in lingual canine-to-canine arch (retainer).

### TREATMENT PROGRESS

Treatment of the chronic pain in the left TMJ lasted four months under the TMD specialist's supervision. In addition, the patient was periodically evaluated throughout the orthodontic treatment. Extraction of the third molars was performed after this period.

For maxillary expansion, a Hyrax-type expander was installed with bands on all molars and premolars, and 1/4 turn activation once a day for 28 days. The patient wore the appliance for six months.

After expander removal, a 0.032-in stainless steel palatal bar was installed, welded to bands

on the first molars and palatal extension as far as the first premolars. The appliance was removed in the early finishing stage and the bands replaced with bonded brackets.

On the lower arch, a 0.032-in stainless steel lingual arch was placed with bands on the lower first molars. The lingual arch was also removed in the early finishing stage and the bands replaced with bonded brackets.

Upper fixed appliance set-up was performed after removal of the palatal expansion appliance at the same time that the palatal bar was installed. The lower fixed appliance was set up three months after lingual arch installation. All second molars were also included in the treatment, with orthodontic bands. Next, a sequence of 0.014-in to 0.020-in diameter stainless steel alignment and leveling archwires was used. Stainless steel 0.019 X 0.025-in archwires were used to increase the axial inclination of upper incisors and retroclination of lower incisors. At this stage, Class III elastic mechanics was introduced. After crossbite correction, occlusal adjustments were performed by compensatory grinding in some consultations until the end of treatment to improve dental intercuspation quality. Stainless steel 0.019 X 0.025-in

archwires were also used when finishing the case in both the upper and lower dental arches.

After ensuring that all the intended goals had been achieved the fixed orthodontic appliance was removed from both arches and the retention phase begun. In the upper arch a wrap-around-type removable device was installed and worn 24/7 in the first year, and then only at nighttime for at least another year. The patient was monitored through regular consultations. A stainless steel lingual canine-to-canine retainer was placed on the lower arch to be used indefinitely. The patient underwent speech therapy for eight months.

## TREATMENT RESULTS

In reviewing the patient's final records, it became clear that the major goals set at the beginning of treatment were attained (Figs 6, 7 and 9). The skeletal Class III (Fig 9 and Table 1) remained unchanged because the patient refused to undergo orthognathic surgery for correction of the maxillomandibular relationship and mandibular deviation (Fig 6).

In the upper arch, proper alignment was achieved as well as some improvement in the shape of the arch, and a deliberate  $10^\circ$  increase in incisor axial inclination (Fig 9 and Table 1), which corrected the anterior crossbite.<sup>1</sup> Expansion



FIGURE 6 - Final facial and intraoral photographs.

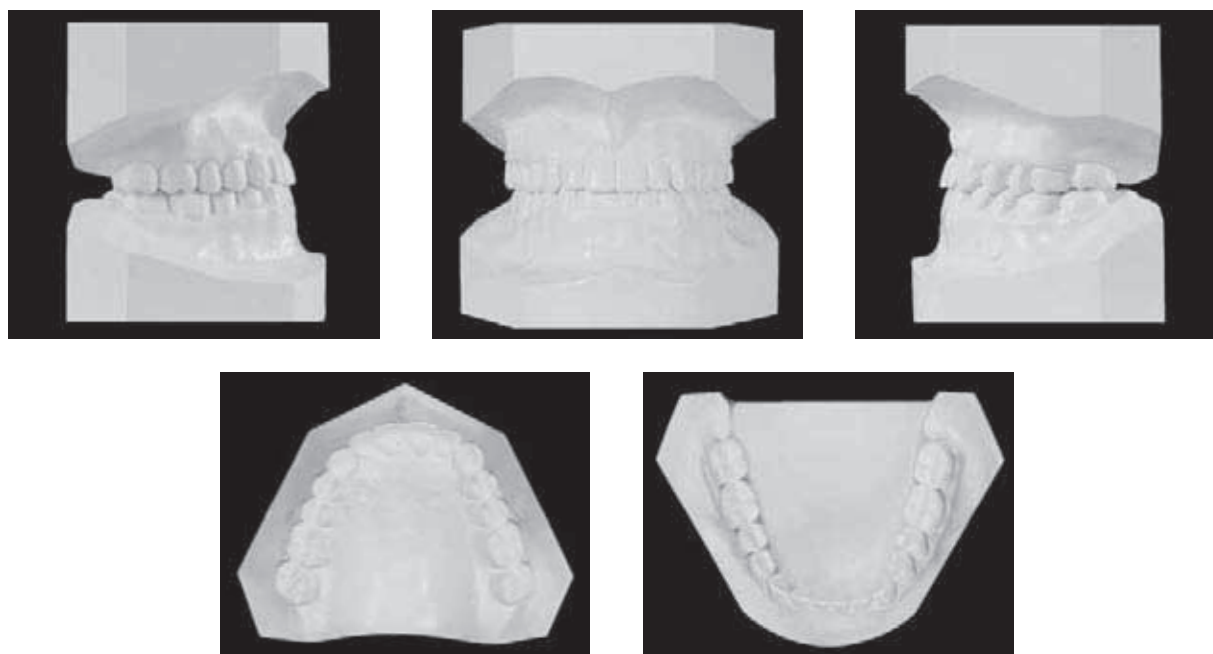


FIGURE 7 - Final plaster models.

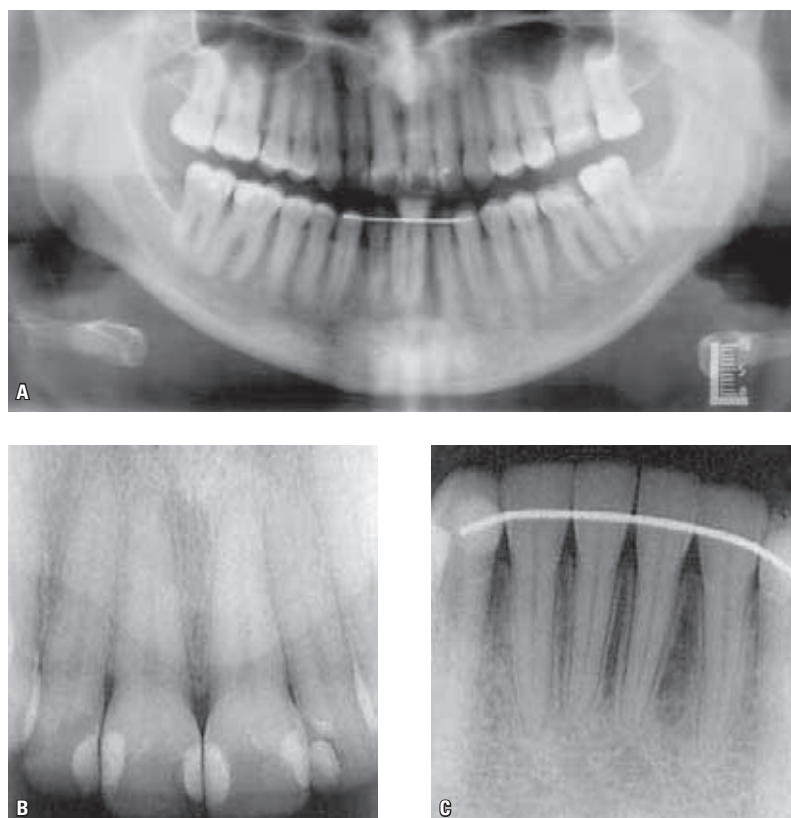


FIGURE 8 - Final radiographs: **A)** Panoramic and **B, C)** incisor periapical.

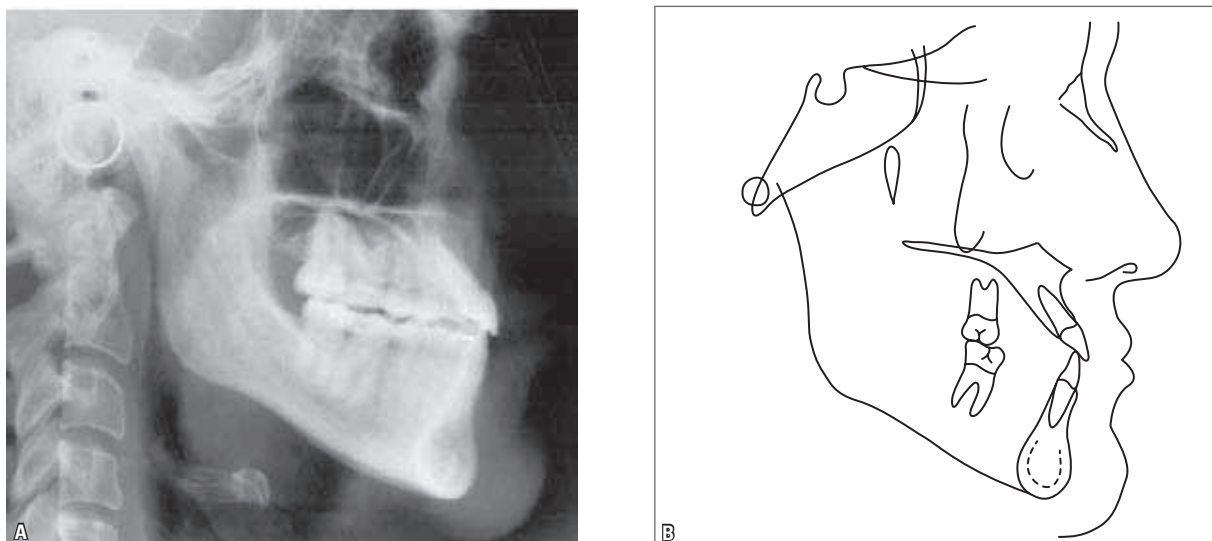


FIGURE 9 - Final lateral cephalogram (A) and cephalometric tracing (B).

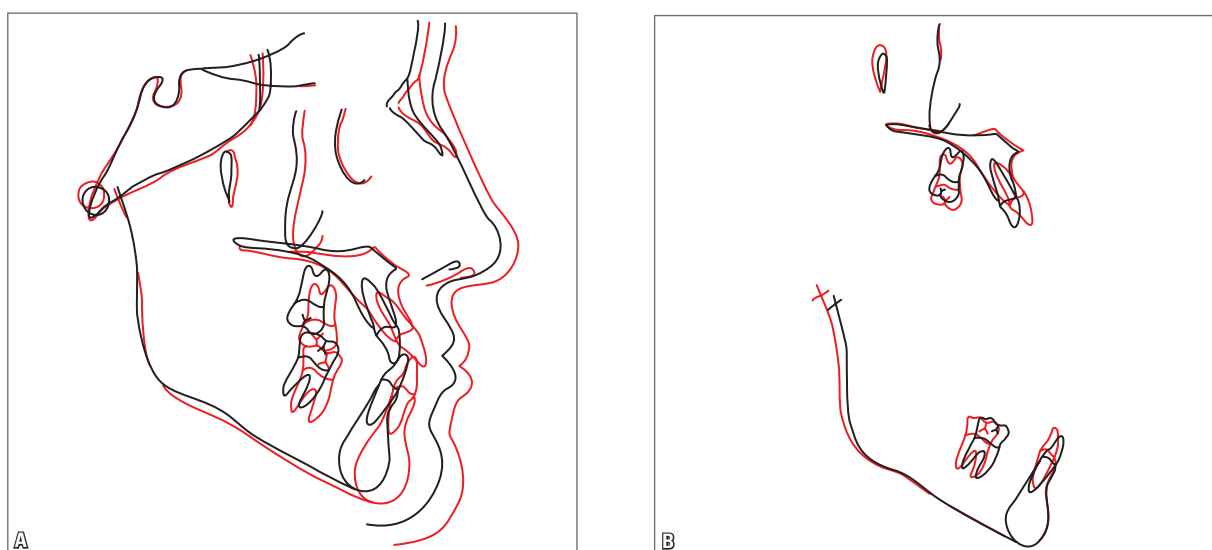


FIGURE 10 - Total and partial superimposition of initial (black) and final (red) cephalometric tracings.

occurred in the premolar and molar regions with a 5 mm increase in intermolar width (Table 2), contributing to posterior crossbite correction while eliminating a functional shift which had been detected and resulted from premature torque in the maxillary left canine<sup>4,7</sup> (Figs 6 and 7).

In the lower arch, some improvement was achieved in tooth alignment and a 9° decrease,

also deliberate, in incisor axial inclination (Fig 9 and Table 1).<sup>1</sup> In the posterior region, a slight 2 mm contraction was noted at molar level (Table 2), which also contributed to posterior crossbite correction (Figs 6 and 7).

The relationship between the upper and lower arches was quite satisfactory, with normal molar occlusion well established on both sides,

TABLE 1 - Summary of cephalometric measurements.

|                  | MEASUREMENTS                               | Standard values | A      | B      | Difference A/B |
|------------------|--------------------------------------------|-----------------|--------|--------|----------------|
| Skeletal Pattern | SNA (Steiner)                              | 82°             | 80°    | 81°    | 1              |
|                  | SNB (Steiner)                              | 80°             | 82.5°  | 84°    | 1.5            |
|                  | ANB (Steiner)                              | 2°              | - 2.5° | - 3°   | 0.5            |
|                  | Convexity Angle (Downs)                    | 0°              | - 8°   | - 9°   | 1              |
|                  | Y-Axis (Downs)                             | 59°             | 61°    | 60°    | 1              |
|                  | Facial Angle (Downs)                       | 87°             | 87°    | 88°    | 1              |
|                  | SN – GoGn (Steiner)                        | 32°             | 29°    | 29°    | 0              |
|                  | FMA (Tweed)                                | 25°             | 28°    | 27°    | 1              |
| Dental Pattern   | IMPA (Tweed)                               | 90°             | 91°    | 81°    | 10             |
|                  | $\underline{1}$ – NA (degrees) (Steiner)   | 22°             | 29°    | 39°    | 10             |
|                  | $\underline{1}$ – NA (mm) (Steiner)        | 4 mm            | 2 mm   | 5.5 mm | 3.5            |
|                  | $\overline{1}$ – NB (degrees) (Steiner)    | 25°             | 25°    | 16°    | 9°             |
|                  | $\overline{1}$ – NB (mm) (Steiner)         | 4 mm            | 5 mm   | 3 mm   | 2              |
|                  | $\frac{1}{1}$ – Interincisal Angle (Downs) | 130°            | 128°   | 128°   | 0              |
|                  | $\overline{1}$ – APo (mm) (Ricketts)       | 1 mm            | 6.5 mm | 5 mm   | 1.5            |
| Profile          | Upper Lip – S Line (Steiner)               | 0 mm            | -2 mm  | -2 mm  | 0              |
|                  | Lower Lip – S Line (Steiner)               | 0 mm            | 0 mm   | 0 mm   | 0              |

TABLE 2 - Intermolar and intercanine widths (in mm).

| MEASUREMENTS                              | A       | B       | Difference A/B |
|-------------------------------------------|---------|---------|----------------|
| Inter canine Width:<br>Upper / Lower (mm) | 35 / 28 | 35 / 26 | 0 / 2          |
| Inter molar Width:<br>Upper / Lower (mm)  | 50 / 50 | 55 / 48 | 5 / 2          |

adequate intercuspation and crossbite correction in the anterior and left regions<sup>6</sup> (Figs 6 and 7).

