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ORTHODONTICS HIGHLIGHTS

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FACIAL SCANNERS ARE AN ACCURATE TOOL FOR FACIAL ASSESSMENT

Three-dimensional imaging techniques are changing healthcare, including orthodontics. Initially, 3D technology was used to create classic orthodontic models, but recently 3D images of the face have attracted attention. They offer diagnostic possibilities beyond those that can be achieved with photographic images in two dimensions (2D). However, there are not any studies assessing the reliability of 3D facial images. Therefore, Italian researchers developed a study[1] to compare the degree of precision that can be achieved using two different facial scanners: Face Hunter® and Dental Pro®. Measurements were taken on 25 patients, both manually and with the scanner. Six reference

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points were used, and a digital-measurement software was used to calculate the distances (Fig 1). Three-dimensional facial surface scans proved to be an excellent analytical tool for clinical assessment. Manual measurement and the Face Hunter® facial scanner were accurate, and did not differ from each other.

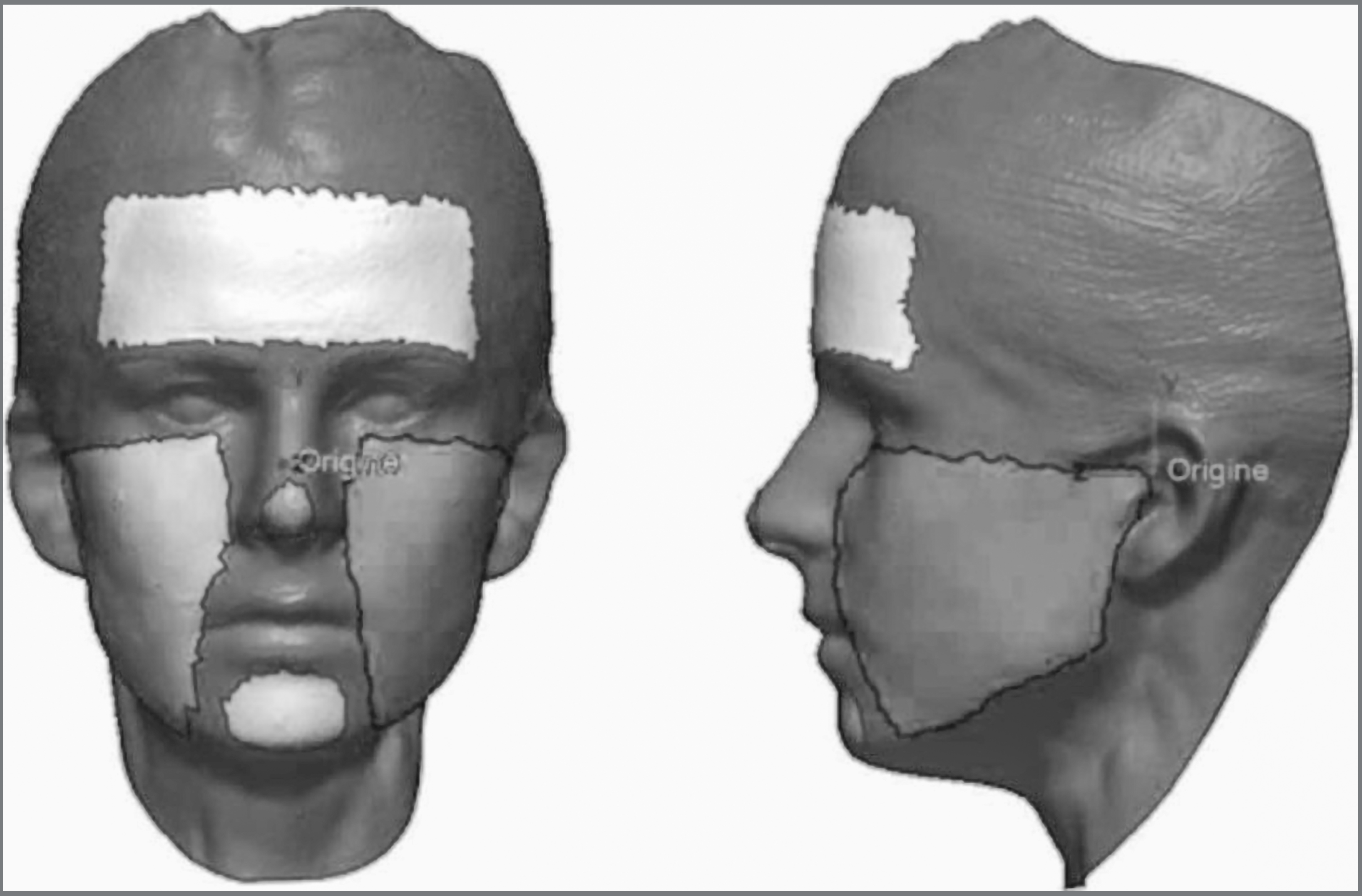

Figure 1: Areas superimposed on the images: right and left cheeks, forehead, tip of nose and chin. Source: Pellitteri et al.[1], 2021.

WHATSAPP IS AN IMPORTANT TOOL TO INCREASE PATIENTS' AWARENESS OF FLOSSING

Optimal oral hygiene requires complete and clear professional instructions, proper tools, and patient motivation. Social media and instant messaging apps can be allies in motivating patients to perform correct oral hygiene. Text messages have been used with satisfactory results in nursing and medicine. Brazilian researchers asked whether sending text messages using WhatsApp would influence patients' awareness of the need to maintain good oral hygiene and increase the frequency of flossing.[2] They selected a sample of 44 patients (mean age, 14.3 years) in use of fixed orthodontic appliance. The patients were divided into two groups of 22 individuals. Patients in one of the groups received daily text messages via WhatsApp for 30 days, to remind them of the need for flossing; those in the other group did not receive the text messages. The Plaque Index (PI) and Gingival Bleeding Index (GBI) were evaluated, and halitosis was assessed, at baseline and after 30 days. The authors found that the daily text messages increased patients' awareness of maintaining good oral hygiene through the use of dental floss.

MEDICATION CAN AFFECT ORTHODONTIC RELAPSE

Successful orthodontic interventions rest on three fundamental pillars: aesthetics, function and stability. Unfortunately, teeth may begin to shift from their corrected position immediately after brackets are removed, in an attempt to achieve a new balance. Studies have indicated that drugs and biological factors can modulate this process. However, the evidence diverges and requires systematic evaluation to be useful in clinical decision-making. Researchers from Dubai and Greece conducted a systematic review of studies in animal models that investigated the effect of medication and biological factors on the recurrence rate after orthodontic tooth movement.[3] They searched eight databases for studies published up to April 2020, and also conducted a manual search. They concluded that the relapse rate after orthodontic treatment can be affected by the consumption or administration of certain substances. They pointed out that these results are from animal studies, but serve as a warning to clinicians to use caution in planning treatments.

RETAINERS MADE WITH CAD/CAM TECHNOLOGY ARE ASSOCIATED WITH FEWER IMAGING ARTIFACTS THAN CONVENTIONAL WIRE RETAINERS

A group of German researchers studied the quality of magnetic resonance imaging (MRI) obtained in the presence of different types of orthodontic retainers made with the CAD/CAM system.[4] This technology has been widely used in contemporary orthodontics, bringing the possibility of using different types of materials, and reducing the orthodontist's laboratory time. However, the diagnosis of oral and maxillofacial diseases can be seriously hampered by image artifacts caused by metallic components, since the region of interest is close to the orthodontic appliance. It is especially important to evaluate the imaging risk posed by fixed orthodontic retainers, as typically they are installed for life. In this study, three retainers made using CAD/CAM technology and a conventional stainless-steel retainer made of Twistflex wire were evaluated (Fig 2). The authors found that all of the CAD/CAM retainers produced substantially smaller numbers of artifacts in the MRI images than the retainer made with Twistflex wire. The artifact volumes were lowest with titanium and nickel-titanium CAD/CAM retainers.

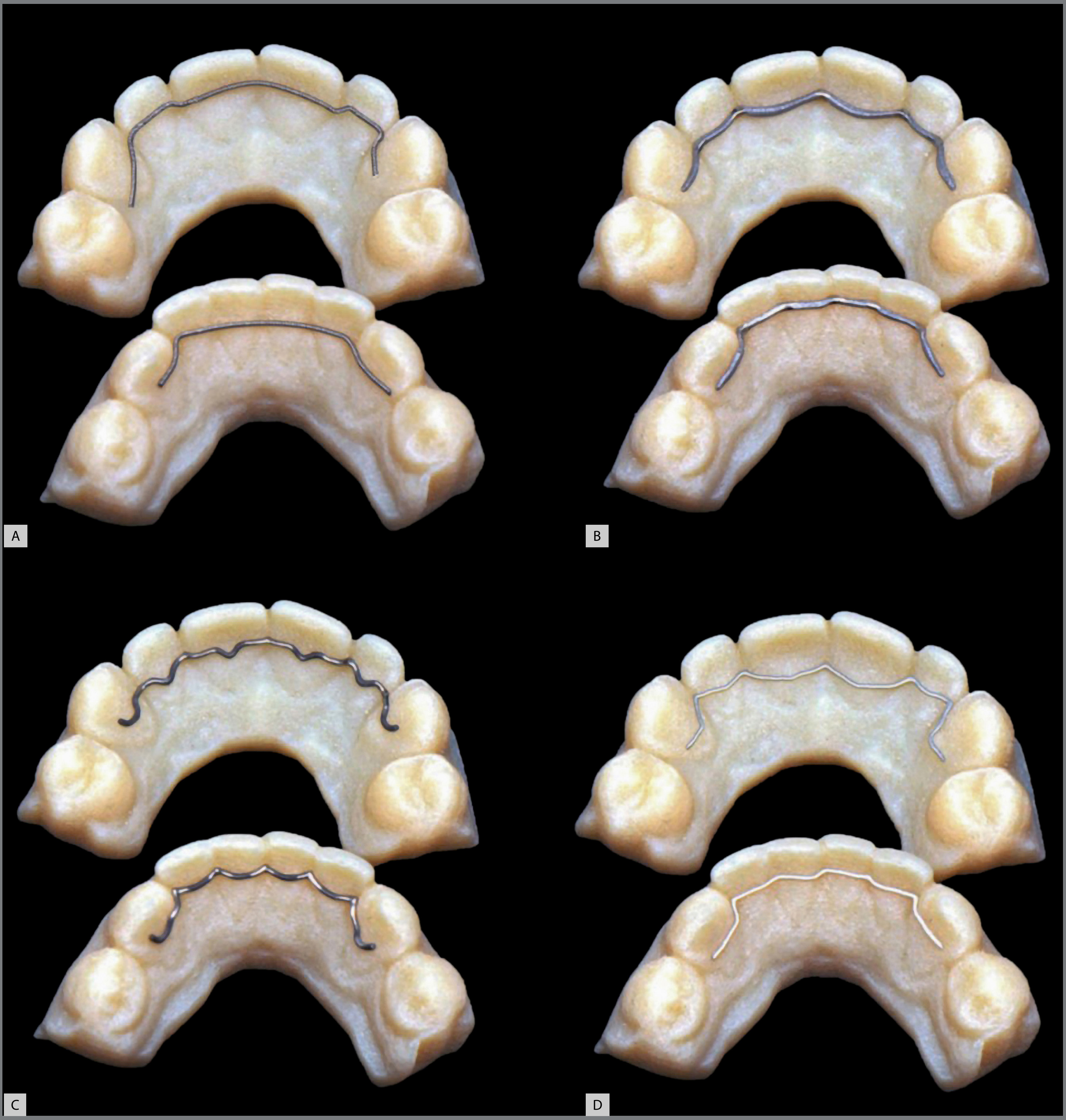

Figure 2: Photographs of the retainers evaluated in the study: **A)** Twistflex (folded); **B)** cobalt-chrome (CAD / CAM); **C)** grade 5 titanium (CAD / CAM); **D)** nickel-titanium (CAD / CAM). Source: Roser et al.[4], 2021.

WHITENING TOOTHPASTES ARE CYTOTOXIC

White teeth are considered synonymous with beauty and empowerment, and consumers are increasingly eager to improve the appearance of their teeth. The oral care industry launches new products every day to satisfy this demand, including whitening gels, mouthwashes, and whitening toothpastes. However, these products must be used with care to maintain the integrity of the oral tissues. A group of Brazilian researchers evaluated the biocompatibility and abrasiveness of conventional and whitening toothpastes,[5] which were tested for cell toxicity, and enamel roughness was evaluated before and after application. Some of the whitening toothpastes exhibited significant cytotoxicity, and the conventional toothpastes produced significant superficial changes in the tooth enamel. The authors highlight the need for additional *in vivo* studies, to assess interactions between toothpastes and other factors.

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COVID-19 and orthodontic treatment: current perspectives

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ABSTRACT

Introduction: A pandemic was declared by the World Health Organization on 30th January 2020, the coronavirus disease (COVID-19) emerged, and led to standstill of Dentistry and Orthodontics.

Description: The COVID-19 is a very multivariant disease. It affects in many different ways; the most reported symptoms resemble very much to that of a seasonal flu. Patients feel rising fever, dry cough and shortness of breath. There are two ways to handle them, the first being remotely guiding and helping them with aid of telecommunication, and second you can prepare the clinic by following all sanitization protocols and keep the clinic open only for such patients. Usage of Environment Protection agents, N95 masks, PPE kits and HEPA filters are some of the basic things to go about.

Conclusion: With the non-stop change of scenario of the COVID-19, meticulous monitoring of the local situation and one eye on the latest instructions given by the WHO and Health ministry should be followed.

Keywords: COVID-19. Orthodontic management. Vaccination.

RESUMO

Introdução: Uma pandemia foi declarada pela Organização Mundial de Saúde em 30 de janeiro de 2020. A doença do Coronavírus (COVID-19) surgiu, e levou à paralisação da Odontologia e da Ortodontia.

Descrição: A COVID-19 é uma doença muito multivariante. Afeta de muitas formas diferentes; e seus sintomas mais relatados assemelham-se muito aos de uma gripe sazonal. Os doentes sentem febre crescente, tosse seca e falta de ar. Há duas maneiras de lidar com eles, sendo o primeiro guiar e ajudar os pacientes remotamente com a ajuda das telecomunicações; e segundo, preparar a clínica, seguindo todos os protocolos de sanitização e manter a clínica aberta apenas para esses pacientes. A utilização de agentes de proteção ambiental, máscaras N95, kits EPI e filtros HEPA são algumas das coisas básicas a serem feitas.

Conclusão: Com a mudança contínua do cenário da COVID-19, deve-se seguir um acompanhamento meticuloso da situação local, observando as últimas instruções dadas pela OMS e pelo Ministério da Saúde.

Palavras-chave: COVID-19. Gestão ortodôntica. Vacinação.

INTRODUCTION

In these testing times of a global pandemic caused due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection, the practice of dentistry and orthodontics has come to a standstill. The coronavirus disease (COVID-19) was declared as a pandemic by the World Health Organization on 30th January 2020. In this situation, all governing and professional bodies have advised to handle only dental patients in emergency situations, also taking a great amount of precaution and preparation.

BACKGROUND

The coronavirus disease (COVID-19) is believed to have originated from the city of Wuhan, in the Hubei province of China, and is caused due to infection by the now-called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The SARS-CoV-2 virus is a single-stranded RNA virus that belongs to a family called *Coronaviridae*, which includes the known Severe Acute Respiratory Syndrome coronavirus (SARS-CoV) of 2002, and even the Middle East respiratory syndrome coronavirus (MERS-CoV) that was seen in 2012.[1,2,3]

The virus genome has been sequenced and it was found to share 79.5% of the genomic sequence with the SARS-CoV.

SOURCE OF TRANSMISSION AND SYMPTOMATOLOGY

On average, it takes 5 to 6 days for symptoms to develop from the time a person is exposed to the virus. Occasionally, it can take up to 14 days and rarely, even longer[1,4,5].

The COVID-19 affects different people in different ways. The most common symptoms resemble very much to that of seasonal flu. Patients experience dry cough, rising fever and tiredness or shortness of breath. Some patients have even been documented having joint pains, headache, loss of taste or smell, sore throat, rashes and/or diarrhea. On the other side, there are asymptomatic patients who can act as "carriers" and act as a pool of infection.

Chest radiography study reveal ground-glass opacities in patients with advanced infections. Most of the patients with good immunity and no comorbidities brush away these symptoms in course of time, by developing the necessary antibodies. Others who have a compromised state develop complications like Severe Respiratory Distress situation or Pneumonia, and the downward spiral into the disease begins[2,6].

SARS-CoV-2 binds to human angiotensin-converting enzyme 2 receptors. The salivary glands of humans are rich in these receptors and thus there is a high potential for transmission of COVID-19 via respiratory droplets in the air, which spread easily to a radius of no further than 6 feet, and then can enter the body directly through eyes, nose, ears and mouth, this would later infect the clinician, who may get critical or, worse, can become a carrier.

Faces have also shown a certain titer level of this virus. An average person touches his face 23 times an hour, and then some of the other inanimate objects around them. Spread of virus can also happen in this way, as the virus can survive for up to three days on such objects and surfaces. Incubation period is known to last for one to two weeks[7].

CLINICAL PRACTICE OF ORTHODONTICS DURING COVID-19 PANDEMIC

Facing such a difficult and highly contagious disease, the government also recommends to handle only emergency patients or patients that will require minimal intervention.

There are two ways in which you can handle them:

1. Remotely guiding and helping them, with help of telecommunication.

2. You can prepare your clinic by following all sanitization protocols and then keep the clinic open only for such patients.

REMOTE ASSISTANCE

Remote handling of the patient requires the orthodontist to have patience and understanding of the patient's psyche. Conversation content should be well planned and thought of. Patients are not aware of the dental terminology, so more colloquial terms should be used. Much more of a listening attitude should be inculcated while they convey about their troubles. Use of calm tone and positive words is most important while the government-mandated restrictions are on. More than the orthodontist, it's the patient who is suffering, as their appliance is still there and treatment will surely be prolonged. Since all this is being done on virtual platforms, encrypted end to end applications should be used, so that the patient also feels secure while this is being done, and the data should also be stored by the clinician. Orthodontic treatment requires meticulous and pragmatic approach from the clinician's aspect, so that proper improvisations can be done for the treatment. Lastly, all these new protocols have to be done after confirmation from the Regional Dental associations, since these things rely on the interpretation of information given by the doctor and are also confidential.

Orthodontists should follow Alexander's principle of "Let It Cook" more religiously, now that the wire sequence duration is prolonged, instead of getting anxious.

- Since most of the patients are in the adolescent category, with the school and colleges closed, unvaried calls should be made regarding the food types to be avoided to prevent breakages. Patients in the adult category will obviously be more understanding and will not be disobedient regarding the instructions.

- Regarding bonded molar tubes or brackets, patients can be asked to use a toothpick to get the loose appliances out, following instructions provided via video call.

- Use of elastics can be taught to the patient by either sending an on-line video or explaining them with help of a model, via a video call.

- With the public transport closed, an impinging wire can easily be cut with help of a nail cutter, cleaned with an alcohol-based sanitizer or by boiling it in water at 100ºC for 20 minutes. This can be done if the archwire is of lower gauge. In case of rigid rectangular wire, a heavy-duty cutter will be needed, which can easily be ordered on-line. Guiding the patient through a video is suggested at all times. Patient should be informed to hold the distal end of the wire secure, so as to prevent the risk of swallowing. Alternatively, a ball of wet cotton can provide temporary relief from the end of a poking wire, in case the patient has run out of relief wax.

- Regarding the expansion screws, patients can be reminded about it and instructed again, with help of a phone call. The expansion should be monitored via video call or by assessing photos of teeth, sent by the patient, and the expansion discontinued at the right time. In such situations, it is safer to err on the side of caution, and avoid over-expansion. Internet links on guidance for the patient to take dental photos should be sent to them in advance.

- Consideration should be given to terminate the procedures that are likely to cause problems if there is another wave of COVID-19, such as:

  1. Activation of slow/rapid expansion screw.
  2. Use of reverse pull headgear or Class III elastics.
  3. Elastics used for correction of crossbite/scissor bite/open bite/midline correction.
  4. Removable posterior bite-blocks to intrude the molars.

- Patients using removable functional appliances should be reminded to wear it, and also instructed regarding cleaning it. All patients, in general, should receive video explaining the hand hygiene protocol.

- In case of aphthous or traumatic ulcers, routine topical anesthetic ointments, which are available over the counter, should be recommended. A photographic examination should be performed, with regard to the size and severity of the ulcer, keeping in mind differential diagnosis of ulcers.

- Retention plates can easily be delivered with contactless delivery technique, and hoping it fits well. Use of the plate and instructions can, again, be done remotely.

- Since the use of ultrasonic scalers will be next to none, use of mouthrinse and a minimum of twice daily brushing protocol has to be more strictly followed and reminded multiple times.

- In case of aligner patients, their next aligner can be easily delivered without contact, and patients' treatment progresses unhindered. If they feel their current aligner is incorrectly adjusted or any other issue, they can be asked to wear the previous aligner. Again, monitoring via photos taken by the patient is helpful, and the internet links for guidance to take correct dental photos should be sent to the patient in advance.

- In case patient does experience serious pain, 500-mg Paracetamol tablets can be prescripted.[8,9]

Once a list of urgent attention-needing cases is made, they can be called to the clinic after conducting a session on the phone, asking the necessary questions to establish a baseline regarding the condition of the patient. Any risk factor for COVID-19 disease and virus exposure history (contact history) has to be ruled out in the telephonic conversation.

IN-CLINIC HANDLING

Before the patient visits the clinic, the following measures should be undertaken:

1. The clinic should be sanitized with Environmental Protection Agent (EPA).[10] Magazine stand, brochures, displays and other unnecessary items should be removed, and only flat surfaces, which can be easily cleaned, should be present in the waiting room and operatory.[11]

2. The waiting room should be marked so that patients know where to sit, maintaining enough distance between the patients. Inform patient to obey the appointment time, so that proper sterilization and disinfection can be done in the meantime. A minimum number of patients should be in the waiting room, and all measures should be executed to decrease or eliminate the waiting time of a patient. A better way would be to ask the patient to sit in their car and wait for their turn. Hand hygiene instructions should be displayed in the waiting room along with an alcohol-based sanitizer, for the patients to use.[11]

3. The door knobs and door glasses should be touched only by people working in the clinic. Since the virus survives on inanimate objects and surfaces, this caution should be taken to prevent patients unwarranted contact with such surfaces.