Facial profile remained concave with a slight improvement in the relationship between the upper and lower lips. In frontal view, a slight decrease occurred in mandibular deviation (Fig 6).

The analysis of panoramic and periapical radiographs (Fig 8), showed good root parallelism with no significant morphological changes. The lateral cephalometric radiograph (Fig 9, A), clearly shows that the anterior crossbite was corrected.

## FINAL CONSIDERATIONS

It is noteworthy that most of the results were related to the difference between MIC and CR, diagnosed during the initial clinical examination. Manipulating the mandible at CR<sup>6</sup> was decisive for correcting the Class III molar relationship. It also contributed to reducing mandibular deviation and diagnosing

the posterior crossbite, which was unilateral but functional.<sup>5</sup> At CR, a transverse relationship was noted between the dental arches.

The initial and final X-rays (Figs 4A and 9A) were performed with different RX devices and changes were introduced in the X-ray acquisition procedures (note the difference in the SN line), thereby restricting the analysis of cephalometric tracing overlays (Fig 10). However, the differences in the axial inclination of upper and lower incisors in the partial superimposition of the maxilla and mandible are remarkable (Fig 10, B) as well as in

the relation between incisors in total superimposition (Fig 10, A).

Today, after 18 months of retention, the patient remains under periodic control and has not shown any occlusal instability. She has displayed outstanding compliance in wearing the upper removable appliance as well as throughout treatment. Nor did she complain of any pain in her left TMJ during the active and retention periods. After removal of the fixed appliances, the patient was referred for replacement of her amalgam restorations (Fig 1) with composite resin fillings (Fig 6).

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# Alveolar bone morphology under the perspective of the computed tomography: Defining the biological limits of tooth movement

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## Abstract

**Introduction:** Computed tomography (CT) permits the visualization of the labial/buccal and lingual alveolar bone. **Objectives:** This study aimed at reporting and discussing the implications of alveolar bone morphology, visualized by means of CT, on the diagnosis and orthodontic treatment plan. **Methods:** Evidences of the interrelationship between dentofacial features and labial/buccal and lingual alveolar bone morphology, as well as the evidences of the effects of the orthodontic movement on the thickness and level of these periodontal structures were described. **Results:** Adult patients may present bone dehiscences previously to orthodontic treatment, mainly at the region of the mandibular incisors. Hyperdivergent patients seems to present a thinner thickness of the labial/buccal and lingual bone plates at the level of the root apex of permanent teeth, compared to hypodivergent patients. Buccolingual tooth movement might decentralize teeth from the alveolar bone causing bone dehiscences. **Conclusion:** The alveolar bone morphology constitutes a limiting factor for the orthodontic movement and should be individually considered in the orthodontic treatment planning.

**Keywords:** Computed tomography. Alveolar bone. Dehiscence. Orthodontics.

## INTRODUCTION

Computed tomography (CT) permits the dental professional to visualize what the conventional radiographs never showed: the thickness and level of the labial/buccal and lingual alveolar bone.

Previously to the introduction of CT, the visualization of labial/buccal and lingual bone plates was not possible due to image superimposition of conventional radiographs and due to gingival covering in clinical analysis.

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The thickness of the alveolar bone defines the boundaries of the orthodontic movement and challenging these limits may cause undesirable collateral effects for the periodontal tissues. The most critical orthodontic movement includes dental arch expansion and incisor buccal-lingual movements.<sup>7</sup> Such mechanics can decentralize teeth from the alveolar bone envelope, causing bone dehiscences and fenestrations and gingival recession, depending on the initial morphology of alveolar bone as well as on the amount of tooth movement.

Due to the high definition and sensitivity, helical and Cone-Beam CT images can show bone dehiscences and fenestrations.<sup>8,9,17,18</sup> Bone dehiscences can be defined as an increase in the distance between the cementoenamel junction (CEJ) and the buccal or lingual alveolar bone crest (Fig 1). Bone fenestrations are alveolar bone discontinuation on the buccal or lingual aspects which exposes a small root region (Fig 2). Before the introduction of CT, efforts to define tooth movement effects on the buccal and lingual bone plates were concentrated on animal experiments<sup>24,29</sup> and on studies with conventional radiographs.<sup>21</sup> Currently, CT studies on the alveolar bone morphology before orthodontic treatment<sup>12,25,30</sup>, as well as on the consequences of tooth movement on the alveolar bone are

numerous.<sup>11,16,22,23</sup> These evidences can change usual treatment plans, pointing the limits of the therapeutic choices in Orthodontics.

The classical Orthodontics considered the amount of dental crowding, the lower incisor position and the growth facial pattern as the tripod which defines diagnosis and treatment planning. Contemporary Orthodontics included the smile and facial esthetics to the list of importance. Future Orthodontics will add the patient initial periodontal morphology to the other four features. With time, Cone-Beam Computed Tomography (CBCT) will answer if it is sound to move tooth to an edentulous region of atrophic alveolar bone. CBCT will elucidate the individual acceptable amplitude of tooth movement during a malocclusion compensation or decompensation. Additionally, the buccal bone plate morphology will help the orthodontist to decide if expansion or extraction should be performed. The visualization of the anatomical details of our patients and the comprehension of tooth movement collateral effects permits to recognize our limits, practicing a more secure Orthodontics.

## MORPHOLOGY OF THE ALVEOLAR BONE

CT axial sections show a general panorama of buccal and lingual bone plate thickness (Figs 3 and 4).

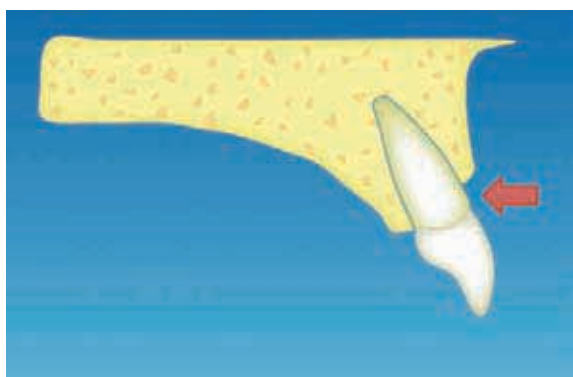


FIGURE 1 - Bone dehiscence.



FIGURE 2 - Bone fenestration.



FIGURE 3 - Axial section of the maxilla at the middle third of the roots of maxillary teeth. Observe the thin labial/buccal bone plates of permanent teeth.

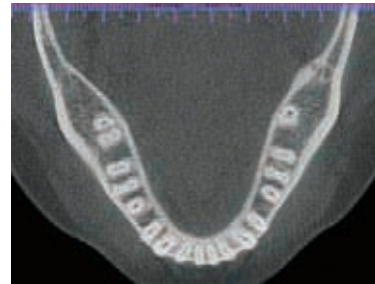


FIGURE 4 - Axial section of the mandible at the middle third of the roots of mandibular teeth.

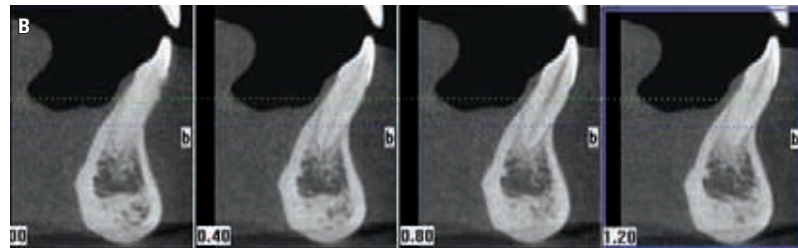
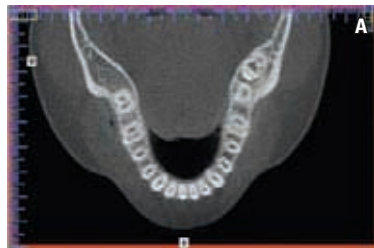


FIGURE 5 - Facial bone dehiscences in the lower incisors in a 21-year-old patient, previously to orthodontic treatment (i-CAT CBCT, voxel size of 0.2 mm). **A)** Axial sections reveal a disproportion between buccal-lingual dimensions of the alveolar ridge and the volume of mandibular incisor roots. **B)** Cross sections of central incisors show an increased distance between the alveolar bone crest and the cemento-enamel junction.

Analyzing an axial section of the maxilla at the level of the middle third of the roots, it becomes clear that the labial/buccal bone plate is very thin both in the anterior and posterior regions (Figs 3 and 4). The permanent canines, due their greater volume, and the mesiobuccal root of the first molars, present a buccal bone plate even thinner compared to the other maxillary teeth. The maxillary lingual bone plate thickness is thicker than the buccal bone plate, and in general, the maxillary incisors have the thicker lingual bone plate (Fig 3).

In the mandible, the labial/buccal bone plate also is very thin, with the exception of the second and third permanent molars which are covered for a very thick buccal bone plate (Fig 4). Equally to the maxilla, the lingual bone plate of mandibular teeth is thicker compared to the buccal bone plate, with the exception of the lower incisor regions which show a very thin bone plate both in

the labial and lingual aspects. In the mandible, the thickness of the alveolar ridge remarkably decreases from the posterior to the anterior region.<sup>25</sup> In the region of mandibular symphysis, visualizing bone dehiscences previously to orthodontic treatment is not rare, mainly in adult patients<sup>7</sup> (Fig 5). The explanation is the disproportion between the buccolingual diameter of the incisor roots and the buccal-lingual diameter of the alveolar ridge which may not have enough thickness to contain all the root volume<sup>7</sup> (Fig 6).

A recent study measured the labial/buccal and lingual bone plate thickness of maxillary and mandibular permanent teeth, previously to orthodontic treatment<sup>5</sup>. For the maxilla, CT axial sections passing 3 and 6 mm apically to CEJ of maxillary teeth were analyzed (Fig 7). For the mandible, the measurements were performed on the axial sections passing 4 and 8 mm apically to CEJ of the lower teeth (Fig 8). The reference values for the labial/buccal

and lingual bone plate thickness in adolescent and young adults is shown in Figures 7 and 8.<sup>5</sup> Lee et al<sup>15</sup> showed similar results for the thickness of the buccal bone plate in Korean adults with normal occlusion.



FIGURE 6 - Sagittal section passing through the mandibular central incisor region. Observe the presence of bone dehiscences. The disproportion between buccal-lingual root diameter and faciolingual dimension of mandibular symphysis is notable (Source: Moraes<sup>20</sup>).

Teeth with eccentric positions in the alveolar ridge, as crowded incisors and canines, constitute risk factors for bone dehiscences and fenestrations<sup>7</sup> (Figs 9 and 10).

The growth facial pattern has an influence on the morphology of labial/buccal and lingual bone plates. Hypodivergent patients present a thicker alveolar ridge, compared to normodivergent or hyperdivergent patients.<sup>12,26</sup> Hyperdivergent patients present a thinner mandibular symphysis and a thinner alveolar ridge in the anterior region of the mandible, compared to the other facial patterns<sup>4,13</sup> (Fig 11). Regarding the thickness of the buccal and lingual bone plates, the difference between hypodivergent and hyperdivergent patients seems to be restricted to the level of the root apex. The thickness of the bone plates at the level of cervical and middle thirds of the root is very similar in different facial patterns.<sup>5</sup> However, the distance from the root apex to the external surface of buccal and lingual cortical bone is greater in hypodivergent patients compared to hyperdivergent patients<sup>26</sup> (Fig 12). Under this perspective, in hypodivergent patients, the orthodontic treatment planning presents less restriction for

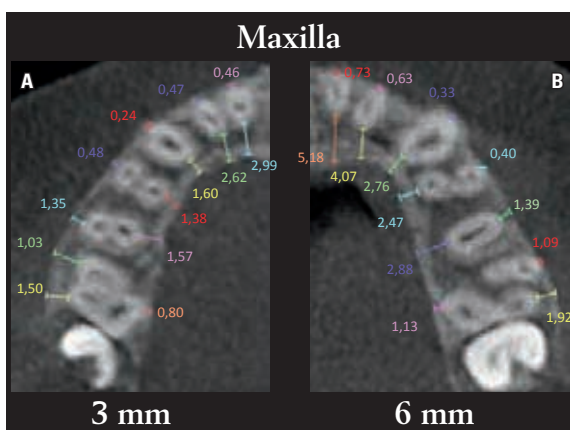


FIGURE 7 - Mean thickness of buccal and lingual bone plates of maxillary teeth, previously to orthodontic treatment, in adolescents and young adults. **A)** Mean thickness 3 mm apically to CEJ; **B)** Mean thickness 6 mm apically to CEJ (Source: Ferreira<sup>5</sup>).

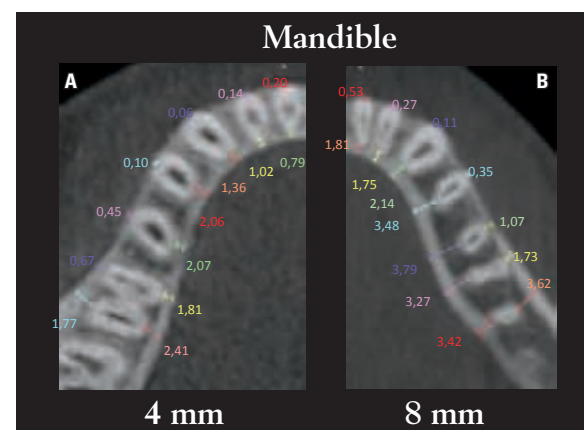


FIGURE 8 - Mean thickness of buccal and lingual bone plates of mandibular teeth, previously to orthodontic treatment, in adolescents and young adults. **A)** Mean thickness 4 mm apically to CEJ; **B)** Mean thickness 8 mm apically to CEJ (Source: Ferreira<sup>5</sup>).