4. Assistants and clinic personnel at desks should be instructed for these new techniques, and should be given the personal protection equipment (PPE) that is approved and adheres to all guidelines. A brief period of training of all staff is mandatory before resuming any clinical services.

After wearing the PPE kit, it can get really hot inside for the dentist and clinic personnel; so, the windows should be kept open, to allow continuous air exchange. As the virus is known to survive in surroundings for many hours, it would be advantageous to maintain a regular flow of fresh air. High Efficiency Particulate Air (HEPA) filters are mechanical air filters that work by forcing air through a fine mesh that traps harmful particles, such as pollen, pet dander, dust mites, and tobacco smoke. To be termed as HEPA grade, it must filter at least 99.97% of all particles with size between 0.15 and 0.2 μm, which is the Achilles heel of HEPA filters. So, when buying, if HEPA is 99.97% efficient then it can be used. But before entering into a panic buying situation, its better to be aware of products that are labeled as true HEPA, HEPA-like or HEPA type, and its performance should be certified by International Organization for Standardization (ISO 29463).[12]

5. Before starting all this, a thought should be given regarding the waste disposal system. Timely collection of biomedical waste should be ensured.

As soon as a patient enters the clinic, their temperature should be checked with a contactless infrared thermometer, since It’s been more than a year after the first case of COVID-19, and the disease has entered the Community Spread Stage, so history of travel does not hold much significance; but the patient can be asked about any history of basic seasonal flu symptoms and a history of contact with any known COVID-19 positive patients. Footwear needs to be kept outside clinic premises, and a protective foot-covering should be given to the patient, for covering the whole foot. Patients should be given a head cover, hand gloves and mask before they enter the operating area. It has been documented that SARS-COV-2 can't survive in an oxidative environment, so preprocedural mouthrinse with 0.2% povidone iodine or 1% hydrogen peroxide should be done. Chlorhexidine mouthwash at 0.12% concentration does keep the viral load low to certain extent only for short period of time.[12,13] It would be really helpful if a generalized set of rules information can be sent via messaging services, so that it can be kept in mind by the patient and, before they enter the clinic, they are well versed in all the precautionary measures.[5,14,15,16]

Various techniques to decrease chairtime, interval between appointments and overall treatment duration can be thought of, as follows:

1. A shift from fixed appliances to a self-ligating bracket system should be thought of, as there is reduced number of wires changes, the interval between appointments is minimum of six weeks, and with the better bracket manufacturing technique the rate of breakages may also be smaller.[8]

2. Treatment planning should be well chosen, and appliances or techniques that deliver maximum results with minimum chairside activation should be employed.

3. Attempts should be made to decrease the patient visits during the retraction process.

4. A shift to 0.018-in slot can be thought of in mild cases that do not require a lot of control, as the wire sequence to reach a 0.016 x 0.022-in stainless steel working wire is shorter.

5. Clear Aligner Technology: Boon for current times!?

- Aligner technology can employ a digital scan instead of impressions, thereby decreasing chairtime and reducing contact with patient saliva.

- To further reduce patient contact, digital treatment plans can be made without use of attachments, so that it reduces patient chairtime. For difficult movements where attachments are imperative, the placement can be delayed by a few weeks or months, to reduce current risk of exposure.

- Space gaining in aligners can be achieved mostly via expansion and interproximal reduction (IPR). IPR should be done in the most non invasive way.

- Aligners can be delivered to a patient with contactless delivery.

- Instructions and maintenance protocol videos or internet links can be sent to the patient.

- Regular remote monitoring via video calls and photos is possible. Chairside monitoring can be performed once in three months or only when non-tracking of teeth is detected.

- If the teeth have moved correctly and treatment has tracked well, even the retainers can be fabricated and delivered remotely, from the last planned position of teeth, via digital treatment plan, without patient contact at all.

Various changes to be made by orthodontist:

1. Clinics should be designated with proper donning and doffing areas for PPE. Doctors should be wearing a full PPE kit, even if any aerosol emission procedure is not carried out. According to AAO (American Association of Orthodontics), Level 3 surgical masks are sufficient to protect against aerosolized coronavirus. According to recent CDC guidelines, N95 Respirator, provides greater protection.[17] Minimal use of a high-speed air rotor handpiece should be adopted in routine practice from now on, as it generates aerosols that may contain the infective virus droplets from the asymptomatic patients' saliva. Use of such handpiece is normally for removal of residual composite or enameloplasty. Shift to contra-angle handpiece should be done, with use of a syringe to drip water on the cutting area, in order to minimize aerosol generation.

2. With the handpiece out of question, only interproximal strips should be used for IPR procedures.

3. Technique of welding and soldering should be taught to assistants.

4. Multiple sets of basic armamentaria must be made, so that the time lapse between each patient can be minimized. For all patient, we should use all autoclaved instruments.

5. Handling and giving the elastics, NiTi coil springs, elastomeric chains and other auxiliaries can be performed by the assistant, to prevent contamination as much as possible.

6. Impression procedure should be bare minimum and if done, the impression should be disinfected with 2% Glutaraldehyde.

7. Fresh bondings and start-ups should be delayed for now, as the chairside time is to be minimized.

8. LED or UV curing light guns should be sanitized after every use.

9. Use of high strength composite as bite blocks can be thought of, so that they can be easily removed when not needed.

VACCINATION AND IMPLICATIONS

A two-dose regimen of BNT162b2 vaccine conferred 95% protection against Covid-19 in persons 16 years of age or older. Safety over a median of two months was similar to that of other viral vaccines.[18] Although the vaccine has been proven effective, questions have been raised about the longevity of the formed antibodies, since in orthodontic treatment, the treatment duration is longer than a year. So a patient who was vaccinated before, may not have antibodies by the end of treatment. Thus, safety measures need to be followed all time.

CONCLUSION

The field of Orthodontics is ever-changing. There is a wide range of parameters and variables, all combined together in many permutations and combinations. Therefore, we are used to continuous evolution of the subject and practice. Change is the only permanent state, so we should face the current crisis with utmost precaution and attention. Treatment modalities will change, patient expectations will change, COVID-19 is an uninvited guest, but it will not leave soon, because the disease is new, its study is still not complete, and the situation is changing day by day. Therefore, innovative thinking and small tweaks will go a long way to help us. Health of our staff and our helping associates should not be compromised at any cost. Difficult times also call for difficult measures, and those should be taken keeping in mind the cost/risk-benefit ratio for the patient and the doctor. Current approach should be to minimize direct patient contact and provide maximum remote assistance and management.

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Conception or design of the study:
NM, SM, RR.

Data acquisition, analysis or interpretation:
NM, SM, KP, RR.

Writing the article:
NM, KP.

Critical revision of the article:
NM, SM, KP, RR.

Final approval of the article:
NM, SM, KP, RR.

Overall responsibility:
NM, KP.

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ORIGINAL ARTICLE

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Validity and reliability of a trigonometry-based method for the measurement of tooth movement on digital models

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ABSTRACT

Objective: The objectives of the present study were to develop a method for longitudinally measuring tooth rotation, inclination and angulation on digital models, and to test the method validity and reliability.

Methods: The initial and final planned models of 14 patients treated with Invisalign® (386 teeth) were exported from ClinCheck®. The rotation, inclination and angulation values were assessed for the incisors, canines, premolars and molars, in both models, using trigonometry. An application was developed in Python 2.7 to automate the measurements. The Δplanned (variation in the position between the initial and final planned models) was obtained for each tooth and each type of movement. To test the validity, the degree of agreement between the Δplanned and the values available in the Invisalign® Table of Movements was assessed using the Intraclass Correlation Coefficient (ICC) and Bland-Altman analysis. For intra and inter-rater reliabilities, the Δplanned was obtained again.

Results: Excellent ICCs (> 0.9) and limits of agreement with narrow and clinically acceptable discrepancies were obtained for the rotation of all teeth (except maxillary canines, which had broader limits: -3.47 — 5.43) and for the inclination of premolars and molars. The inclination of anterior teeth and angulation of all teeth had ICCs and limits that were not indicative of great agreement. The reliability was high for the three movements (discrepancy <2°).

Conclusions: The method developed is reliable and suitable for longitudinally measuring inclination (posterior teeth) and rotation (except maxillary canines). It has limited value for the other movements measurements.

Keywords: Dental models. Tooth movement techniques. Odontometers. Rotation. User-computer interface.

RESUMO

Objetivo: Os objetivos do presente estudo foram desenvolver um método para medir longitudinalmente a rotação, inclinação e angulação dentárias em modelos digitais, e testar sua validade e reprodutibilidade. **Material e Métodos:** Os modelos inicial e final planejado de 14 pacientes tratados com Invisalign® (386 dentes) foram exportados do ClinCheck®. Os valores de rotação, inclinação e angulação foram calculados para incisivos, caninos, pré-molares e molares, em ambos os modelos, por meio de trigonometria. Um aplicativo desenvolvido em Python 2.7 foi utilizado para automatização das medidas. O Δplanejado (variação na posição entre os modelos inicial e final planejado) foi obtido para os movimentos descritos, nos diferentes grupos de dentes. A validade do método foi verificada pelo grau de concordância entre o Δplanejado e os valores disponíveis na Tabela de Movimentos do Invisalign®, utilizando-se o Coeficiente de Correlação Intraclasse (ICC) e a análise de Bland-Altman. O Δplanejado foi novamente calculado para análise da reprodutibilidade intra e interexaminadores. **Resultados:** Excelentes ICCs (> 0,9) e limites de concordância com discrepâncias reduzidas e clinicamente aceitáveis foram obtidos para a rotação de todos os dentes (exceto os caninos superiores, que expressaram limites mais amplos: -3,47 — 5,43) e para a inclinação de pré-molares e molares. A inclinação dos dentes anteriores e a angulação de todos os dentes apresentaram ICCs e limites não representativos de boa concordância. A reprodutibilidade foi alta para os três movimentos (discrepância < 2°). **Conclusões:** O método desenvolvido é reprodutível e se mostrou adequado para mensuração longitudinal da inclinação de dentes posteriores e rotação de todos os dentes, exceto caninos superiores. Apresenta valor limitado para as demais mensurações.

Palavras-chave: Modelos dentários. Técnicas de movimentação dentária. Rotação. Interface usuário-computador.

INTRODUCTION

Dental inclinations, angulations, and rotations are essential aspects to be evaluated during orthodontic treatment and are included in Andrews's six keys to normal occlusion.[1]

Longitudinal evaluations of inclination and angulation between the beginning and conclusion of treatment are typically measured with the aid of lateral head films[2-4] or panoramic radiographs.[5,6] However, only incisor inclination and posterior teeth angulation can be measured using lateral radiographs, while only dental angulation can be assessed in panoramic radiographs. Moreover, superimposition remains a problem in both types of exams.[7] Although cone-beam computed tomography (CBCT) may overcome these limitations, it is not indicated as a routine exam.[8]

The measurement of dental rotations is a significant factor for predicting posttreatment stability.[9] Little's irregularity index[10] expresses the degree of anterior segment alignment, but has limited value for the expression of rotation because the results are a combination of rotation and inclination.[11] The American Board of Orthodontics (ABO) introduced the objective grading system (OGS) to evaluate finished cases according to eight criteria.[12] Among these, the buccolingual inclination is used to indirectly assess the inclination of posterior teeth. Alignment is another criterion, but for the same reasons of Little's irregularity index, has limited value for expressing rotation reading.

Longitudinal evaluations of dental positioning are important both clinically and scientifically. Some studies have measured tooth inclination and angulation using plaster or digital models in a cross-sectional manner,[7,13-15] with the longitudinal assessment being restricted to the use of radiographic exams.

Digital models can allow obtaining angular measurements, both cross-sectionally and longitudinally. Huanca et al.[13] and Lombardo et al.[16] described a method based on trigonometry that allowed the assessment of teeth inclination,[13] angulation,[13] and rotation[16] on digital models. The idea of obtaining dental positioning by means of trigonometry seems to be a viable option, but since these methodologies were not validated, the purposes of the present study were (1) to develop a method to longitudinally measure tooth rotation, inclination and angulation on digital models and (2) to test its validity and reliability.

MATERIAL AND METHODS

This study included the digital models of 14 patients who started orthodontic treatment with Invisalign® (Align Technology, Santa Clara, CA, USA) at the research clinic of the Dental School at *Universidade de São Paulo* (FOUSP). Ethical approval was obtained by Research Ethics Committee (number 2.701.787) of the aforementioned institution, and written consent was obtained from all subjects.

The initial and final planned models (predicted by the software as an estimate of treatment results) were exported from ClinCheck® (Align Technology, Santa Clara, CA, USA). Therefore, for each patient, four models were exported in *Standard Triangle Language* (.stl): two initial (one upper; one lower) and two final planned (one upper; one lower). The initial models were obtained through polyvinyl siloxane impressions.

The methodology development was based on the description of Huanca et al.[13] for quantifying inclination and angulation, and Lombardo et al.[16] for rotation. The values were obtained through trigonometry for each tooth in the initial and final models, and angular variation was calculated (Δrotation, Δinclination, and Δangulation) for each tooth of the 14 patients (n=386 teeth). An application was developed in Python 2.7 to automate the measurements.

METHOD FOR THE ACQUISITION OF ROTATION, INCLINATION, AND ANGULATION VALUES

The *.stl* models obtained from ClinCheck® were imported into Geomagic Control® (North Carolina, USA) *software.* Five points were marked per tooth on the initial model (Fig 1). Subsequently, the "best fit" alignment was performed for each tooth from the initial model with the respective tooth from the final planned model. The points were thus copied from the initial to the final model (Fig 2A).

Establishing the Reference Plane

The establishment of a reference plane is necessary to make angular measurements. A "best fit" alignment of all teeth (except second molars, Fig 2B) was performed. Then, the reference plane was defined on the initial model as the best adjustment of the lingual gingival points of all teeth (Fig 2C) and labeled Plane 1. A median reference plane was created and referred to as Plane 2 (Fig 2D). Planes 1 and 2 were copied to the final planned model.

After this procedure, the Cartesian Space (XYZ) was reoriented so that the XY Plane would coincide with Plane 1 and the YZ Plane, with Plane 2.

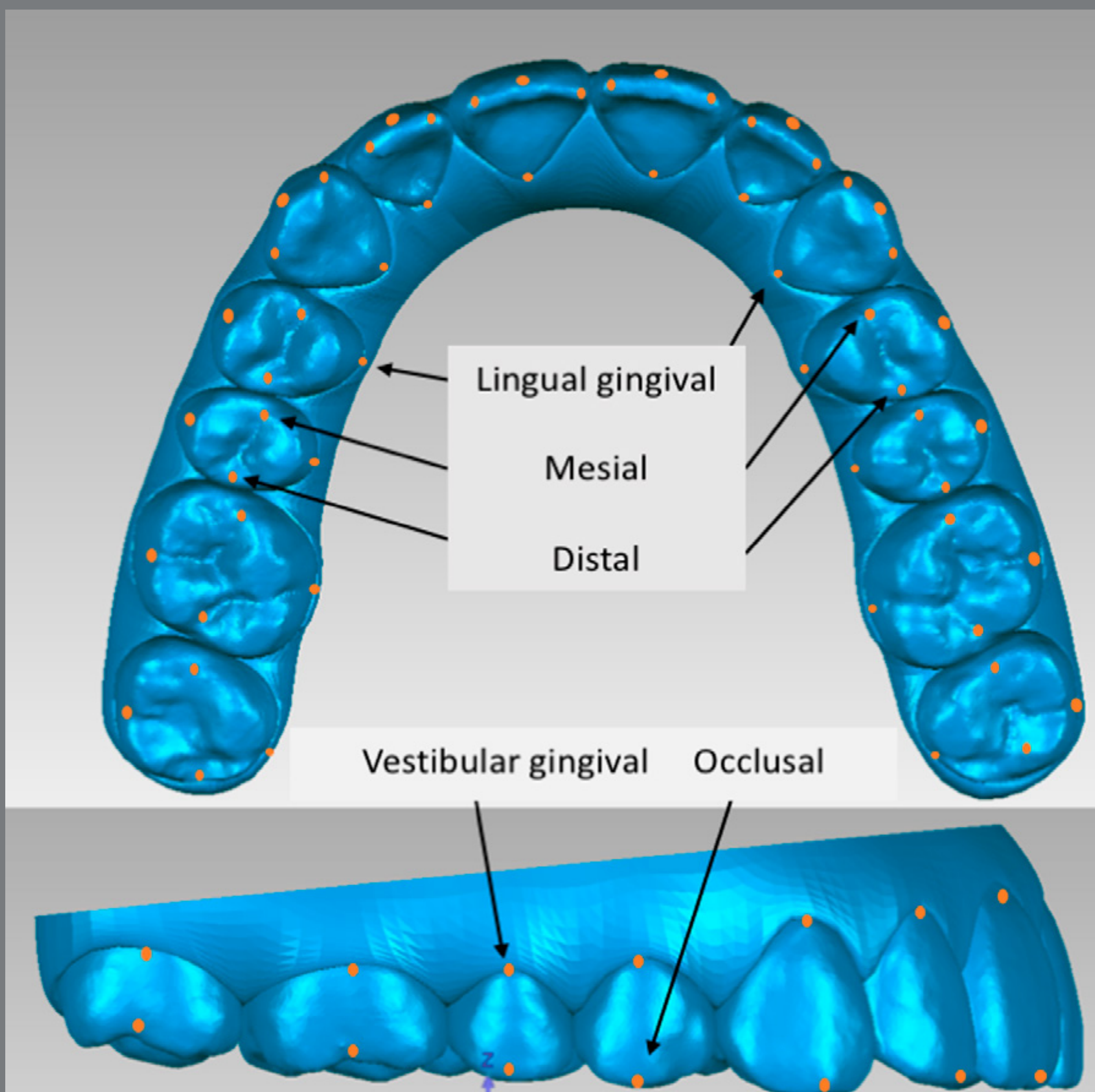

Figure 1: Disposition of points lingual gingival, mesial, distal, occlusal and vestibular gingival.

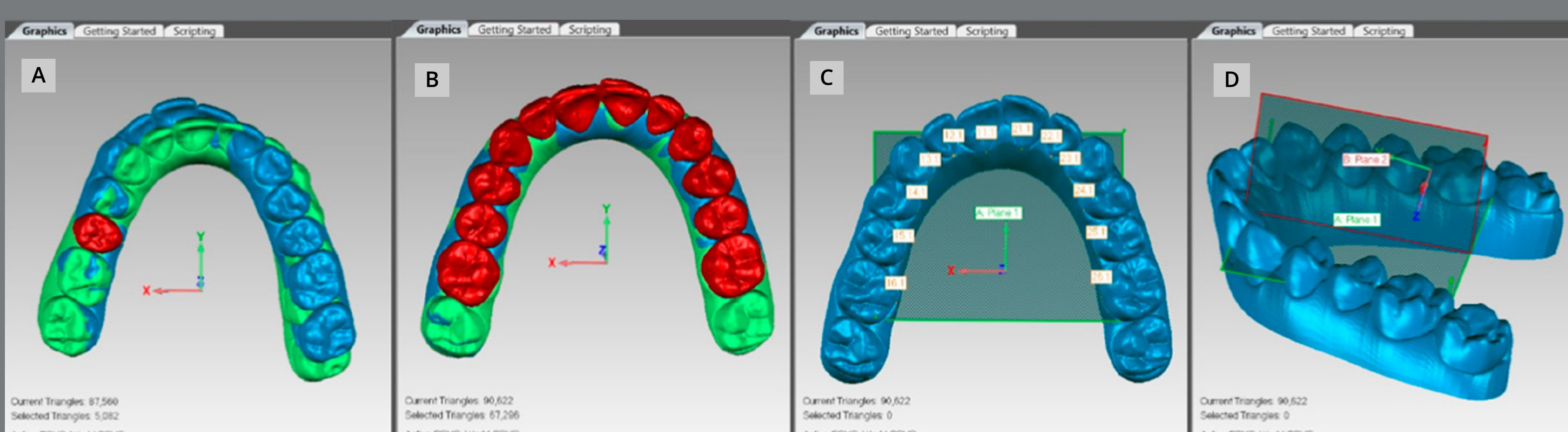

Figure 2: initial model in blue and final planned model in green. **A)** "Best fit" alignment of unit #15. After the alignment, all the five points of this tooth on the initial model were copied to this same tooth on the final model. **B)** "Best fit" alignment of all teeth. **C)** Plane 1 created by the best adjustment between the lingual gingival points of all teeth (except second molars). **D)** Plane 2 created perpendicular to Plane 1 and Plane XZ.

Rotation measurements

Rotation was set as the angle between a line formed by the mesial and distal points of each tooth and the Y-axis (Figs 3 and 4). To minimize the risk of errors and automate the process, angular measurements were not manually performed. The coordinates of each point (X, Y, Z values) were exported from Geomagic® in *.iges* format and imported into the applications.

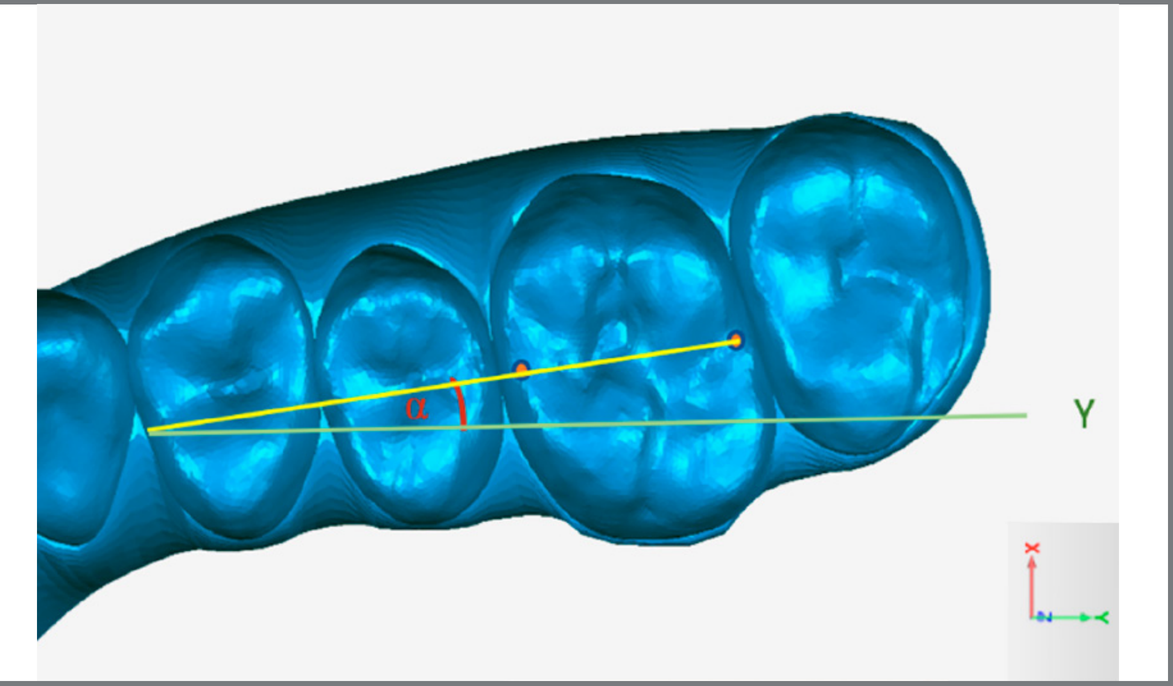

Figure 3: Yellow represents the straight line formed by mesial and distal points, and green, the straight line parallel to Y axis; α represents the angle formed by these two lines.