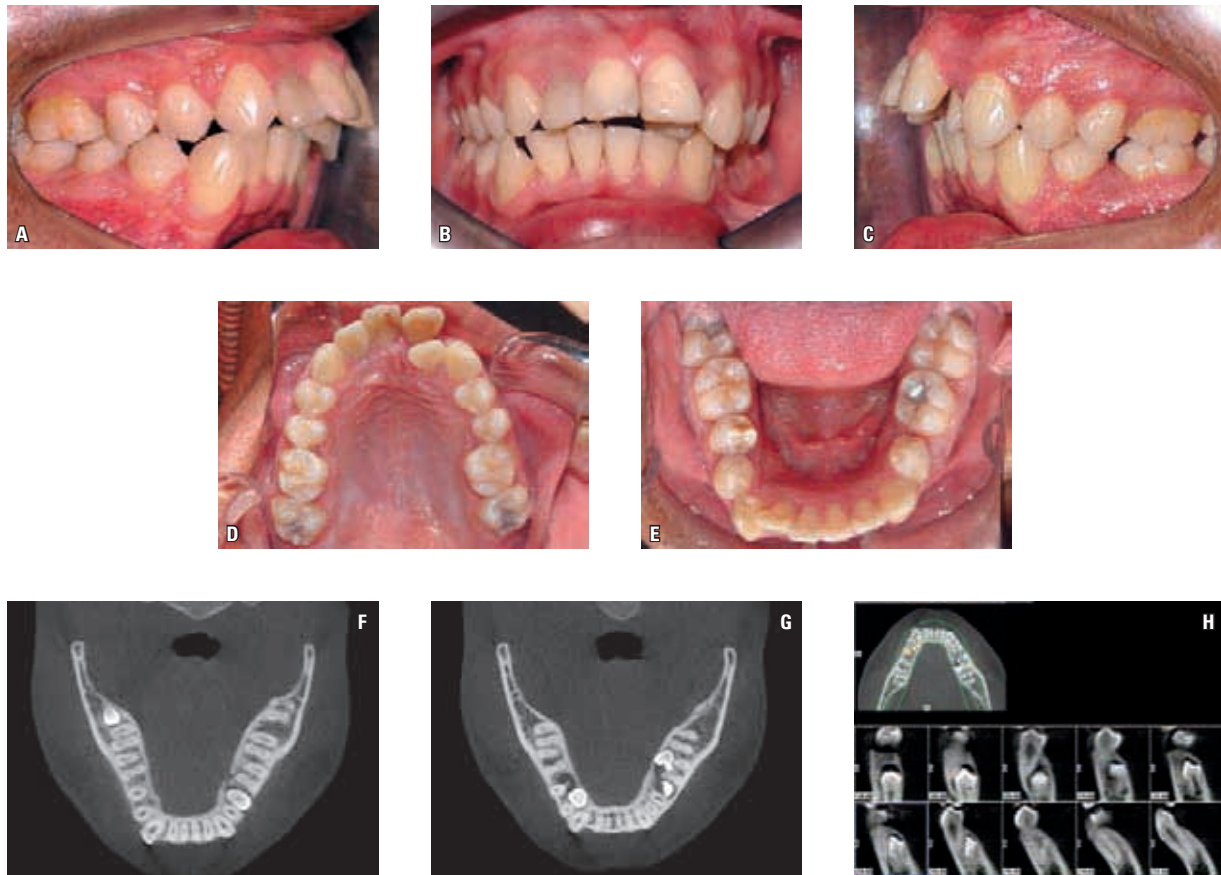


FIGURE 9 - **A-E)** This case illustrates a Class II malocclusion with maxillary and mandibular anterior crowding. Observe that the right mandibular canine is dislocated toward buccal. **F, G)** Axial sections at the level of CEJ and at the level of the cervical third of the root of the right canine, respectively. In figure **G)** observe the absence of alveolar bone in the buccal aspect of the right canine. **H)** Cross sections of the right mandibular canine. The most lower and right image shows the presence of buccal bone dehiscence.

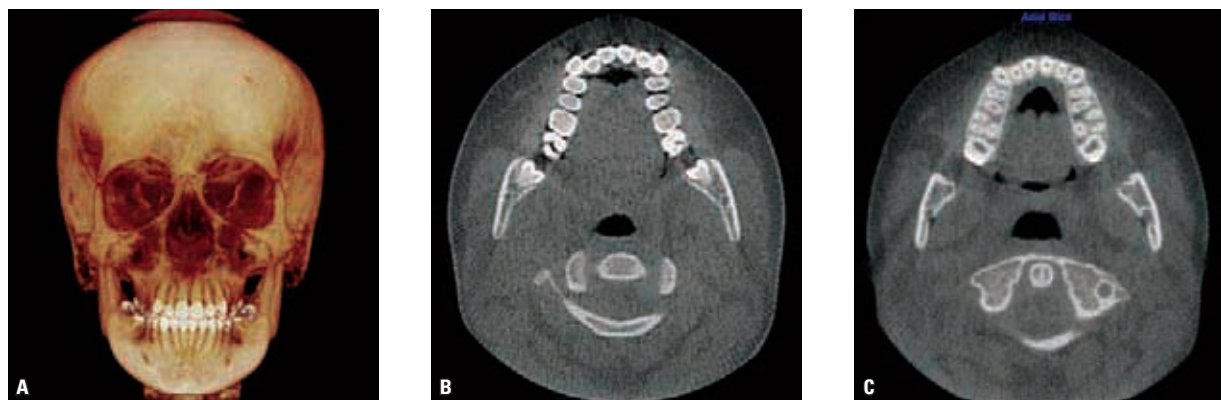


FIGURE 10 - Buccal bone dehiscences at the canine region. **A)** 3D reconstructions; **B, C)** axial sections at the level of the crown and at the cervical third of the root of the maxillary canines. Observe the absence of buccal bone plate in figure **C**.

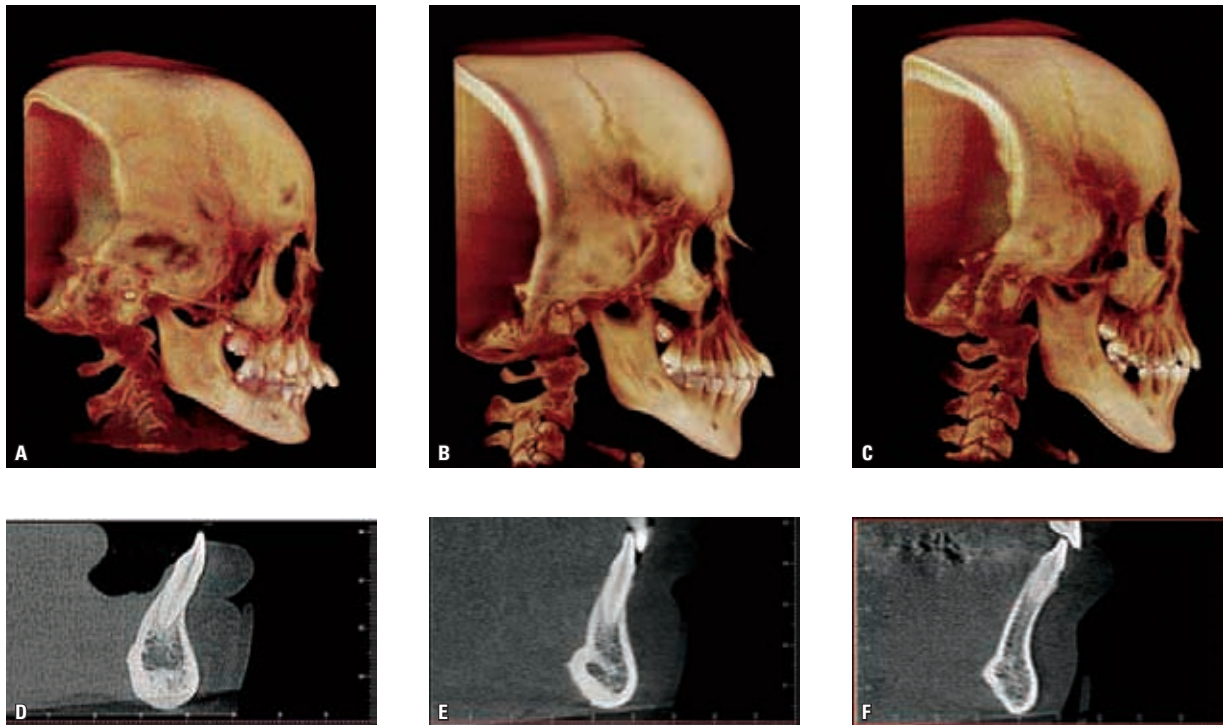


FIGURE 11 - Morphology of mandibular symphysis in different facial types: **A** and **D**) Hypodivergent patient; **B** and **E**) Normodivergent patient; **C** and **F**) Hyperdivergent patient.

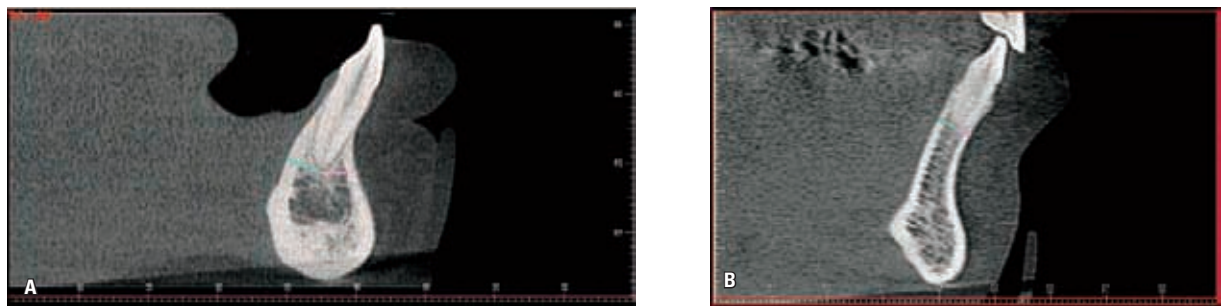


FIGURE 12 - The main difference between hypodivergent and hyperdivergent patients, regarding the morphology of the alveolar bone, is the thickness of the labial/buccal and lingual bone plates at the level of root apices. In hypodivergent patients (**A**), there is a thicker alveolar ridge, as well as a thicker facial and lingual bone plate thickness in the apical third of the roots, compared to hyperdivergent patients (**B**). On the other hand, the thickness of buccal and lingual bone plates at the level of cervical and middle thirds of the roots is very similar for both facial growth patterns.

moving the lower incisors in the labial-lingual direction. Conversely, hyperdivergent patients present more restrictions for moving the lower incisors in the labial-lingual direction, mainly at the level of the root apex. In this way, in face of the need of labial-lingual movement of the mandibular incisors, tooth tipping should be

preferred instead of bodily tooth movement in hyperdivergent patients. Tooth translation would move, besides the tooth crown, also the root apex, with the possibility to move tooth throughout the limits of the alveolar bone. On the other hand, tooth tipping with a rotation center at the level of the root apex could

change tooth crown position, while the root apex would be maintained inside the alveolar bone limits. Round arch wires, or rectangular arch wires with reduced size compared to the bracket slot size, could be used for accomplishing tipping movements in these patients. Additionally, when the maintenance of the position of root apex is intended, the classic procedure of resistant wire torque should not be performed during anteroposterior tooth movement.

The labial-lingual movement of the mandibular incisors should be carefully planned in hyperdivergent patients with bimaxillary protrusion, in Class III camouflage treatments, in dental Class II compensation or in Class III malocclusions treated surgically. In long face patients with an extreme vertical growth pattern, the ideal position of the mandibular incisors should be the initial, and therefore natural, incisor position.

Comparing hyperdivergent patients with different sagittal maxilomandibular relationships, it was verified that Class III patients present a mandibular symphysis even thinner than Class I and Class II patients.<sup>14,30</sup> Considering these evidences, the Orthodontist should be careful when planning labial-lingual movements of the mandibular incisors, both for compensatory and surgical treatment planning. Again, tipping movement of mandibular incisors should be preferred instead of bodily tooth movements in hyperdivergent Class III patients.

Besides the mandibular symphysis region, other area which is critical regarding the thickness of bone plates is the anterior region of the maxilla in cleft patients (Fig 13). In children with bilateral cleft lip and palate, although the thin thickness of alveolar bone plates surrounding the cleft neighboring teeth (Table 1), the alveolar crests show a normal level, without the presence of bone dehiscences. The thin periodontal bone surrounding the teeth next to the alveolar cleft constitutes a limitation for tooth movement previously to the alveolar bone graft procedure in these patients.

## PERIODONTAL CONSEQUENCES OF BUCCAL-LINGUAL TOOTH MOVEMENT

Tooth movements which may decentralize teeth from the alveolar ridge represent the most critical movement for developing bone dehiscences.<sup>7</sup> Therefore, buccal-lingual movements present more risk for breaking the limits of the alveolar bone, causing buccal and lingual bone plate resorption.

There is a clear correlation between buccal-lingual tooth movement and the occurrence of buccal bone dehiscences. Study in animals showed that the labial movement of the incisors, even using light forces, produces an increase in the distance between buccal alveolar crest and CEJ.<sup>24,29</sup> Interesting studies conducted in human maxillary bones extracted during autopsy presented similar conclusions<sup>27,28</sup> (Fig 14). Decreasing changes in the thickness and level of labial/buccal bone plates when teeth are moved toward this direction indicate the absence of equivalent compensatory bone apposition under the buccal periosteum. The occurrence of bone dehiscences after incisor sagittal movements also have been suggested in studies conducted with conventional radiographs and laminography<sup>21</sup> and in clinical studies which reported the development of gingival recession in teeth moved naturally or orthodontically toward the vestibulum.<sup>1,2,3</sup>

Bone dehiscence caused by tooth movement cannot be seen clinically. The gingival clinical features do not change after the apical migration of the bone crest level, at least in the short term. Gingival recession has not been observed immediately after the development of bone dehiscences. The junctional epithelia migration and the loss of attachment have not followed the apical migration of the labial/buccal bone crest,<sup>24,29</sup> mainly in the absence of gingival inflammation.<sup>29</sup> In reality, the occurrence of bone dehiscences is followed by the establishment of a long conjunctive attachment, and then, the gingival sulcus does not become deeper.<sup>29</sup>

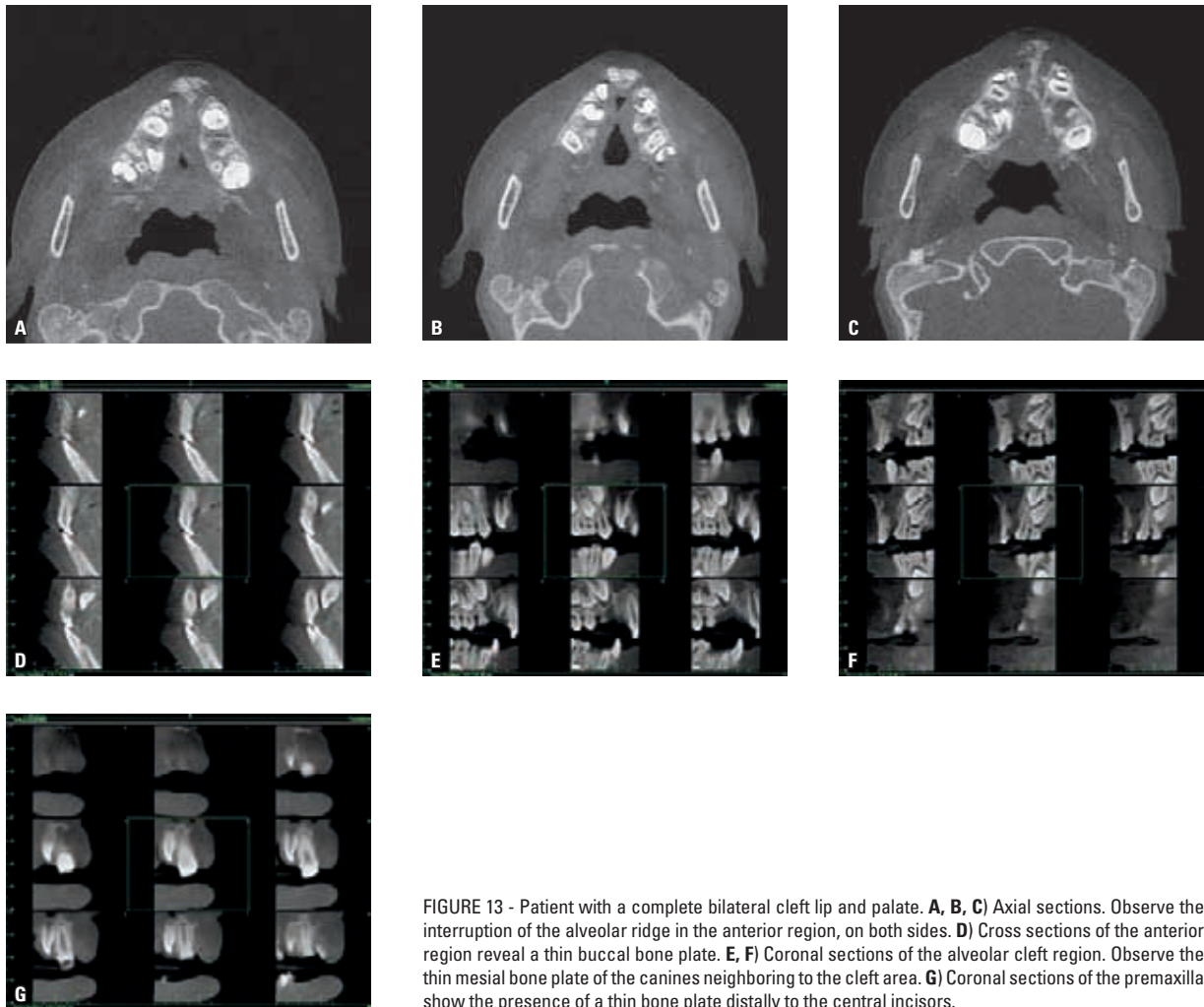


FIGURE 13 - Patient with a complete bilateral cleft lip and palate. **A, B, C**) Axial sections. Observe the interruption of the alveolar ridge in the anterior region, on both sides. **D**) Cross sections of the anterior region reveal a thin buccal bone plate. **E, F**) Coronal sections of the alveolar cleft region. Observe the thin mesial bone plate of the canines neighboring to the cleft area. **G**) Coronal sections of the premaxilla show the presence of a thin bone plate distally to the central incisors.

TABLE 1 - Mean and standard deviation for alveolar bone thickness of teeth adjacent to palatal cleft (transforamen bilateral fissure), in mixed dentition children with mean age of 9 years.

| LEVEL<br>(in relation to the CEJ) | ALVEOLAR BONE THICKNESS          |      |         |      |        |      |                                  |      |         |      |        |      |
|-----------------------------------|----------------------------------|------|---------|------|--------|------|----------------------------------|------|---------|------|--------|------|
|                                   | Teeth Mesial to the cleft (n=20) |      |         |      |        |      | Teeth distal to the cleft (n=20) |      |         |      |        |      |
|                                   | Buccal                           |      | Lingual |      | Distal |      | Buccal                           |      | Lingual |      | Mesial |      |
|                                   | mean                             | SD   | mean    | SD   | mean   | SD   | mean                             | SD   | mean    | SD   | mean   | SD   |
| 3 mm                              | 0.62                             | 0.42 | 1.44    | 0.67 | 1.55   | 0.79 | 0.75                             | 0.58 | 2.07    | 1.07 | 1.59   | 1.10 |
| 6 mm                              | 0.95                             | 0.37 | 2.78    | 2.05 | 1.60   | 0.66 | 1.05                             | 0.40 | 2.42    | 1.93 | 1.61   | 1.08 |
| Root Apex                         | 1.49                             | 0.51 | 2.33    | 1.34 | 2.72   | 4.69 | 1.67                             | 0.48 | 3.59    | 2.43 | 1.16   | 0.94 |



FIGURE 14 - Mandible extracted during autopsy in a young patient who passed away in an accident while the comprehensive orthodontic treatment was been performed. Remarkable bone dehiscences in the mandibular symphysis were related to incisor lingual movement during anterior retraction, as well as to rotational movements of the incisor in a thin symphysis (Source: Wehrbein, Bauer and Diedrich<sup>27</sup>).

Computed tomography widened even more our vision regarding the repercussion of tooth movement on the buccal and lingual alveolar bone. CT has revealed that arch expansion, incisor protrusion or retraction represent the movements which have the greater risk of causing bone dehiscences<sup>7</sup>. The orthodontic retraction of maxillary and mandibular incisors cause a decrease in the thickness of the lingual bone plate in the coronal and middle third of the roots, as well as lingual bone dehiscences.<sup>23</sup> The thickness of the labial bone plate has not been changed during incisor retraction, with the exception of the coronal third of the facial bone plate in the mandibular incisor region which may present a reduction.<sup>23</sup>

The pre-surgical orthodontic treatment for decompensating hyperdivergent Class III patients can determine notable bone dehiscences in the area of mandibular symphysis.<sup>14</sup> In the permanent dentition, both the maxillary rapid expansion<sup>11,12</sup> and the slow maxillary expansion,<sup>7</sup> might cause buccal bone dehiscences in the posterior teeth, mainly in patients with an initial thin buccal bone plate (Fig 15). Maxillary first premolars showed more critical bone dehiscences than the first molars during RME, due to the anatomical

characteristics of the maxilla<sup>11</sup> (Fig 16). The maxillary first premolars are located in an area which becomes narrower upwards (Fig 16, A). In this area, when there is a bodily buccal movement, the root may perforate the alveolar bone much more easily.<sup>11</sup> The first molars are located in a maxillary region that widens upwards (Fig 16, B). Hyrax expanders caused more extensive dehiscences than Haas type expanders.<sup>11</sup>

All these evidences are important to guide the Orthodontists to prevent future gingival recessions. Predisposing and precipitant factors of gingival recession should be prevented in patients submitted to maxillary expansion. Initially, the professional should recommend the gingival graft in regions with a poor amount of keratinized mucosa as well as to motivate oral hygiene in order to avoid traumatic brushing or gingival inflammation. Additionally, the periodontal consequences of rapid maxillary expansion in the permanent dentition highlight the importance of early intervention. During the deciduous and mixed dentition RME produces a larger orthopedic effect and transfers the anchorage to deciduous molars and canines. Although there is no evidence that RME cause buccal bone dehiscences in the deciduous

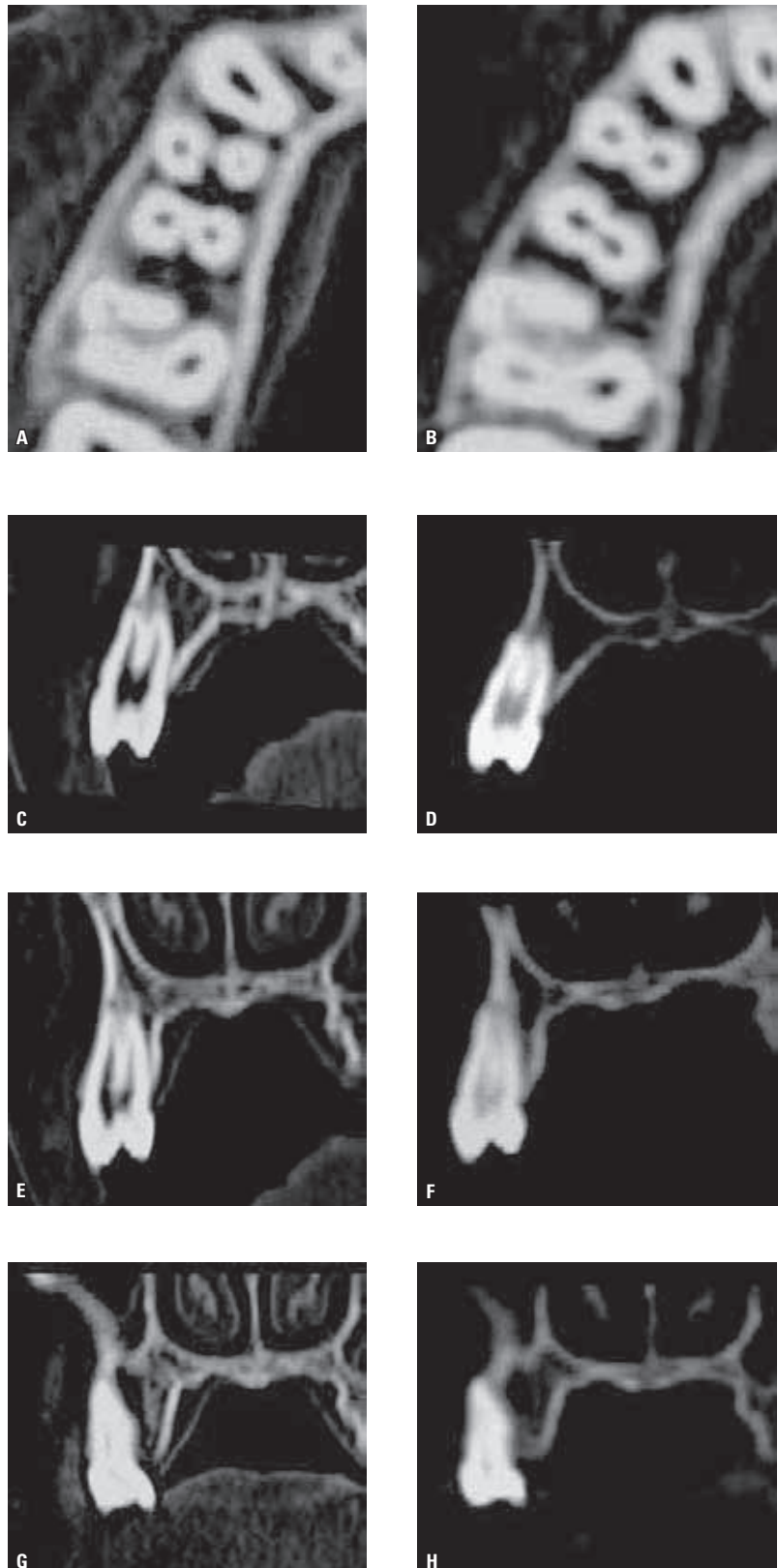


FIGURE 15 - Periodontal effects of RME. **A, B**) Maxillary axial sections before and after RME, respectively. Observe that the orthodontic effect of maxillary expansion produced a decrease in the thickness of the buccal bone plate of posterior teeth. **C, D**) Cross sections of a maxillary first premolar before and after RME, respectively. Observe the development of buccal bone dehiscences after expansion, in a region which originally had a very thin bone plate. **E, F**) The same example in the opposite side of the dental arch. **G, H**) Cross sections of the maxillary first molar before and after RME, respectively, showing that tooth movement has occurred through the alveolar bone and not together with the alveolar bone.