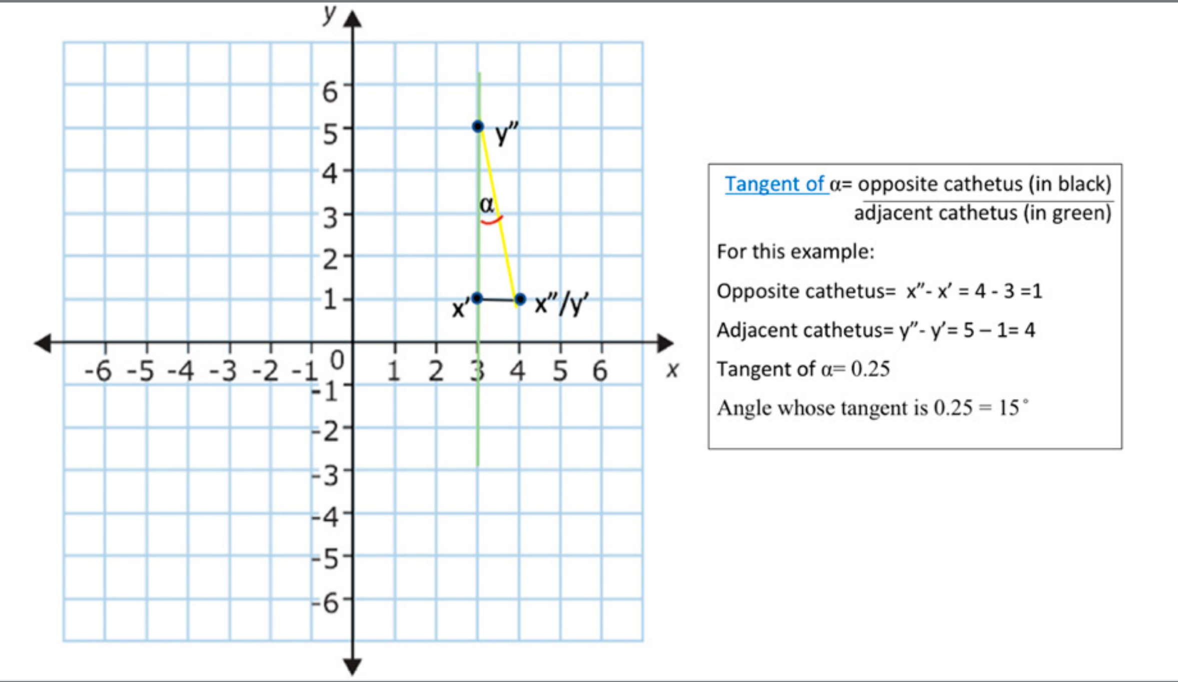

Figure 4: obtaining the rotation measurement by the arctangent function.

Angulation and inclination measurements

For the measurement of these two angles, to fully capture the movement and not one vector component only, it was necessary to reorient the Cartesian Space for each tooth with the aid of a rotational matrix, resetting the rotation. Thus, the Y axis was rotated to coincide with the line between the mesial and distal points of each tooth, and only after this rotation, the values of angulation and inclination were obtained. This procedure was essential to avoid the influence of tooth rotation on the calculation of inclination and angulation.

The developed application performed the realignment for each tooth. Given a line between the occlusal point and vestibular gingival point, the value of the angulation corresponded to the angle between the projection of this line on YZ plane and the Z-axis (Figs 5 and 6), while the inclination corresponded to the angle between the projection of the same line on the XZ plane and the Z-axis (Fig 7).

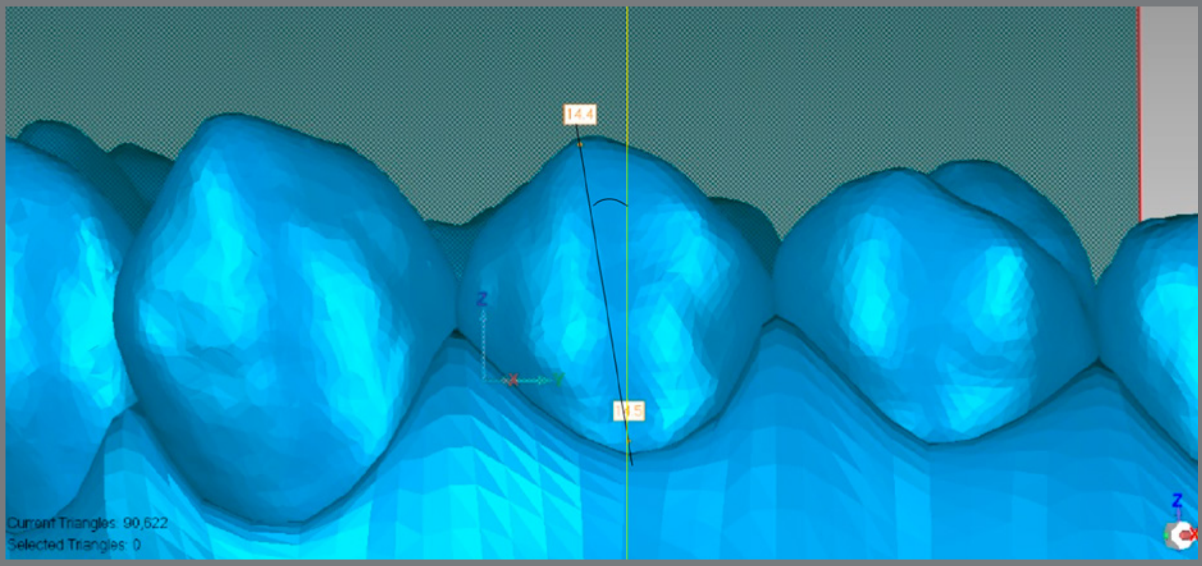

Figure 5: Black represents the line formed by occlusal and vestibular gingival points; yellow represents the Z-axis. The angulation is given in relation to YZ plane.

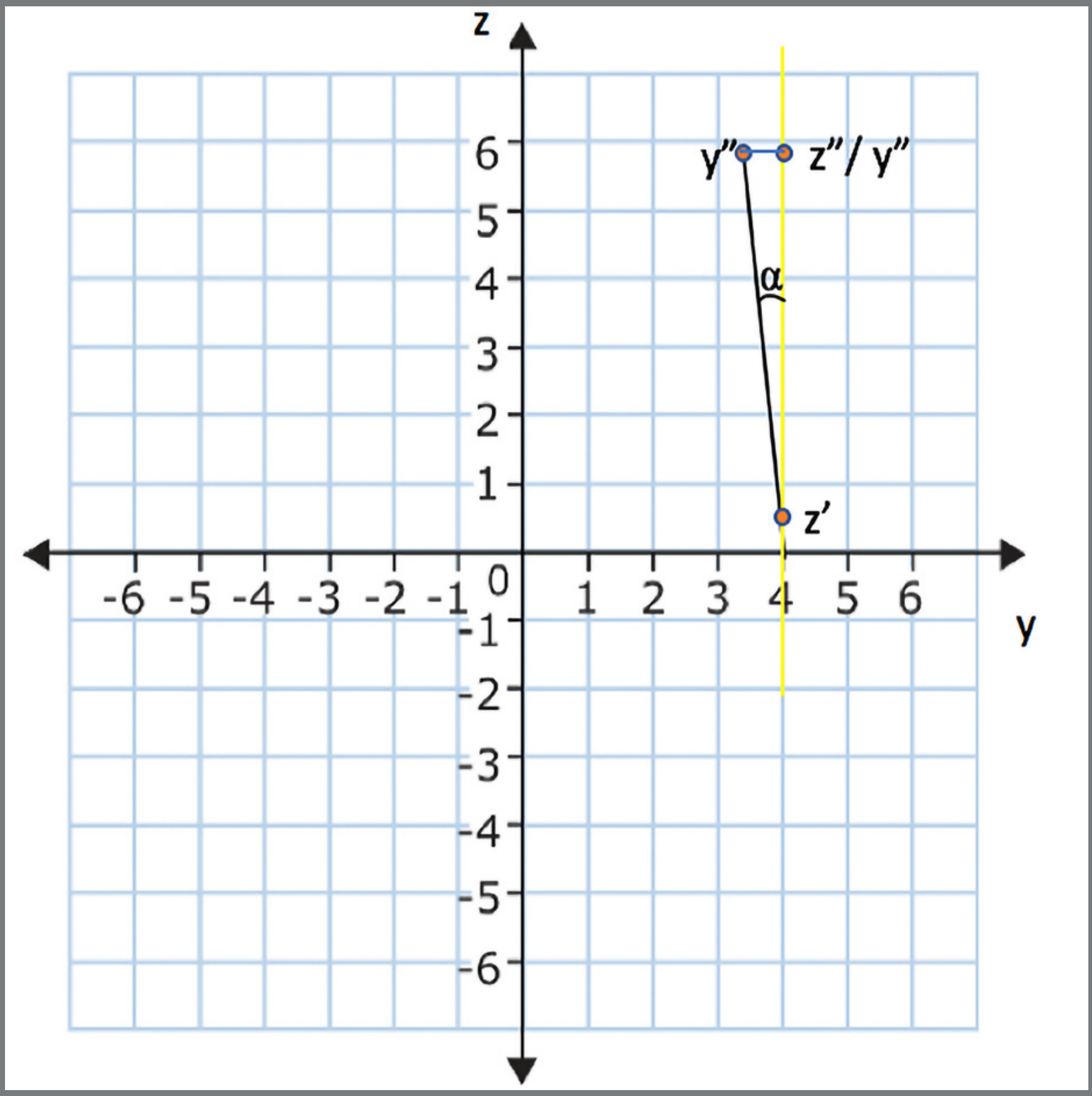

Figure 6: Obtaining the angulation measurement by the arctangent function.