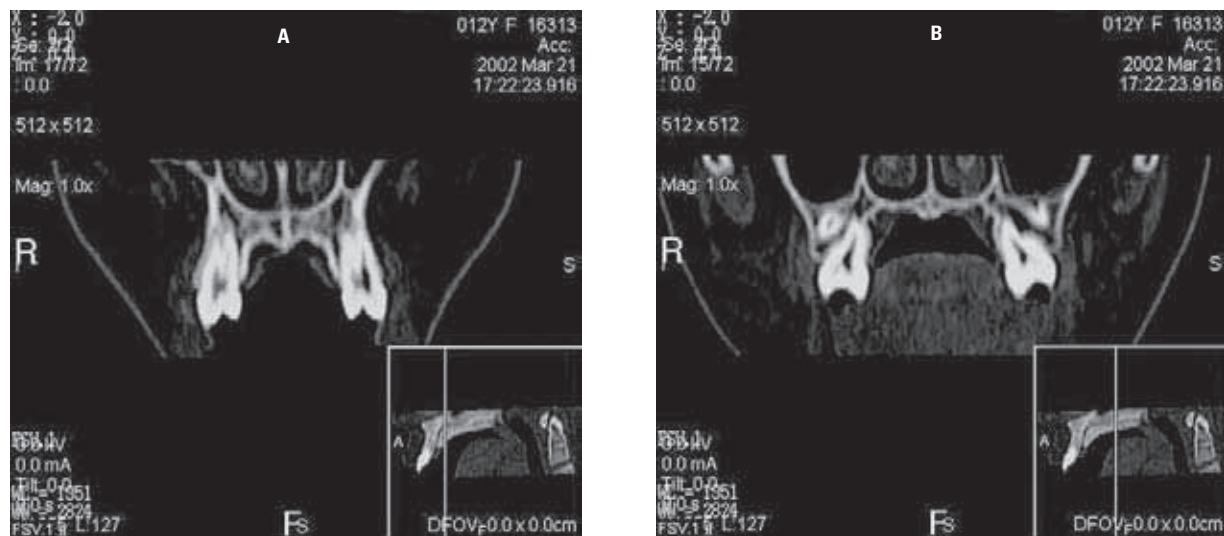


FIGURE 16 - Maxillary external contour on CT coronal reconstruction: **A)** First premolar area. **B)** First molar area. First premolars are located in a maxillary region which becomes narrower upwards (**A**). In this area, when there is a bodily buccal movement, the root may easily perforate the alveolar bone.

and mixed dentitions, despite the possibility of some degree of periodontal involvement, the future eruption of the succeeding permanent teeth will be followed by new alveolar bone reestablishing the periodontal integrity.

Computed tomography studies also have demonstrated that, during the retention phase, some partial regeneration of bone dehiscences caused by tooth movements may take place.<sup>7</sup> However, we are just at the beginning. With the introduction of CBCT, the future seems promising in providing additional evidences on the longitudinal effect of several orthodontic mechanics on the alveolar bone.

#### PERIODONTAL CONSEQUENCES OF MESIO-DISTAL TOOTH MOVEMENT

Another clinical situation which demands certain concern with the integrity of buccal and lingual bone plates is the mesiodistal movement of posterior teeth toward regions with atrophic

alveolar bone. In patients with tooth agenesis or loss of permanent first molars, closing the arch space by means of mesial movement of posterior teeth is mechanically possible, mainly with the aid of skeletal anchorage devices. However, edentulous alveolar ridge usually presents a reduced buccolingual dimension. When moving posterior teeth toward atrophic alveolar bone regions, what can happen with the alveolar bone surrounding these teeth? Does the buccal and lingual alveolar bone follow the tooth movement, or does this type of movement cause bone dehiscences?

An interesting study was conducted on the extracted jaws of a 19-year-old patient who passed away in an accident while she was under comprehensive orthodontic treatment.<sup>28</sup> The patient presented agenesis of the maxillary second premolars and the right maxillary lateral incisor. The orthodontic treatment was conducted closing the spaces of tooth agenesis. The histological analyzes showed the presence

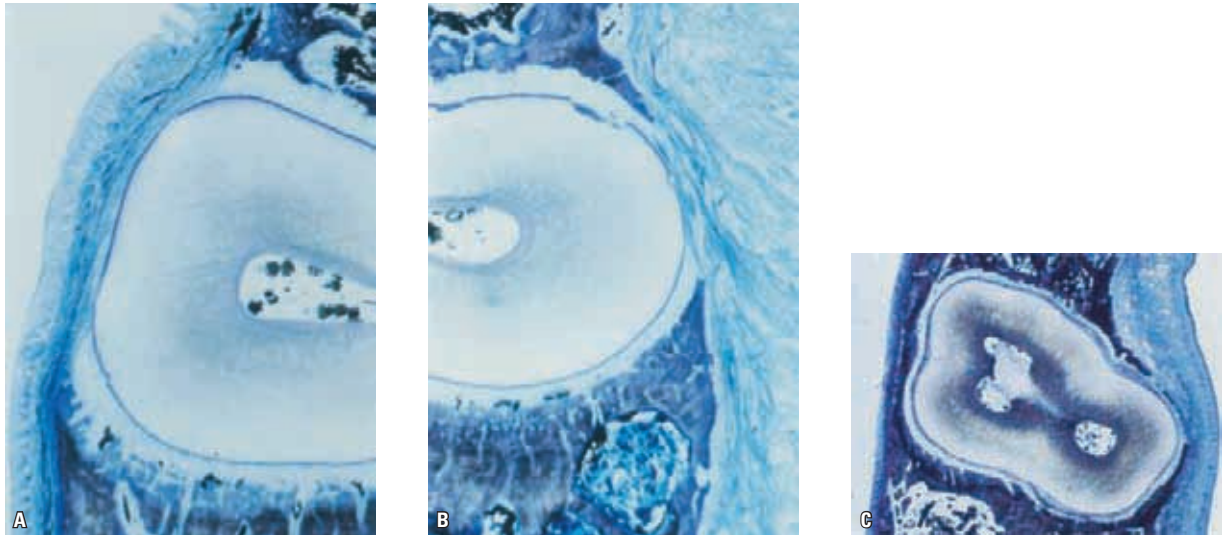


FIGURE 17 - Histological axial sections of a human maxilla extracted during autopsy. Observe bone dehiscences caused after tooth movement toward regions of atrophic alveolar bone (due to tooth agenesis). **A)** Buccal regions of the maxillary right first premolar; **B)** Lingual region of the same tooth; **C)** Lingual regions of the maxillary right first molar (Source: Wehrbein, Fuhrmann and Diedrich<sup>28</sup>).

of bone dehiscences in the teeth moved to the regions of atrophic alveolar bone<sup>28</sup> (Fig 17). Additionally, the authors observed that the alveolar bone may follow tooth body movement, causing compensatory bone neoformation in the buccal and lingual periosteum, when the tooth movement was very slow.<sup>28</sup> Cone-Beam Computed Tomography has much value for permitting the clinician to follow these clinical cases and for showing the pattern of bone remodeling in the region of atrophic alveolar bone.

Other critical movement for the development of bone fenestrations and dehiscences is the mesiodistal movement of maxillary molars toward areas with maxillary sinuses extensions<sup>28</sup> as well as rotational tooth movements.<sup>27</sup> During orthodontic alignment, the rotation correction can cause resorption of the facial and lingual bone plates when the tooth has a root with the buccal-lingual dimension greater than the mesiodistal diameter.<sup>27</sup>

#### CT SCANS REQUIREMENTS FOR VISUALIZING ALVEOLAR BONE PLATES

In 1995, helical CT was validated for the identification of labial/buccal and lingual alveolar bone.<sup>10</sup> Only alveolar bone plates with the thickness smaller than 0.2 mm could not be apparent in medical CT images.<sup>10</sup> Moreover, a study in human cadavers showed that artificial horizontal bone defects made in the buccal and lingual alveolar plates were identified in helical CT images while could not be visualized in periapical radiographs<sup>9</sup>. In 1996, an experimental study which performed artificial bone dehiscences in the maxillary bone of human cadavers has concluded that CT was the only mean of diagnosis which permits a quantitative evaluation of buccal-lingual thickness of both the alveolar ridge and the buccal and lingual bone plates.<sup>6</sup> In 2008, a high accuracy of CBCT for quantitative analyses of the level of buccal and lingual bone plates was demonstrated.<sup>17,18</sup>

The sensitivity and specificity for the identifications of bone dehiscences and fenestrations were evaluated in tridimensional reconstructions of CBCT images taken with voxel size of 0.38 mm and 2 mA.<sup>16</sup> Tridimensional reconstructions of dry skulls showed good sensitivity and specificity (0.8) for the identifications of bone fenestrations<sup>16</sup>. On the other hand, the identifications of bone dehiscences presented high specificity (0.95) but low sensitivity (0.40).<sup>16</sup> This means that CBCT 3D reconstructions show a small frequency of false-positive results and a high frequency of false-negative results for bone dehiscences. In other words, when bone dehiscences are apparent in CBCT 3D reconstructions, it means that they really exist. However, in the regions that bone dehiscences are not visualized, one cannot conclude that they do not exist.

When the visualization of small anatomical structures (as the buccal and lingual bone plates) in CBCT is desirable, the exam should be performed following some requirements for obtaining good image definition. The spacial definition of the CBCT image (smaller distance for the identification of two different structures) does not correspond to the voxel dimension

(CT smaller image unit).<sup>19</sup> Some properties of CT images as the partial volume mean, the artifacts and the noise can interfere to the spacial resolution.<sup>19</sup> For obtaining a good spatial resolution, the Field of View (FOV) and the voxel dimension should be both the smallest possible.<sup>19</sup> Moreover, the patient should be oriented to avoid movements during the CT exam, preventing movement artifacts.

### FINAL CONSIDERATIONS

Since the last decade, with the introduction of CBCT, Orthodontics has widened its potential for performing a more realistic diagnosis and prognosis. The morphology of the alveolar bone, visualized in CT images, can alter usual orthodontic goals. The repercussions of tooth movements on the alveolar bone, analyzed by means of CBCT, will point the limits of Orthodontics, defining the procedures which can and cannot be performed in each patient individually.

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Sterrett JD, Oliver T, Robinson F, Fortson W, Knaak B, Russell CM. Width/length ratios of normal clinical crowns of the maxillary anterior dentition in man. *J Clin Periodontol*. 1999 Mar;26(3):153-7.

### Articles with more than six authors

De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, et al. A critical review of the durability of adhesion to tooth tissue: methods and results. *J Dent Res*. 2005 Feb;84(2):118-32.

### Book chapter

Higuchi K. Osseointegration and orthodontics. In: Branemark PI, editor. *The osseointegration book: from calvarium to calcaneus*. 1. Osseointegration. Berlin: Quintessence Books; 2005. p. 251-69.

### Book chapter with editor

Breedlove GK, Schorfheide AM. Adolescent pregnancy. 2<sup>nd</sup> ed. Wiczorek RR, editor. White Plains (NY): March of Dimes Education Services; 2001.

### Dissertation, thesis and final term paper

Kuhn RJ. Force values and rate of distal movement of the mandibular first permanent molar. [Thesis]. Indianapolis: Indiana University; 1959.

### Digital format

Oliveira DD, Oliveira BF, Soares RV. Alveolar corticotomies in orthodontics: Indications and effects on tooth movement. *Dental Press J Orthod*. 2010 Jul-Aug;15(4):144-57. [Access Jun 12, 2008]. Available from: [www.scielo.br/pdf/dpjo/v15n4/en\\_19.pdf](http://www.scielo.br/pdf/dpjo/v15n4/en_19.pdf)

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### 1. Registration of clinical trials

Clinical trials are among the best evidence for clinical decision making. To be considered a clinical trial a research project must involve patients and be prospective. Such patients must be subjected to clinical or drug intervention with the purpose of comparing cause and effect between the groups under study and, potentially, the intervention should somehow exert an impact on the health of those involved.

According to the World Health Organization (WHO), clinical trials and randomized controlled clinical trials should be reported and registered in advance.

Registration of these trials has been proposed in order to (a) identify all clinical trials underway and their results since not all are published in scientific journals; (b) preserve the health of individuals who join the study as patients and (c) boost communication and cooperation between research institutions and with other stakeholders from society at large interested in a particular subject. Additionally, registration helps to expose the gaps in existing knowledge in different areas as well as disclose the trends and experts in a given field of study.

In acknowledging the importance of these initiatives and so that Latin American and Caribbean journals may comply with international recommendations and standards, BIREME recommends that the editors of scientific health journals indexed in the Scientific Electronic Library Online (SciELO) and LILACS (Latin American and Caribbean Center on Health Sciences) make public these requirements and their context. Similarly to MEDLINE, specific fields have been included in LILACS and SciELO for clinical trial registration numbers of articles published in health journals.

At the same time, the International Committee of Medical Journal Editors (ICMJE) has suggested that editors of scientific journals require authors to produce a registration number at the time of paper submission. Registration of clinical trials can be performed in one of the Clinical Trial Registers validated by WHO and ICMJE, whose addresses are available at the ICMJE website. To be validated, the Clinical Trial Registers must follow a set of criteria established by WHO.

### 2. Portal for promoting and registering clinical trials

With the purpose of providing greater visibility to validated Clinical Trial Registers, WHO launched its Clinical Trial Search Portal (<http://www.who.int/ictrp/network/en/index.html>), an interface that allows simultaneous searches in a number of databases. Searches on this portal can be carried out by entering words, clinical trial titles or identification number. The results show all the existing clinical trials at different stages of implementation with links to their full description in the respective Primary Clinical Trials Register.

The quality of the information available on this portal is guaranteed by the producers of the Clinical Trial Registers that form part of the network recently established by WHO, i.e., WHO Network of Collaborating Clinical Trial Registers. This network will enable interaction between the producers of the Clinical Trial Registers to define best practices and quality control. Primary registration of clinical

trials can be performed at the following websites: [www.actr.org.au](http://www.actr.org.au) (Australian Clinical Trials Registry), [www.clinicaltrials.gov](http://www.clinicaltrials.gov) and <http://isrctn.org> (International Standard Randomized Controlled Trial Number Register (ISRCTN)). The creation of national registers is underway and, as far as possible, the registered clinical trials will be forwarded to those recommended by WHO.

WHO proposes that as a minimum requirement the following information be registered for each trial. A unique identification number, date of trial registration, secondary identities, sources of funding and material support, the main sponsor, other sponsors, contact for public queries, contact for scientific queries, public title of the study, scientific title, countries of recruitment, health problems studied, interventions, inclusion and exclusion criteria, study type, date of the first volunteer recruitment, sample size goal, recruitment status and primary and secondary result measurements.

Currently, the Network of Collaborating Registers is organized in three categories:

- Primary Registers: Comply with the minimum requirements and contribute to the portal;
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Consequently, authors are hereby recommended to register their clinical trials prior to trial implementation.