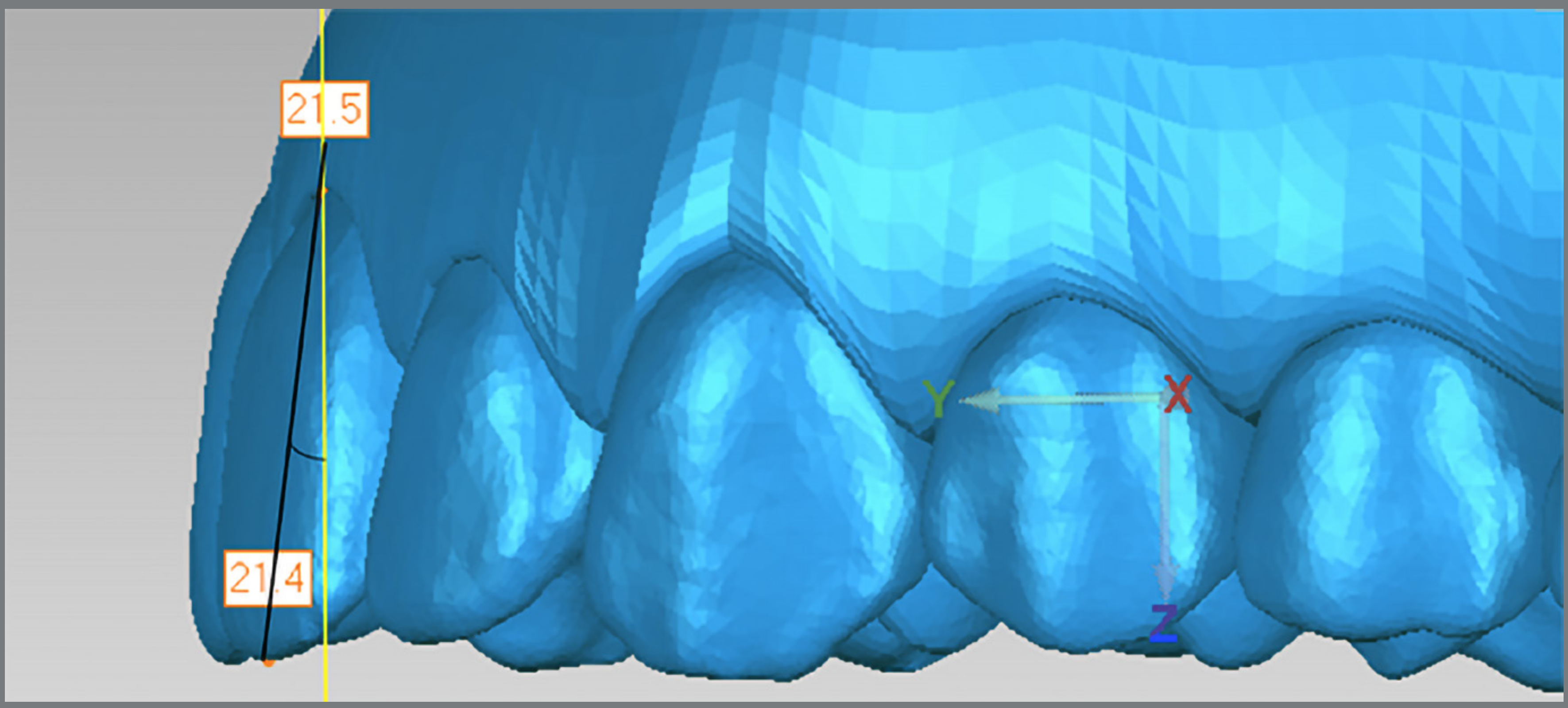

Figure 7: Black represents the line formed by occlusal and vestibular gingival points; yellow represents the Z-axis. The inclination is given in relation to XZ plane. It is also obtained by the arctangent function.

DEVELOPMENT OF THE APPLICATIONS

Two applications were developed in Python 2.7. The first application extracts the coordinates from *.iges* file exported from Geomagic® and saves the file in *.csv* format, while the second reads the data and performs the measurements. Applications and instructions are available at *http://app.renatadefaria.com.br/IGES%20Coordinates%20extractor/* and *http://app.renatadefaria.com.br/Teeth%20position%20on%20digital%20models/*. In the second application, a *.csv* file (containing the three-dimensional coordinates of each point) was used as an input, and a new *.csv* file was generated, which contained: (1) the degree of rotation of each tooth, (2) the coordinates resulting from the rotational matrix, and (3) the angles of inclination and angulation calculated from the rotated coordinates.

SAMPLE CHARACTERISTICS

Convenience sample composed of 4 men and 10 women, with a mean age of 31.37 years (range from 20.85 to 57.13) was used. The inclusion criteria were patients undergoing orthodontic treatment with Invisalign® at the research clinic at FOUSP. All of them initially presented a reduced or negative overbite, with a mean value of -0.28 mm (minimum of -2.0; maximum of 1.3), and a mild degree of crowding (< 3.5 mm). An overbite increase was planned for all the patients.

This study was composed of 386 teeth (194 maxillary; 192 mandibular) divided into the groups: incisors, canines, premolars, and molars (*n* per group in Tables 1 and 2).

For ICC, the sample size calculation was performed considering an α of 0.05, a power of 80% (β = 0.2), and a moderate ICC of 0.7. A sample size of 10 teeth per group was necessary.[17] For Bland-Altman analysis, the parameters used to estimate the sample size were an α of 0.05, a power of 80% (β = 0.2), an expected mean difference of 3.5°, an expected standard deviation of the differences of 1.7°, and the maximum expected difference of 10°. A sample size of 11 teeth was found to be necessary.

Table 1: ICC and Dahlberg index for ΔMethod x ΔInvisalign Table (maxillary arch).

	Rotation			Inclination			Angulation			
	ICC	CI 95%	D	ICC	CI 95%	D	ICC	CI 95%	D	n
Incisors	0.97*	0.95-0.98	1.13	0.70*	0.53-0.81	3.01	0.72*	0.57-0.83	2.08	56
Canines	0.98*	0.96-0.99	1.72	0.69*	0.43-0.84	2.34	0.53*	0.21-0.75	3.53	28
Premolars	0.99*	0.98-0.99	0.82	0.92*	0.88-0.96	1.47	0.66*	-0.06-0.90	2.88	54
Molars	0.97*	0.96-0.98	0.70	0.91*	0.85-0.95	1.32	0.64*	-0.07-0.88	2.83	56
Total	0.98*	0.97-0.99	1.06	0.82*	0.76-0.86	2.12	0.66*	0.33-0.81	2.75	194

*p<0.05; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; D: Dahlberg.

Table 2: ICC and Dahlberg index for ΔMethod x ΔInvisalign table (mandibular arch).

	Rotation			Inclination			Angulation			
	ICC	CI 95%	D	ICC	CI 95%	D	ICC	CI 95%	D	n
Incisors	0.99*	0.99-1.00	0.63	0.71*	0.55-0.82	3.58	0.47*	0.24-0.65	2.71	56
Canines	0.99*	0.98-0.99	1.01	0.82*	0.65-0.91	3.08	0.89*	0.77-0.95	2.19	28
Premolars	0.99*	0.99-1.00	0.76	0.94*	0.90-0.96	2.92	0.86*	0.76-0.92	1.81	54
Molars	0.98*	0.97-0.99	0.45	0.96*	0.94-0.98	0.51	0.60*	0.28-0.77	1.50	54
Total	0.99*	0.99-1.00	0.70	0.83*	0.78-0.87	2.74	0.76*	0.69-0.81	2.09	192

*p<0.05; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; D: Dahlberg.

Since Δrotation, Δinclination, and Δangulation variations were obtained between the initial and final planned models of patients undergoing treatment with Invisalign®, the proposed method was expected to produce Δs similar to those presented in the Invisalign®'s Table of Movements.

STATISTICAL ANALYSIS

The validity was verified by the Intraclass Correlation Coefficient (ICC) (2-way random, single measurement, absolute agreement), and by the Bland-Altman analysis of agreement between the Δ calculated with the method and the Δ available in the Table of Movements provided by Invisalign®.

Descriptive statistics of the difference (ΔInvisalign Table – ΔMethod) were computed, and a 1-sample Student *t*-test was applied to verify the presence of systematic error. The random error was assessed by the Dahlberg formula.

For the intra-rater reliability analysis, 50% of the models were randomly selected and remarked after one month, and the ΔMethod was obtained again. The same 50% models were remarked by a second rater for the assessment of inter-rater reliability. The ICC (2-way mixed, single measurement, absolute agreement) and Bland-Altman were used for both analyses. Descriptive statistics of the difference, a 1-sample Student *t*-test, and the Dahlberg formula were also applied.

Variables were expressed as the mean and standard deviation. The normality assumption was investigated by the Kolmogorov-Smirnov test.

RESULTS

VALIDITY

Tables 1 and 2 describe the results of the ICC, whereas Tables 3 and 4 describe the P-value for the 1-sample Student *t*-test (comparing the difference between ΔInvisalign and ΔMethod to 0), the mean of the difference, the 95% confidence interval for the differences and the Bland-Altman limits of agreement.

Considering the data provided by Invisalign® as the gold standard, the method for calculating rotation was shown to be accurate for maxillary and mandibular teeth because it presented excellent ICC agreement values (greater than 0.9 for all groups) and because the Bland-Altman limits of agreement showed narrow and clinically acceptable (≤ 3º) discrepancies (except maxillary canines). The difference between the method and the Table of Movements was close to 0 (and not significantly different) for each group of teeth, indicating that no systematic bias was found. For maxillary canines, broader limits of agreement (-3.47 — 5.43) and systematic bias ($p = 0.03$) were demonstrated. For these teeth, the method tended to measure an average of 0.98° (0.10 — 1.86) less than the Invisalign® Table.

When evaluating the inclination, results have shown high overall ICCs (> 0.90) and narrow limits of agreement (≤ 3°) for posterior teeth. Systematic errors were not found. Anterior teeth, however, presented limits of agreement with discrepancies higher than the clinically relevant difference. Angulation presented ICCs that were not always indicative of a great relationship, and the limits of agreement were not as interesting; additionally, systematic errors were present for premolars and molars.

Table 3: Descriptive statistics, 1-sample t test, and 95% CI values for differences and limits of agreement (positive numbers represent underestimations, and negative represent overestimations of measurements obtained by the method with respect to Invisalign Table). Maxillary arch.

Differences (Invisalign Table – Method)	P value	Mean Difference (degrees)	SD (degrees)	IC 95% (degrees)	Limits of agreement (degrees)	n
Rotation						
Incisors	0.06	0.40	1.57	-0.15 – 0.82	-2.67 – 3.11	56
Canines	0.03*	0.98	2.27	0.10 – 1.86	-3.47 – 5.43	28
Premolars	0.15	0.19	0.91	-0.07 – 0.44	-1.59 – 1.98	54
Molars	0.10	0.16	0.71	-0.03 – 0.36	-1.23 – 1.55	56
Inclination						
Incisors	0.60	0.39	4.29	-0.85 – 1.45	-8.01 – 8.80	56
Canines	0.87	-0.10	3.36	-1.40 – 1.20	-6.69 – 6.47	28
Premolars	0.99	-0.003	1.5	-0.42 – 0.41	-2.94 – 2.94	54
Molars	0.46	0.15	1.47	-0.25 – 0.54	-2.73 – 3.03	56
Angulation						
Incisors	0.36	-0.29	2.34	-0.94 – 0.35	-4.88 – 4.30	56
Canines	0.06	1.73	4.77	-0.11 – 3.58	-9.34 – 11.08	28
Premolars	< 0.001*	3.70	1.60	3.28 – 4.18	0.56 – 6.84	54
Molars	< 0.001*	3.55	1.70	3.10 – 4.00	0.22 – 6.88	56

*p<0.05.