Yours sincerely,

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# Analysis of initial movement of maxillary molars submitted to extraoral forces: a 3D study

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## Abstract

**Objective:** To analyze maxillary molar displacement by applying three different angulations to the outer bow of cervical-pull headgear, using the finite element method (FEM). **Methods:** Maxilla, teeth set up in Class II malocclusion and equipment were modeled through variational formulation and their values represented in X, Y, Z coordinates. Simulations were performed using a PC computer and ANSYS software version 8.1. Each outer bow model reproduced force lines that ran above (ACR) (1), below (BCR) (2) and through the center of resistance (CR) (3) of the maxillary permanent molars of each Class II model. Evaluation was limited to the initial movement of molars submitted to an extraoral force of 4 Newtons. **Results:** The initial distal movement of the molars, using as reference the mesial surface of the tube, was higher in the crown of the BCR model ( $0.47 \times 10^{-6}$ ) as well as in the root of the ACR ( $0.32 \times 10^{-6}$ ) model, causing the crown to tip distally and mesially, respectively. On the CR model, the points on the crown ( $0.15 \times 10^{-6}$ ) and root ( $0.12 \times 10^{-6}$ ) moved distally in a balanced manner, which resulted in bodily movement. In occlusal view, the crowns on all models showed a tendency towards initial distal rotation, but on the CR model this movement was very small. In the vertical direction (Z), all models displayed extrusive movement (BCR  $0.18 \times 10^{-6}$ ; CR  $0.62 \times 10^{-6}$ ; ACR  $0.72 \times 10^{-6}$ ). **Conclusions:** Computer simulations of cervical-pull headgear use disclosed the presence of extrusive and distal movement, distal crown and root tipping, or bodily movement.

**Keywords:** Headgear. Finite Element Method (FEM). Tooth Movement.

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## INTRODUCTION

Angle Class II malocclusion is characterized by anteroposterior dental discrepancy, which interferes with patients' maxillomandibular relationship. It is a rather significant condition whose prevalence ranges from 35% to 50% of the Brazilian population.<sup>10</sup> Although currently several methods are available to correct it, such as intra-oral appliances (Jones jig, Distal Jet, Pendulum, etc.), skeletal anchorage devices and headgear, treatment choice will depend on case-by-case assessment, patient compliance and professional skills. Despite its esthetic limitations and the need for compliance, headgear (HG) is a conventional, still widely used appliance that enables different force lines to be applied. HG can assist in correcting skeletal problems and achieving distal movement of permanent maxillary molars.<sup>3</sup> Its use requires knowledge of basic biomechanical concepts, such as center of resistance, tooth rotation and force action lines<sup>14</sup> for monitoring tooth movement during treatment.<sup>20,25</sup> When symmetrically changing the length and/or angulation of its outer arch, or when applying different force vectors, the impact on dental and skeletal structures can be altered.<sup>20,29</sup> The effects are often undesirable and it is up to orthodontists to reduce such effects by predicting the possible force action line angulations and their relationship with the center of resistance of the tooth to be moved.<sup>25</sup> The viewing of these side

effects has been extensively reported in literature,<sup>1,4,9,17,21,26,29</sup> usually by superimposing profile X-rays. Some studies have shown that a major limitation of this method lies in the difficulty to isolate molar movement without allowing the growth of the basal bones to interfere with the analysis.<sup>18</sup> Thanks to technological advances, studies have been conducted through computer simulations, some with a view to analyzing tooth movement in dental casts and others to evaluate the impact of masticatory forces on the tooth, and its stability.<sup>2,5</sup> The effects of force vectors applied to mini-implants have also been investigated<sup>6</sup> as well as the response of different facial patterns to extraoral forces.<sup>8</sup> None of these, however, addressed the influence of these forces on the movement of permanent first molars by the finite element method (FEM). The authors of this study aimed to analyze the displacement of maxillary molars by tipping the outer arch of cervical-traction headgear in three different directions and using FEM.

## MATERIAL AND METHODS

Maxillary models were reproduced using teeth set up in Class II malocclusion and cervical-traction headgear with the outer bows modified at three different heights, thereby determining force lines that, although different, had the same length. The imaginary line that resulted from the force vectors ran above, below and through the

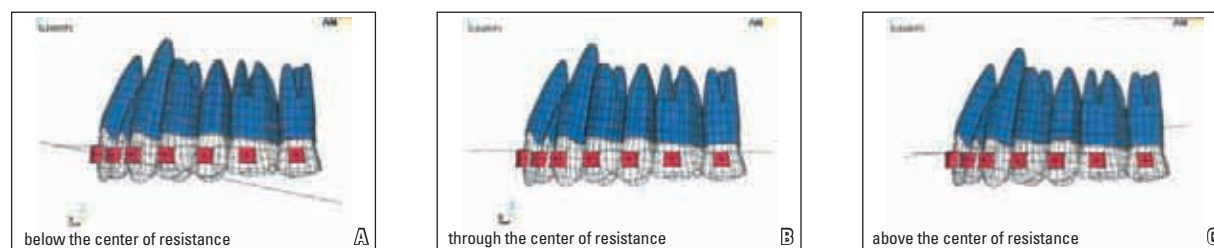


FIGURE 1 - Reproduction of the three models of cervical headgear with different outer bow inclinations in relation to X, Y and Z coordinates, using the Ansys 8.1 program: **A**) BCR (below the center of resistance); **B**) CR (through the center of resistance) and **C**) ACR (above the center of resistance).



The values shown in Table 1 and 2 confirmed the initial molar displacement in each HG model, displaying its direction and orientation at each maxillary molar point.

## DISCUSSION

Finite element method (FEM) was employed through variational formulation and the mechanical properties of organic tissues and orthodontic materials were obtained in the orthodontic literature,<sup>7,19,23,28</sup> which enabled the characterization of the elements and the geometry of the body using numerical modules.

The effects of forces applied to the first molars examined in these models are virtually the same as those observed in clinical practice. Figure 4 illustrates the differences that occur at key

points (root and crown) of the first permanent molar on the BCR and ACR force line models in the anteroposterior orientation (X coordinate). A uniform distal movement can also be observed on the CR model. Points 1 and 2 are located in the mesiobuccal and palatal roots of the molar. Points 3 and 4 are in the distal and mesial surfaces of the buccal tube bonded to the molar crown. Thus, reverse tipping can be noted, depending on the force lines of the two models (BCR and ACR).

Melsen and Dalstra<sup>18</sup> demonstrated, by superimposing patients' X-rays, that the type of tooth movement that occurs while wearing headgear with a downward or upward outer bow angulation was dependent on the force action line in both groups. Patients who wore headgear with

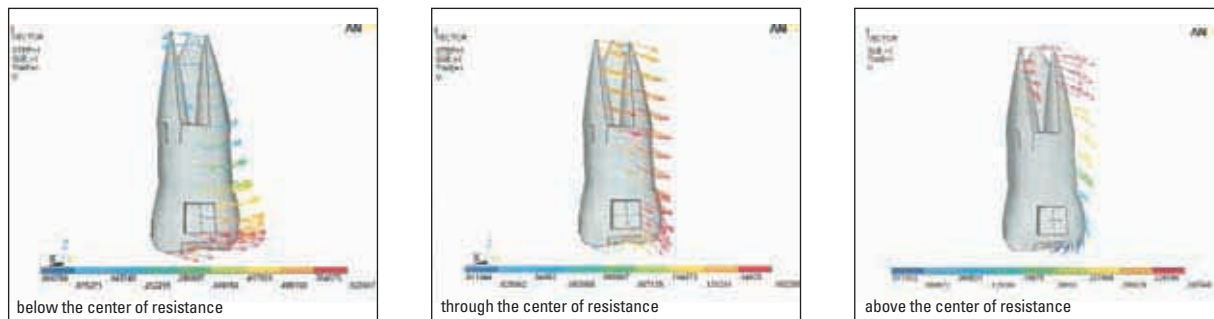


FIGURE 3 - Figure showing the initial distal movement of the first molar in the three computer simulation models. (A) BCR illustrates posterior (distal) tipping of the crown; (B) CR, uniform distal movement of the crown and root; (C) ACR illustrates posterior (distal) tipping of the root.

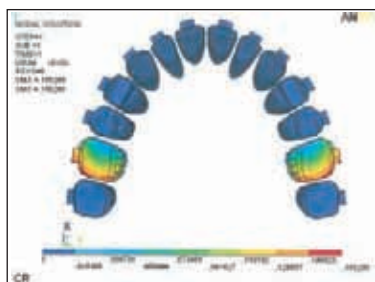
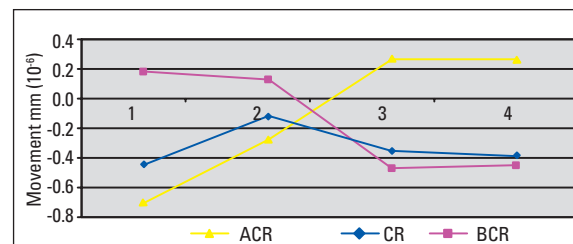


FIGURE 4 - Occlusal view showing initial distal rotation of the crown on the CR model.



GRAPH 1 - Graph showing the initial movement of the first molar (anteroposterior direction) at points in the palatal (1) and mesiobuccal (2) roots, and at mesial (3) and distal (4) points of the tube bonded to the crown, as observed in all three computer simulation models (ACR, CR and BCR).

TABLE 1 - Values in mm ( $\times 10^{-6}$ ) reflecting the initial movement of the first permanent molar in the anteroposterior direction (X coordinate), on the three models.

| Nodes / coordinates    | Ux BCR  | Direction | Ux CR   | Direction | Ux ACR  | Direction |
|------------------------|---------|-----------|---------|-----------|---------|-----------|
| mesial root (5413)     | 0.06821 | M         | 0.12336 | D         | 0.32432 | D         |
| distal root (5489)     | 0.05468 | M         | 0.13153 | D         | 0.32687 | D         |
| tube B (13665)         | 0.52272 | D         | 0.13128 | D         | 0.09499 | M         |
| tube M (14510)         | 0.47447 | D         | 0.14887 | D         | 0.01425 | M         |
| tube D (14528)         | 0.45748 | D         | 0.16665 | D         | 0.02567 | M         |
| D region of CR (14609) | 0.13785 | D         | 0.14141 | D         | 0.28577 | D         |
| D region of CR (14618) | 0.16082 | D         | 0.13761 | D         | 0.18142 | D         |
| D region of CR (14624) | 0.13875 | D         | 0.12894 | D         | 0.26128 | D         |

Captions: M (mesial), D (distal), Ux (resultant of initial movement in the anteroposterior direction), V (buccal) and CR (center of resistance).

TABLE 2 - Values in mm ( $\times 10^{-6}$ ) reflecting the initial movement of first permanent molars in the vertical direction (Z coordinate) on the three models. Negative values represent extrusive movement at such points.

| Nodes / coordinates    | Uz BCR   | Direction | Uz CR    | Direction | Uz ACR   | Direction |
|------------------------|----------|-----------|----------|-----------|----------|-----------|
| mesial root (5413)     | -0.24398 | ex        | -0.46214 | ex        | 0.23297  | in        |
| distal root (5489)     | -0.99368 | ex        | -0.23581 | ex        | -0.63052 | ex        |
| tube V (13665)         | -0.18231 | ex        | -0.62664 | ex        | -0.72586 | ex        |
| tube M (14510)         | -0.11875 | ex        | -0.63811 | ex        | 0.31449  | in        |
| tube D (14528)         | 0.17873  | in        | -0.19519 | ex        | -0.10243 | ex        |
| D region of CR (14609) | -0.51664 | ex        | -0.26472 | ex        | -0.39593 | ex        |
| D region of CR (14618) | -0.13161 | ex        | -0.41045 | ex        | -0.26438 | ex        |
| D region of CR (14624) | -0.54192 | ex        | -0.32091 | ex        | -0.18191 | ex        |

Captions: in (intrusion), ex (extrusion), Uz (resulting initial movement in the vertical direction), V (buccal), M (mesial), D (distal), P (palatal) and CR (center of resistance).

a downward angulation displayed extrusion and distally tipped crowns, while those with an upward angulation exhibited translatory (bodily) movement.<sup>18</sup> The authors used the center of resistance as a reference, as in the present study, which found distally tipped crowns on the BCR model, distally tipped roots on the ACR model and bodily movement on the CR model.

Extrusion evidence found in the three models can be explained by the point of origin of force application, which was located low in the patients' cervical region.<sup>20,29</sup> This movement, however, is not necessarily undesirable, since in some cases, e.g., patients with a reduced lower facial third, extrusion is expected, given its im-

pact on their facial profile as a whole.<sup>24,29</sup> Care should be taken in cases where it is necessary to raise the outer bow in order to achieve an action line that is better suited for the effect desired in the molar, since any elevation in the outer bow will increase the extrusive component (Table 2, reference node tube V).

Ashmore et al<sup>2</sup> described the movement of first permanent molars during treatment with headgear (combined traction) on plaster models analyzed in 3D. The results showed little extrusion due to the fact that the high-pull force used in their study ran through the CR, producing bodily movements. Despite the reduced amount of movement and the cervical traction, the same

results were found in this study: uniform distal movement of the crown and root, and mild extrusion on the CR model.

Oosthuizen et al<sup>20</sup> reported that the center of resistance of the maxillary first molar is positioned approximately at the trifurcation of the roots, at the mid-height of the cervical third. When the action line of a force does not go through the center of resistance, the tooth being moved tips under its center of rotation, i.e., depending on the position of this line, the molar will display a tipping movement.<sup>20</sup> The mechanical function explained above further reinforces the clinical findings as well as the findings of this study, based on finite elements.

The center of resistance of the tooth or skeletal unit to be moved provides the rationale for the organization of a force system.<sup>27</sup> The effects caused by varying the outer bow can also be applied to orthopedic movements since the reasoning behind the distribution of forces through vectors is similar. The only difference lies in the location of the center of resistance.

According to Klein's superimposition cephalometric studies, molar movement could be observed free from the influence exerted by the patient's growth<sup>15</sup>. He found that in 17 of 23 cases molars experienced distal bodily movement.<sup>15</sup> Unlike Piva et al<sup>22</sup>, Schiavon Gandini et al.<sup>24</sup> demonstrated in cephalometric radiographs that even in cases where the maxilla was rotated downwards, the axial inclination of the molar remained unchanged and there was greater distal tipping of the root, even when the force line ran through the center of resistance. Schiavon Gandini et al<sup>24</sup> standardized outer bow angulation while Klein<sup>15</sup> resorted to cervical traction only.

Several authors have stated that it is possible to prevent undesirable displacements, such as mesial or distal crown tipping, through changes in the outer bow of the headgear, by either raising or lowering it, but that depends

more on the operator than on the patient.<sup>15,16</sup> Traction line angulation can be changed only by varying outer bow angle and length.<sup>20,25</sup> It is possible, however, with such changes, to cause extrusive movements that undermine vertical control mechanics, especially when the outer bow is raised to correct distal molar tipping (tip back). In this situation, it is advisable to employ combined traction.

Similarly to the findings of this study, Haas believes that the tendency displayed by molars to rotate around their own axis in the lingual direction only occurs because force application derives from a low position in the outer bow (patient's cervical region). He therefore proposes that the inner bows of the headgear be expanded, thereby improving molar positioning.<sup>12</sup> Other authors recommend the use of a removable palatal bar to control vertical movement and correct undesirable rotations and torques during treatment.<sup>11,13,30</sup> Besides, rectangular archwires can obviously be used to control torque when a patient is in this treatment phase.

Piva et al<sup>22</sup> suggest that 3D studies be conducted given the limitations of radiography, which does not disclose pure molar movement through overlays (superimposition) due to changes in growing patients. Thanks to the use of the finite element method (FEM), the results of this research succeeded in reflecting maxillary molar movement in isolation by varying the outer bows of the headgear.

## CONCLUSIONS

It was shown that the use of cervical-traction headgear causes extrusive and distal movement. Force line orientation is important to control maxillary molar movement, which can be translatable (bodily), tip back or tip forward, when distal movement occurs through the use of a headgear. Determining this approach depends on the clinical situation and on orthodontic treatment planning.

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# 2D / 3D Cone-Beam CT images or conventional radiography: Which is more reliable?

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## Abstract

**Objective:** To compare the reliability of two different methods used for viewing and identifying cephalometric landmarks, i.e., (a) using conventional cephalometric radiographs, and (b) using 2D and 3D images generated by Cone-Beam Computed Tomography. **Methods:** The material consisted of lateral view 2D and 3D images obtained by Cone-Beam Computed Tomography printed on photo paper, and lateral cephalometric radiographs, taken in the same radiology clinic and on the same day, of two patients selected from the archives of the Specialization Program in Orthodontics, at the School of Dentistry, Fluminense Federal University (UFF). Ten students from the Specialization Program in Orthodontics at UFF identified landmarks on transparent acetate paper and measurements were made of the following cephalometric variables: ANB, FMIA, IMPA, FMA, interincisal angle, I-NA (mm) and I-NB (mm). Arithmetic means were then calculated, standard deviations and coefficients of variance of each variable for both patients. **Results and Conclusions:** The values of the measurements taken from 3D images showed less dispersion, suggesting greater reliability when identifying some cephalometric landmarks. However, since the printed 3D images used in this study did not allow us to view intracranial landmarks, the development of specific software is required before this type of examination can be used in routine orthodontic practice.

**Keywords:** Cone-Beam Computed Tomography. Radiography. Orthodontics.

## INTRODUCTION

With the advent of the first standardized cephalograms obtained with the aid of the cephalostat, developed by Broadbent<sup>2</sup> and Hofrath<sup>8</sup> as of 1931, it became possible to identify previously inaccessible reference points in living beings and dry skulls.<sup>16</sup> Since then, cephalometric examination has become essential for orthodontists, who can now count on a more reliable guide to diag-

nose, plan and predict malocclusion cases.<sup>16</sup>

Nonetheless, several factors can influence the identification of these points, such as definition accuracy, reproducibility of landmark location and image quality. Moreover, these points—especially those outside the sagittal plane—are subject to distortion.<sup>1,11</sup> Despite these potential errors, cephalometric radiographs are still in widespread use.<sup>9,12</sup>

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In the 1980s, devices emerged in the United States that employ the Cone-Beam technique. Cone-Beam is a special type of computed tomography in which the X-ray beam that generates the image features a special conic shape, unlike conventional CT (CCT), which uses a fan-shaped beam known as fan beam. Tomography obtained with this technology is also called volumetric computerized tomography (VCT).<sup>5</sup> The images are obtained in three dimensions and it is also possible to render 2D images through software.

These advances in imaging have improved considerably the identification of hard-to-detect structures, which may increase the accuracy and reliability of orthodontic diagnosis and treatment planning.<sup>14</sup> In comparison with conventional radiography, examination with computed tomography can potentially provide a wealth of additional information. Cone-Beam CT allows all conventional dental radiographs (panoramic, lateral and frontal cephalograms, occlusal, peri-apical and bite-wings) to be reconstructed and then added to the multiplanar and 3D reconstructions. Furthermore, measurements made from volumetric CT feature a 1:1<sup>7</sup> ratio, unlike conventional cephalometric radiography, whose magnification may vary from 4.6% to 7.2%.<sup>1</sup>

Considering that these two tests are currently available to orthodontists, this investigation aimed to compare how reliably cephalometric landmarks can be identified (a) when viewed on conventional radiographs, and (b) when viewed on 2D and 3D images generated by Cone-Beam CT, by analyzing the dispersion of the values obtained from the measurements performed on each image.

## MATERIAL AND METHODS

### Material

In this study, we used the examinations of two patients selected from the files of the Specialization Program in Orthodontics, School of Dentistry, Fluminense Federal University (UFF).

The material consisted of lateral 2D and 3D images obtained by Cone-Beam computed tomography and printed on photo paper at 1:1 ratio, and conventional cephalometric radiographs, taken in the same radiology clinic on the same day.

## Methods

### Cephalometric examination

Profile cephalometric radiographs were obtained by following the standards established during the First Roentgenographic Cephalometric Workshop, held in 1957 in the city of Cleveland, United States of America.<sup>15</sup>

The radiographs were taken after the patient's head had been immobilized in a cephalostat positioned in the Frankfurt horizontal plane. The head was fixed so that the sagittal plane remained parallel to the film and perpendicular to the ground (Fig 1).



FIGURE 1 - Profile cephalometric radiograph.

### CT scan

The CT scans were obtained using i-CAT Volumetric Cone-Beam Computed Tomography device (Imaging Sciences). During image acquisition, patients sat in an open environment in their natural anatomic position while the equipment took one 360° spin around the head, which lasted from 20 to 40 seconds. The 3D images captured in the scanner were then exported to software viewer Visio i-CAT, which helped us to render 2D and 3D images (Figs 2 and 3).

These images were printed on the same type of photo paper.

### Cephalometric landmark tracing

The landmarks were identified on transparent acetate paper, measuring 20.0 by 18.5 cm, and marked with black pencil. A light box (illuminator) was used for viewing the X-rays.

- Nasion (N): foremost point of the frontonasal suture, seen in lateral view.<sup>16</sup>
- Subspinale (A-point): deepest point in the

contour of the premaxilla.<sup>16</sup>

- Supramentale (B-point): deepest point in the contour of the mandibular alveolar process.<sup>16</sup>
- Menton (Me): inferiormost point in the contour of the mandibular symphysis.<sup>16</sup>
- Orbitale (Or): inferiormost point on the inferior margin of the left orbit.<sup>16</sup>
- Porion (Po): highest point of the external auditory conduit.<sup>16</sup>

### Planes and lines

- NA Line: joining the nasion (N) and subspinale (A) points.
- NB Line: joining the nasion (N) and supramentale (B) points.
- Long axis of upper central incisor.
- Long axis of lower central incisor.
- Mandibular plane: tangent to the lower border of the mandible in the posterior region, and to the menton (Me) in the symphysis region.
- Frankfurt horizontal plane: joining porion (Po) and orbitale (Or).



FIGURE 2 - 2D image obtained with Cone-Beam Computed Tomography, in lateral view.



FIGURE 3 - 3D image obtained with the Cone-Beam Computed Tomography, in lateral view.

### Measurements (Fig 4)

- ANB: intersection of lines NA and NB.
- FMIA: intersection of the Frankfurt horizontal plane with the long axis of the lower central incisor.
- IMPA: intersection of the long axis of the lower central incisor with the mandibular plane.
- FMA: intersection of the mandibular plane with the Frankfurt horizontal plane.
- Interincisal angle: intersection of the long axes of the upper and lower central incisors.
- NA (mm): linear distance measured from the most prominent maxillary point on the central incisor crown to line NA.
- 1-NB (mm): linear distance measured from the most prominent maxillary point on the central incisor crown to line NB.

All measurements were performed by ten examiners, students from the Specialization Program in Orthodontics, Universidade Federal Fluminense (UFF). After one week the measurements were repeated in order to evaluate intraobserver error.

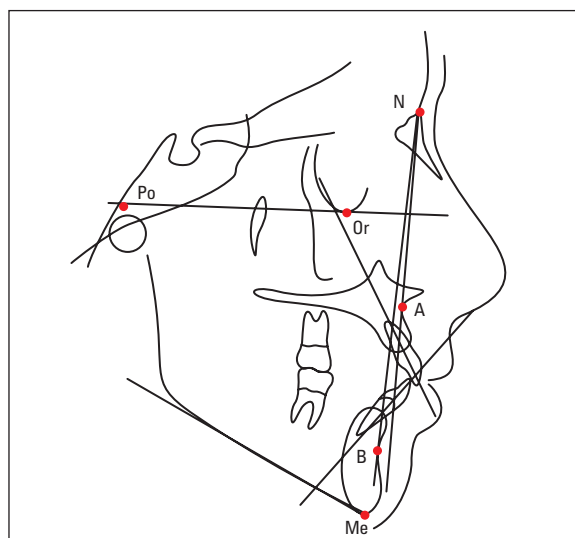


FIGURE 4 - Cephalometric tracing showing landmarks and lines.

The examiners were calibrated and briefed on the landmarks, planes and angles to ensure homogeneous measurements. The linear measurements were obtained with the aid of a millimeter ruler.

### Statistical Analysis

Means, standard deviations and coefficients of variance were calculated. The Shapiro-Wilk test was used to check normality between the values obtained on two measurement occasions. When the existence of normal value distribution was noted, the paired t-test was applied to obtain the level of statistical significance. Otherwise, the sign test was used. In both cases a significance level of 1% was used.

### RESULTS

Tables 1 and 2 show the means, standard deviations and coefficients of variance for the measurements taken on the lateral cephalometric radiographs and on the 2D and 3D images generated by Cone-Beam Computed Tomography.

Patient 1 was found to exhibit values of standard deviations and coefficients of variance that were lower—in the 3D images—for ANB, FMIA, FMA, and 1-NA (mm). Regarding IMPA and the interincisal angle, standard deviations and coefficients of variance were lower in the conventional radiographs. For variable 1-NB (mm), the standard deviation and coefficient of variance were smaller in the 2D images (Table 1).

Patient 2 was found to exhibit values of standard deviations and coefficients of variance that were lower—in the 3D images—for IMPA, FMA, and 1-NB (mm). For variables ANB, interincisal angle and 1-NA (mm) standard deviations and coefficients of variance were smaller in the 2D images. For angle FMIA, the standard deviation and coefficient of variance were lower in the conventional radiographs (Table 2).

A comparison between the two measurements (Table 3) showed that there were no statistically significant differences at 1% probability.

TABLE 1 - Values of means (M), standard deviations (SD) and coefficient of variance (CV) of the measurements in lateral cephalometric radiography and CT images, in 2D and 3D, Patient 1.

| MEASURES                  | PATIENT 1 |      |       |        |      |       |        |      |       |
|---------------------------|-----------|------|-------|--------|------|-------|--------|------|-------|
|                           | X-ray     |      |       | 2D     |      |       | 3D     |      |       |
|                           | M         | SD   | CV(%) | M      | SD   | CV(%) | M      | SD   | CV(%) |
| ANB                       | 3.40      | 0.70 | 20.58 | 3.60   | 0.70 | 19.44 | 3.70   | 0.48 | 12.97 |
| FMIA                      | 45.60     | 3.72 | 8.15  | 50.20  | 4.68 | 9.32  | 50.20  | 3.01 | 6.00  |
| IMPA                      | 106.00    | 3.33 | 3.14  | 106.10 | 3.54 | 3.33  | 105.30 | 3.62 | 3.43  |
| FMA                       | 28.40     | 3.89 | 13.69 | 23.80  | 4.56 | 19.15 | 24.50  | 1.51 | 6.16  |
| $\underline{1} : \bar{T}$ | 110.40    | 3.98 | 3.60  | 110.00 | 5.56 | 5.05  | 113.90 | 5.74 | 5.03  |
| $\underline{1} - NA$      | 6.35      | 0.88 | 13.85 | 5.65   | 1.11 | 19.64 | 5.20   | 0.63 | 12.11 |
| $\bar{T} - NB$            | 7.70      | 0.54 | 7.01  | 7.00   | 0.23 | 3.28  | 7.00   | 0.71 | 10.14 |

TABLE 2 - Values of means (M), standard deviations (SD) and coefficient of variance (CV) of the measurements in lateral cephalometric radiography and CT images, in 2D and 3D, Patient 2.

| MEASURES                  | PATIENT 2 |      |       |        |      |       |        |      |       |
|---------------------------|-----------|------|-------|--------|------|-------|--------|------|-------|
|                           | X-ray     |      |       | 2D     |      |       | 3D     |      |       |
|                           | M         | SD   | CV(%) | M      | SD   | CV(%) | M      | SD   | CV(%) |
| ANB                       | 8.30      | 0.95 | 11.44 | 8.50   | 0.71 | 8.35  | 7.85   | 0.67 | 8.53  |
| FMIA                      | 45.10     | 1.37 | 3.04  | 49.10  | 2.81 | 5.72  | 46.80  | 2.35 | 5.02  |
| IMPA                      | 103.60    | 2.22 | 2.14  | 103.00 | 2.45 | 2.38  | 102.70 | 1.89 | 1.84  |
| FMA                       | 31.40     | 1.90 | 6.05  | 27.90  | 3.60 | 12.90 | 30.50  | 1.58 | 5.18  |
| $\underline{1} : \bar{T}$ | 128.80    | 2.74 | 2.13  | 132.50 | 2.71 | 2.04  | 128.90 | 3.24 | 2.51  |
| $\underline{1} - NA$      | 3.25      | 1.62 | 49.85 | 2.25   | 0.54 | 24.00 | 2.80   | 0.88 | 31.43 |
| $\bar{T} - NB$            | 8.60      | 0.84 | 9.77  | 7.40   | 0.70 | 9.46  | 7.60   | 0.46 | 6.05  |

TABLE 3 - P-values for the paired t-test and sign test, according to the normal (or not normal) distribution of the variable values measured on two different occasions, for each image.

| MEASURES                        | PATIENT 1             |                       |                       | PATIENT 2             |                       |                       |
|---------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                                 | X-ray                 | 2D                    | 3D                    | X-ray                 | 2D                    | 3D                    |
| ANB                             | 0.754 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> | 0.754 <sup>n.s.</sup> | 0.109 <sup>n.s.</sup> |
| FMIA                            | 0.031 <sup>n.s.</sup> | 0.016 <sup>n.s.</sup> | 0.109 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> | 0.098 <sup>n.s.</sup> | 0.294 <sup>n.s.</sup> |
| IMPA                            | 0.270 <sup>n.s.</sup> | 1.000 <sup>n.s.</sup> | 0.535 <sup>n.s.</sup> | 0.671 <sup>n.s.</sup> | 0.625 <sup>n.s.</sup> | 0.109 <sup>n.s.</sup> |
| FMA                             | 0.379 <sup>n.s.</sup> | 1.000 <sup>n.s.</sup> | 0.754 <sup>n.s.</sup> | 0.754 <sup>n.s.</sup> | 0.145 <sup>n.s.</sup> | 1.000 <sup>n.s.</sup> |
| $\underline{1} : \underline{1}$ | 0.109 <sup>n.s.</sup> | 0.228 <sup>n.s.</sup> | 0.109 <sup>n.s.</sup> | 0.754 <sup>n.s.</sup> | 0.522 <sup>n.s.</sup> | 0.229 <sup>n.s.</sup> |
| $\underline{1} - NA$            | 1.000 <sup>n.s.</sup> | 0.021 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> | 0.754 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> |
| $\underline{1} - NB$            | 0.109 <sup>n.s.</sup> | 0.109 <sup>n.s.</sup> | 1.000 <sup>n.s.</sup> | 1.000 <sup>n.s.</sup> | 0.754 <sup>n.s.</sup> | 0.344 <sup>n.s.</sup> |

n.s. = non significant (p&gt;0.01).