Table 4: Descriptive statistics, 1-sample t test, and 95% CI values for differences and limits of agreement (positive numbers represent underestimations, and negative represent overestimations of measurements obtained by the method with respect to Invisalign Table). Mandibular arch.

Differences (Invisalign Table – Method)	P value	Mean Difference (degrees)	SD (degrees)	IC 95% (degrees)	Limits of agreement (degrees)	n
Rotation						
incisors	0.75	-0.04	0.90	-0.28 – 0.20	-1.80 – 1.72	56
canines	0.62	-0.14	1.45	-0.70 – 0.42	-2.98 – 2.70	28
premolars	0.84	0.02	0.61	-0.15 – 0.18	-1.17 – 1.21	54
molars	0.17	-0.09	0.50	-0.23 – 0.04	-1.07 – 0.89	54
Inclination						
incisors	0.22	-0.62	3.63	-1.62 – 0.38	-7.73 – 6.49	56
canines	0.22	0.60	2.53	0.39 – 1.60	-4.35 – 5.55	28
premolars	0.80	0.05	1.45	-0.35 – 0.45	-2.79 – 2.89	54
molars	0.88	0.01	0.72	-0.18 – 0.21	-1.40 – 1.41	54
Angulation						
incisors	0.18	-0.69	3.8	-1.70 – 0.33	-8.14 – 6.76	56
canines	0.65	0.23	2.59	-0.81 – 1.28	-4.84 – 5.30	28
premolars	0.01*	0.79	2.17	0.18 – 1.39	-3.46 – 5.04	54
molars	< 0.001*	1.13	1.82	0.64 – 1.63	-2.44 – 4.70	54

*p<0.05.

Considering that the values for the random error (Dahlberg) were mainly less than 3°, and considering the clinical plausibility, only differences higher than 3° were considered relevant.

RELIABILITY

The intra-examiner reliability is described in Tables 5 and 6, while the inter-examiner is described in Tables 7 and 8. The method was shown to be highly reliable for measuring the three kinds of movements, since the discrepancies were less than 1° for intra-rater, and less than 2° for inter-rater reliabilities.

Table 5: ICC and Dahlberg index for Δplanned in the test-retest (intra-rater reliability).

	Rotation			Inclination			Angulation			
	ICC	95% CI	D	ICC	95% CI	D	ICC	95% CI	D	n
Maxillary and Mandibular teeth	1.00*	1.00-1.00	0.08	0.99*	0.99-1.00	0.16	0.98*	0.98-0.99	0.55	196

*p<0.05; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; D: Dahlberg.

Table 6: Descriptive statistics, 1-sample t test, and 95% CI values for differences and limits of agreement (positive numbers represent underestimation, and negative represent overestimation of measurements obtained by the test with respect to retest).

Differences (Retest - Test)	P value	Mean Difference (degrees)	SD (degrees)	95% CI (degrees)	Limits of agreement (degrees)	n
Rotation	0.47	-0.006	0.12	-0.02 – 0.01	-0.24 – 0.23	196
Inclination	0.32	-0.016	0.23	-0.05 – 0.01	-0.47– 0.43	196
Angulation	0.91	0.003	0.43	-0.06 – 0.06	-0.84 – 0.84	196

Table 7: ICC and Dahlberg index for Δplanned (inter-rater reliability).

	Rotation			Inclination			Angulation			n
	ICC	95% CI	D	ICC	95% CI	D	ICC	95% CI	D	
Maxillary and mandibular teeth	1.00*	0.99-1.00	0.15	0.96*	0.95-0.97	0.61	0.98*	0.98-0.99	0.74	196

*p<0.05; ICC: Intraclass Correlation Coeficient; CI: Confidence Interval; D: Dahlberg.

Table 8: Descriptive statistics, 1-sample *t* test, and 95% CI values for differences and limits of agreement (positive numbers represent overestimation, and negative represent underestimation of measurements obtained by the rater 2 with respect to rater 1).

Differences (Rater 2 – Rater 1)	P value	Mean difference (degrees)	SD (degrees)	95% CI (degrees)	Limits of agreement (degrees)	n
Rotation	0.54	0.009	0.22	-0.02 – 0.04	-0.42 – 0.44	196
Inclination	0.96	-0.002	0.68	-0.10 – 0.09	-1.33– 1.33	196
Angulation	0.75	-0.019	0.86	-0.14 – 0.10	-1.69 – 1.67	196

*p<0.05.

DISCUSSION

In the present study, dental rotation, inclination and angulation were longitudinally obtained by calculating the Δplanned. To the best of our knowledge, this is the first study to test the validity and reliability of a method for longitudinal evaluation of teeth positioning using digital models.

Bearing in mind that correlation coefficients lower than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and higher than 0.9 are indicative of low, moderate, good and excellent relationships,[18] respectively, it can be noticed that rotation measurements had excellent indexes for all groups of teeth (Tables 1 and 2). Similarly, the evaluation of inclination for premolars and molars also presented excellent values. The same results were not found for the inclination of anterior teeth and angulation of all teeth, which mostly presented low or moderate indexes.

The correct statistical approach to measure the degree of agreement between two methods is not obvious.[19,20] It has been discussed that the ICC must not be considered alone for this analysis because high correlation does not necessarily mean that two methods agree.[19] The Bland-Altman limits of agreement were applied to overcome this problem.

We presume that limits with discrepancies >3° are clinically relevant, and therefore consider the method as having limited value when longitudinally measuring the maxillary canine's rotation, the inclination of anterior teeth and angulation of all teeth (Tables 3, 4). For the maxillary canines, for example, the method tends to underestimate the real rotation value up to 5.43°, or overestimate up to 3.47 (-3.47 — 5.43). In cases in which there is no problem in accepting this discrepancy, the method to perform this measurement can be applied.

The fact that the Table of Movements and the method yielded different results for some measurements might be related to limitations in the stability of the reference plane between the initial and final planned models. When Invisalign® receives the initial digital models, or when they create it using impressions, the model has its own reference plane. It happens that probably a setup is performed on this model to generate the final model, and the Δmeasurements are obtained in relation to this plane, which remains stable. The stability of the plane is guaranteed because the first file generates the second. Nevertheless, a problem is found when the task is needed in the opposite way: create a stable reference plane for the two files.

According to Ferrario et al.[21], the stability of the plane is important for longitudinal analyses because the final measurements will be obtained in relation to a different reference. The sample in the present study was composed of individuals with a tendency towards an anterior open bite, and treatment planning included extrusion of anterior teeth, thereby rotating the plane in the anteroposterior direction. For this reason, instead of constructing two reference planes (one on the initial and other on the final model), we opted to make a "best fit" alignment of the teeth from both models and to construct a single plane as an attempt to attenuate this problem. Additionally, we opted to construct the plane differently from the recommendation of Richmond et al.[15], that have used the incisal edges and cuspid tips. Instead, we used the same approach as Huanca Ghislanzoni et al.[13], who advocated that constructing the plane closer to the gingival region would make it less susceptible to changes caused by alterations in dental inclination, curve of Spee or Wilson. All these approaches, however, appeared to be insufficient for guaranteeing plane stability.

Although it cannot be affirmed, we believe that the reason for the great agreement of the inclination of posterior teeth, despite the instability of the plane, might be related to the process of obtaining this measurement. Because measurements were made in relation to the XZ plane, an alteration in the anteroposterior direction would compromise a measurement in the anterior region, but may not highly compromise measurements in the posterior region. However, an alteration in the lateral direction, as expected for patients who are treated for canted occlusal planes (not the case of the present sample), will probably affect the measurement in the posterior region and may not greatly compromise it in the anterior one. Regarding rotation, it must be remembered that while inclination and angulation were obtained in relation to the Z-axis, rotation was obtained in relation to the Y-axis. The positioning of this axis was not significantly changed by alteration in the reference plane, which was corroborated by the results of the present study, at least for small variances.

The use of a stable plane of reference, such as a cranial plane, could probably solve problems of instability. Digital models and tomographic images can therefore be superimposed, as performed by Castro et al.[22] However, as mentioned before, CBCT is not indicated as a routine exam.[8]

For reliability, excellent ICCs and levels of agreement were achieved, with very low discrepancies for all kinds of movements. This fact is probably due to the consistency in transferring points from the initial to the final model. Nouri et al.[14] measured dental inclinations cross-sectionally in models by two means: manually, with the use of a tooth inclination protractor (TIP), and digitally, by means of *software* developed for this purpose. As a result, these authors verified that the digital method had a slightly higher intra-rater level of reliability than the manual method, with ICCs of 0.88, 0.76 and 0.87 for the incisors, canines and posterior teeth, respectively. Moreover, Kodaka et al.,[23] who measured inclination manually, and Castro et al.,[7] who measured inclination and angulation in digital manner, both cross-sectionally, obtained a total ICC of 0.98 for intra-rater reliability. Our results are similar to these results, since we achieved an ICC of 0.99 (0.99-1.00) for inclination, and of 0.98 (0.98-0.99) for angulation.

Although it is not the purpose of the study, one of the possible applications of this method is to quantify how predictable the digital planning of clear aligners is. The Δplanned and Δachieved movements of patients undergoing treatment with aligners can therefore be compared. We believe that, in this specific situation, even the methods that presented limited validity could be applied. The explanation is that if both Δs are calculated by the same method, any presumed error will most likely be maintained for both variations, making the comparison valid. Besides, the method proved to be highly reliable for all the measurements.

CONCLUSIONS

The method developed is highly reliable for evaluating the three movements, and valid for the longitudinal evaluation of the rotation of all teeth (except maxillary canines) and the inclination of premolars and molars, even when a small anteroposterior change in the reference plane is present.

It has limited value to measure the rotation of maxillary canines, the inclination of incisors and canines or angulation of all teeth, at least in models in which an alteration in the overbite is present.

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Effect of the different debonding strength of metal and ceramic brackets on the degree of enamel microcrack healing

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ABSTRACT

Objective: This study aims to determine shear debonding strength of metal and ceramic brackets, and the degree of enamel crack healing.

Material and Methods: Extracted human maxillary premolars were flattened on the buccal surface, and randomly separated into five groups (n = 15). In control groups (groups 1 and 2), metal and ceramic brackets were bonded on flat polished enamel, while in experimental groups (groups 3 and 4), metal and ceramic brackets were bonded on the surface with boundary where corner cracks were created. Additionally, fifteen specimens (group 5) were also prepared for an indentation procedure with no bracket installation. The degree of crack healing was measured. All brackets were detached with a universal testing machine, and the adhesive remnant index (ARI) was also identified. Healing degree and apparent fracture toughness were then calculated.

Results: Between groups with similar bracket types, there was no statistically significant difference in debonding strength. Regarding bracket types, ceramic brackets provided significantly higher debonding strength than metal brackets. There was a significant difference in ARI scores between metal and ceramic brackets. The corner cracks showed signs of healing in both horizontal and vertical directions. No statistically significant difference in the healing rates among the groups was found and the apparent fracture toughness increased from the initial to the final measurement.

Conclusions: Within the limitations of this study, even though ceramic brackets required significantly higher debonding force compared to metal brackets, debonding stress was limited to the bonding site and did not affect the surrounding cracks on enamel.

Keywords: Debonding strength. Microcrack healing. Ceramic brackets. Indentation.