## DISCUSSION

Since the introduction of the cephalostat, Broadbent (1931) underlined the importance of coordinating the lateral and posteroanterior cephalometric films (two extraoral radiographs orthogonal to each other would be taken to acquire a three-dimensional image of the patient) in order to arrive at a distortion-free definition of the craniofacial skeleton. But this approach is not truly three-dimensional as it relies on identifying the same spot in both radiographs and on the use of geometry to calculate the three-dimensional position. The major limitations of this method were obvious. Accuracy depended on a proper correspondence between the landmark locations in the two radiographs, and non-visible points could not be used.<sup>6</sup>

Nevertheless, innovations in digital imaging are changing the way these common methods are used in diagnosis and treatment planning.<sup>14</sup> Volumetric computerized tomography or Cone-Beam, was introduced into dentistry in 2000 at Loma Linda University (USA), and since then its clinical application has been widespread, side by side with significant technological development, bringing with it faster results and higher resolution images.<sup>10</sup>

These advances in imaging will certainly improve the ability to identify anatomical landmarks that are not easily detectable in the images currently available, thereby increasing the accuracy and reliability of orthodontic diagnosis and treatment planning.<sup>14</sup>

Some systems allow CT scan reconstructions that are comparable to cephalometric projections.<sup>4</sup> The purpose of this study was to compare how reliably different cephalometric landmarks could be identified when visualized on conventional radiographs versus on 2D and 3D images generated by Cone-Beam CT, by analyzing the dispersion of the values of measurements taken on each image.

The examiners were calibrated prior to identifying the landmark and taking the measure-

ments, which were repeated after a one week interval in order to test intraobserver reliability. The results showed no statistically significant differences at 1% probability (Table 3). Thus, the values obtained at the time were acceptable for use in this research.

In order to evaluate the dispersion of the values of cephalometric variables, coefficient of variance was applied and the results are displayed in Tables 1 and 2. When data from both tables were analyzed in conjunction, we noted that the values of measurements performed on the images obtained from the 3D Cone-Beam CT showed less dispersion in seven situations, and this result was repeated—considering the data of patients 1 and 2—solely for the FMA angle. This finding seems to suggest that three-dimensional images are more reliable for the identification of some cephalometric landmarks which are difficult to detect in 2D images, such as porion (Po), orbitale (Or), subspinale (A), supramentale (B) and nasion (N). Likewise, the lower mandibular border seemed easier to identify. However, 3D images do not seem to be as reliable for identifying the long axes of the upper and lower incisors because they showed the highest coefficient of variance for IMPA angle values in one patient, and interincisal angle values in patient 2. It is interesting to note also that the printed 3D images, as used in this study, did not allow the visualization of intracranial points, often essential for cephalometric analysis. Therefore, the development of specific software is required before this type of examination can be used in routine orthodontic practice.

The values of the variables measured on conventional radiographs exhibited less dispersion in three situations (Tables 1 and 2). As lower coefficients of variance were found for the values of the IMPA, FMIA and interincisal angles, we can assume that this type of examination provides greater reliability when identifying images of the long axes of the upper and lower incisors. On the other hand, it showed the highest coefficient of

variance in four situations. This ANB angle result was repeated in the examination of patients 1 and 2, which suggests that the subspinale (A) and supramentale (B) points are difficult to visualize radiographically.

The values of the variables measured on the 2D Cone-Beam CT images showed less dispersion in four situations. However, none of these was repeated in two patients (Tables 1 and 2), which seemed to indicate that this result is related to the anatomical peculiarities inherent in each image. The highest coefficients of variance were found in seven situations, considering the joint results of the two patients. It should be borne in mind, however, that the images of anatomical structures in the radiographic examination were visualized with the aid of a light box, unlike the 2D Cone-Beam CT images, which may be construed as an advantage for the former.

Measures I-NB and ANB showed very discrepant results with respect to the coefficient of variance of the three images of patient 1, but this was not the case with patient 2. It is likely that this fact can be ascribed to their anatomical differences.

The results of this study are consistent with the findings published in 2005 by Nakajima et al<sup>13</sup> who, after evaluating Cone-Beam CT tech-

nology, concluded that 3D images provide useful information for orthodontic diagnosis and treatment planning.

Furthermore, it is relevant to mention that the measurements made by Cone-Beam Computed Tomography feature a 1:1<sup>3,7</sup> ratio while conventional radiography exhibits a magnification of up to 7.2%, according to Bergensen.<sup>1</sup>

One need not, however, abandon conventional two-dimensional cephalometric measurements in moving to three-dimensional technology since 3D images can be rendered in 2D, similarly to a radiograph. Besides, cephalometric landmarks can also be traced on 3D images. According to Halazonetis,<sup>6</sup> new cephalometric landmarks are likely to be introduced and many new cephalometric analyses, similar to existing two-dimensional analyses, are bound to be created.

## CONCLUSIONS

The values of the measurements taken from 3D images showed less dispersion, suggesting greater reliability when identifying some cephalometric landmarks. However, as the printed 3D images used in this study did not allow us to view intracranial landmarks, the development of specific software is required before this type of test can be used in routine orthodontic practice.

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# Evaluation of referential dosages obtained by Cone-Beam Computed Tomography examinations acquired with different voxel sizes

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## Abstract

**Objectives:** The aim of this study was to evaluate the dose-area product (DAP) and the entrance skin dose (ESD), using protocols with different voxel sizes, obtained with i-CAT Cone-Beam Computed Tomography (CBCT), to determine the best parameters based on radioprotection principles. **Methods:** A pencil-type ionization chamber was used to measure the ESD and a PTW device was used to measure the DAP. Four protocols were tested: (1) 40s, 0.2 mm voxel and 46.72 mAs; (2) 40s, 0.25 mm voxel and 46.72 mAs; (3) 20s, 0.3 mm voxel and 23.87 mAs; (4) 20s, 0.4 mm voxel and 23.87 mAs. The kilovoltage remained constant (120 kVp). **Results:** A significant statistical difference ( $p < 0.001$ ) was found among the four protocols for both methods of radiation dosage evaluation (DAP and ESD). For DAP evaluation, protocols 2 and 3 presented a statistically significant difference, and it was not possible to detect which of the protocols for ESD evaluation promoted this result. **Conclusions:** DAP and ESD are evaluation methods for radiation dose for Cone-Beam Computed Tomography, and more studies are necessary to explain such result. The voxel size alone does not affect the radiation dose in CBCT (i-CAT) examinations. The radiation dose for CBCT (i-CAT) examinations is directly related to the exposure time and milliamperes.

**Keywords:** Cone-Beam Computed Tomography. Radiation. Voxel.

## INTRODUCTION

Successful dental treatment must be based on full planning and that includes the use of images to help with diagnosis. Computed tomography (CT) provides important three-

dimensional images and its use is increasing. However, the radiation dose accumulated in head and neck structures and its high cost are major disadvantages of this technique.<sup>1-8</sup>

A new CT technology, Cone-Beam Com-

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puted Tomography (CBCT), has recently become available. This technology was specifically developed for the head and neck region and provides three-dimensional volumetric images similar to medical tomographic images, at low cost and with reduction of patient exposure to radiation, because its field of vision (FOV) is limited to the axial dimension.<sup>2,5,7,9-12</sup> The voxel size is lower on CBCT compared with conventional CT. On the i-CAT device, for example, the voxel size can vary from 0.12 to 0.4 mm for the acquisition of images from the mandible, whereas on conventional CT the voxel size is normally 0.5–1 mm.<sup>6,13</sup> Generally, the smaller the voxel size and the longer the scanning time, the better the resolution and the details. However, a smaller voxel size is associated with a longer scanning time, which has some disadvantages such as greater possibility of patient movement during the examination, elevated radiation doses and longer reconstruction time.<sup>14,15</sup>

The aim of this study was to evaluate the dosage area product (DAP) and entrance skin dose (ESD), using protocols with different voxel sizes, using the i-CAT CBCT device, to determine better parameters based on radioprotection principles.

## MATERIALS AND METHODS

The DAP and ESD measurements using CBCT images from the i-CAT device (Imaging Sciences International, Hatfield, PA) were performed according to the protocols in Table 1. The scan height (collimation) was 6 cm for all protocols. The examinations were repeated four times for each protocol.

The RADCAL 9095 dose meter (Radcal Corp., Monrovia, CA, USA) and the PTW DAP meter (PTW, Freiburg, Germany) were used. All equipment was calibrated in laboratories within the Brazilian Metrology Network (Rede Brasileira de Metrologia-RBM). A pencil-type ioniza-

TABLE 1 - Protocols for image acquisition for the i-CAT device.

| Protocol | Scanning time (s) | Voxel size (mm) | Peak voltage (kVp) | mAs   |
|----------|-------------------|-----------------|--------------------|-------|
| 1        | 40                | 0.20            | 120                | 46.72 |
| 2        | 40                | 0.25            | 120                | 46.72 |
| 3        | 20                | 0.30            | 120                | 23.87 |
| 4        | 20                | 0.40            | 120                | 23.87 |

tion chamber (100 mm) was fixed on one end of the tomograph, coupled to an electrometer, so that it was possible to measure the doses given while the images were obtained (ESD). A multiplicative factor calculation was performed based on the distance between the x-ray beam output and the sensor, to compensate for the distance from the center of the device to the position of the ionization chamber. For the DAP measurement, a PTW device was coupled to the other end of the device.

The Kruskal-Wallis and Dunn tests were used to assess the data;  $p < 0.001$  was considered statistically significant.

## RESULTS

The median values for ESD and DAP for the four protocols are shown in Table 2. Statistically significant differences ( $p < 0.001$ ) were found among the four protocols for both radiation dose evaluation methods.

Dunn's test showed that in the DAP evaluation, protocols 2 and 3 showed a statistically significant difference, and it was not possible to detect which of the protocols were significantly difference in the ESD evaluation.

## DISCUSSION

CBCT is a new technology and adequate knowledge is necessary to measure the radiation dose. We believe that the proposed method, using the ESD and DAP, can be considered for dose measurements in this type of examination.

TABLE 2 - Mean values of radiation doses (ESD and DAP) for the four protocols.

| Protocol | Entrance Skin Dose - ESD<br>(mGy) | Dose Area Product-DAP<br>(mGy m <sup>2</sup> ) |
|----------|-----------------------------------|------------------------------------------------|
| 1        | 3.77                              | 44.92                                          |
| 2        | 3.78                              | 45.30                                          |
| 3        | 2.00                              | 24.43                                          |
| 4        | 2.00                              | 24.98                                          |
|          | (p = 0.00083)                     | (p = 0.000145)                                 |

Protocols 1 and 2 showed very similar ESD and DAP values, and even though the voxel sizes were different, the exposure time (ET), the kilovoltage (kVp) and the milliamperage x exposure time (mAs) remained constant. The same applies to protocols 3 and 4 (Tables 1 and 2). This shows that the voxel size does not influence the radiation dose; that is, when the exposure factors (ET, kVp and mAs) are the same, a single alteration of the voxel size does not alter the radiation dose significantly. However, the protocols couple the use of smaller voxels with greater exposure time and milliamperage, which invariably cause an increase in the exposure dose. Completely pre-established protocols are provided by the i-CAT manufacturer.<sup>15</sup>

A greater voxel size, associated with a low

mAs and reduced ET, is able to reduce the dose by as much as 50%.<sup>16</sup> In our study, whereas the ET and mAs practically doubled from protocols 3 and 4 to protocols 1 and 2, the radiation doses (ESD and DAP) behaved similarly for all protocols, being approximately doubled in protocols 1 and 2 compared with protocols 3 and 4 (Tables 1 and 2).

The limitation of the Dunn test in presenting significant difference among the protocols and in evaluating ESD occurred because of the small sample. But, despite the small sample, protocols 2 and 3 showed a significant difference between (p=0.0065) for the DAP; this was only possible because of the extremely relevant difference that exists between these protocols.

In conclusion, DAP and ESD are presented as evaluation methods for radiation doses in CBCT, and more studies are necessary to further elucidate such findings. The voxel size alone does not affect the radiation dose in CBCT (i-CAT) examinations. The radiation dose for CBCT (i-CAT) examinations is directly related to the exposure time and milliamperage.

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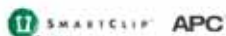
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