RESUMO

Objetivo: O presente estudo teve como objetivo determinar a resistência ao cisalhamento de braquetes metálicos e cerâmicos, e o grau de reparo de fraturas no esmalte. **Métodos:** Pré-molares superiores, extraídos de humanos, foram aplainados na face vestibular e aleatoriamente divididos em cinco grupos (n = 15). Nos grupos controle (Grupos 1 e 2), os braquetes metálicos e cerâmicos foram colados em esmalte liso e polido; enquanto nos grupos experimentais (Grupos 3 e 4), os braquetes metálicos e cerâmicos foram colados em superfície delimitada, em cujos cantos foram criadas fissuras. Adicionalmente, foram também preparados 15 espécimes (Grupo 5) para um teste com indentação, sem a instalação de braquetes. O grau de reparo das fraturas foi avaliado. Todos os braquetes foram descolados usando uma máquina universal de testes, e o índice de adesivo remanescente (ARI) também foi avaliado. O grau de reparo e a tenacidade à fratura aparente foram então calculados. **Resultados:** Entre os grupos com o mesmo tipo de braquetes, não houve diferença estatisticamente significativa na força de descolagem. Com relação aos tipos de braquetes, os cerâmicos apresentaram uma força de descolagem significativamente maior do que os metálicos. Houve uma diferença significativa nos escores ARI entre os braquetes metálicos e os cerâmicos. As fraturas de canto mostraram sinais de reparo nos sentidos horizontal e vertical. Não foi detectada diferença estatisticamente significativa no grau de reparo entre os grupos, e a tenacidade à fratura aparente aumentou da mensuração inicial para a final. **Conclusão:** Considerando-se as limitações desse estudo, apesar de os braquetes cerâmicos necessitarem de força de descolagem significativamente maior do que os braquetes metálicos, a tensão de descolagem foi limitada ao sítio de colagem, não afetando as fraturas de esmalte ao redor.

Palavras-chave: Força de descolagem. Reparo de microfraturas. Braquetes cerâmicos. Indentação.

INTRODUCTION

Enamel cracks may be a consequence of several factors, including abnormalities in the maturation process, occlusal overloading, temperature variations, therapeutic procedures, and surface injuries from bracket removal — especially with the use of ceramic brackets.[1] Several studies have determined that bonding of ceramic brackets to enamel provided higher bond strength when compared to conventional metal brackets.[2-4] Such firm adhesion may cause some degree of micro surface damage in the form of crazing, crack or fracture on the enamel surface when brackets are removed.[5]

The enamel micro-defects after bracket removal are of great interest for orthodontists who use fixed orthodontic appliances.[6,7] Presence of cracks may cause stain and plaque accumulation on the enamel and increase the risk for dental caries. Additionally, propagation of cracks may lead to more surface disintegration and structural loss.[8] However, there is some evidence of enamel microcrack healing as a natural defense to prevent crack propagation to the dentin and to dental pulp.[9]

Few studies have evaluated enamel defects before bonding,[1,7] and analyzed the presence of alteration of the control enamel microcracks before and after bonding brackets. Regarding the bracket types, there is a lack of knowledge on the relative microcrack characterization on debonded enamel after brackets removal.

From the fractographical and mechanical aspects, the objectives of this study were to compare debonding strength and degree of crack repair on the debonded enamel after removal of metal and ceramic brackets.

MATERIAL AND METHODS

Seventy five extracted human maxillary premolars were used for this research. These premolars were extracted due to orthodontic indications. These specimens, originated from both genders, between 16 and 40 years of age, were collected from patients at the surgical department in the School of Dentistry, Naresuan University, and private dental clinics, following an ethical approval protocol by the Institutional Review Board of Naresuan University. All premolars were caries-free, with no existing restorations nor root canal fillings, and with no sign of prominent cracks, abrasion or erosion. After extraction, all specimens were washed in running water to remove all blood and adhered tissue, stored in 0.1% thymol solution and then tested within a month of extraction, to reduce the potential for organic and inorganic losses.

After root separation using a high-speed carborundum disc, the specimens were positioned in a 2-cm diameter plastic ring with the most convex buccal surface of the tooth 2-3 mm above the surface of a self-cured acrylic resin, and then kept in 25°C water for 24 hours, for complete resin polymerization. A series of abrasive papers, with grits P1000, P1200, and 3-μm and

1-μm diamond pastes were consecutively used to standardize the curvature of the buccal surface of the teeth. The polishing protocol consisted of the use of a grinder polisher, driven with a 20-Newton force for 20 seconds, to achieve a flat area to bond the bracket base (9.28 ± 0.08 mm^2 for metal and 10.38 ± 0.08 mm^2 for ceramic brackets). The polishing was carried out horizontally relative to the cutting plane of the plastic ring.

All samples were randomly divided into five groups depending on the bracket type and with or without indentations:

» Group 1: Metal brackets bonded on non-indented specimens (n=15).
» Group 2: Ceramic brackets bonded on non-indented specimens (n=15).
» Group 3: Metal brackets bonded on indented specimens (n=15).
» Group 4: Ceramic brackets bonded on indented specimens (n=15).
» Group 5: Indented specimens with no brackets (n = 15).

Before indention making in groups 3, 4, and 5, a four-millimeter-width rectangular barrier was attached to the middle of the polished area to separate the indented from the bonded areas (Fig 1A). Six micro-indentations were performed close to the edges of the barrier using a microhardness tester with a Vickers diamond indenter (Zwick/Roell; Indentec) loaded with a 500-gram force for 10 seconds (Fig 1B). Three indentations were created at the upper boundary including A, B, and C points from left to right, and another three indentations were created at the lower boundary including D, E, and F points from right to left (Fig 1B).

Each indentation created four corner cracks extending from the indentation. They were classified according to the direction of the crack in relation to the center of the bonded area, as follows; 1) Centripetal vertical crack, 2) Centrifugal vertical crack, 3) Clockwise horizontal crack, and 4) Counterclockwise horizontal crack (Fig 1B). The lengths of those twenty-four diagonal microcracks were measured with Vickers indentation diagonals at baseline using a binocular stereo microscope of the microhardness tester at magnifications of 100X and 400X before bracket bonding and also after debonding. By using machine software (Zwick/Roell) to draw measuring lines, which were calibrated with the size and depth of the indentation diagonal, between the indentation's corner and the prominent crack tips, the crack length can be precisely measured.

The illustration of non-indented and indented specimens before bracket attachment is shown in Figure 2. The specimen's unbonded areas were then covered with a barrier tape to avoid adhesive contamination on the microcracks and to control the bonding area (Fig 1C).The bonded surface of each

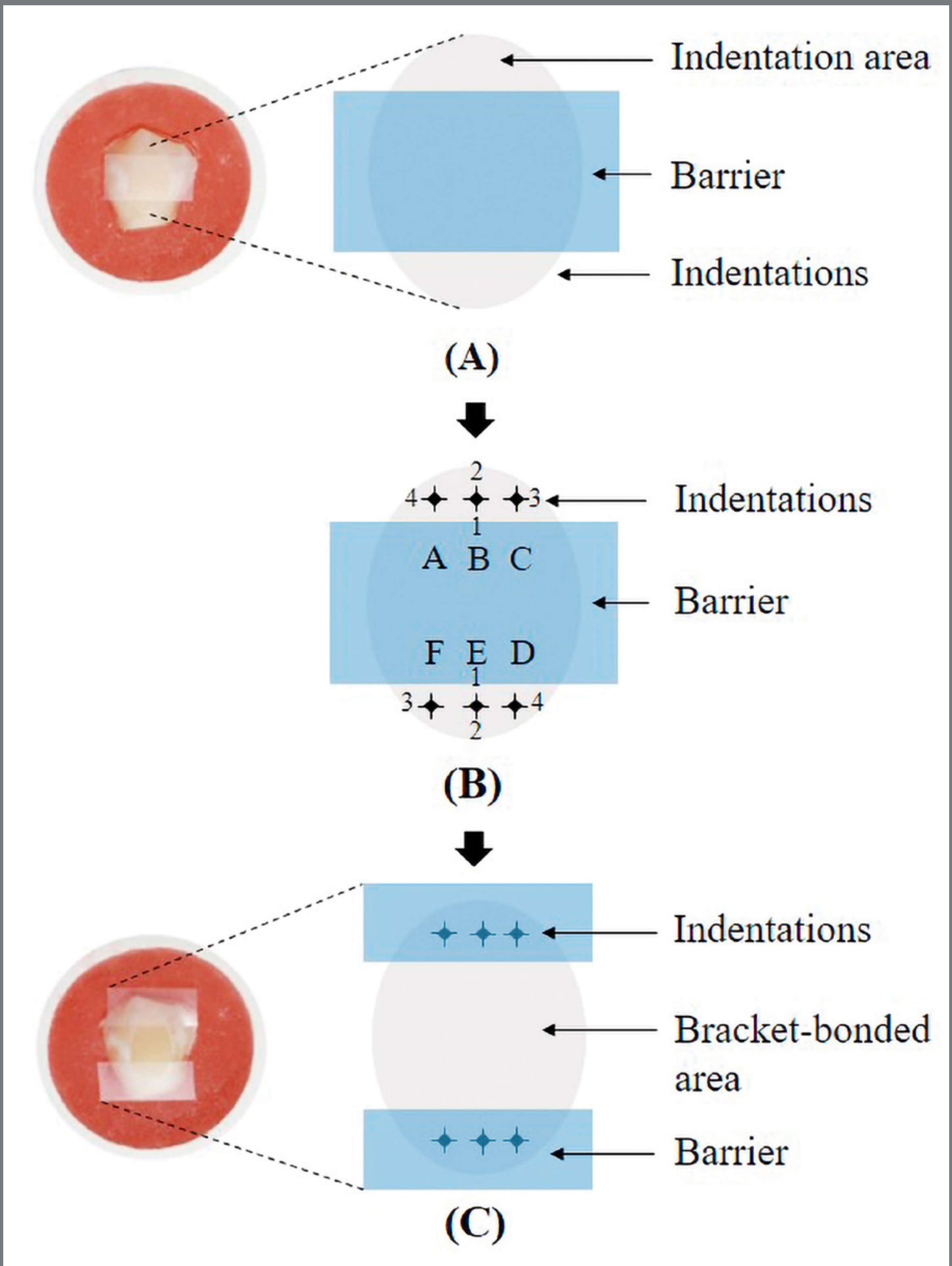

Figure 1: Schematic drawing of how to create a control bonded surface and the orientation of the indentations and corner cracks around the bracket base area. **A**) The first barrier used for separation before indentation, to locate indentation zone at the bracket boundary. **B**) Indentation making (nomenclature of the indented microcracks performed at the boundary according to their directions: A_1, B_1, C_1, D_1, E_1, and F_1 (centripetal vertical cracks); A_2, B_2, C_2, D_2, E_2, and F_2 (centrifugal vertical cracks); A_3, B_3, C_3, D_3, E_3, and F_3 (clockwise horizontal cracks); A_4, B_4, C_4, D_4, E_4, and F_4 (counterclockwise horizontal cracks). C) The second barrier used for protection of the indentations from resin infiltration before bracket attachment.

specimen was prepared by etching with 37% phosphoric acid (3M Unitek) for 30 seconds, followed by 15-second water rinsing and 10-second drying with oil-free compressed air. The etched enamel was then painted with Transbond XT primer (3M Unitek) before application of Transbond XT paste (3M Unitek)

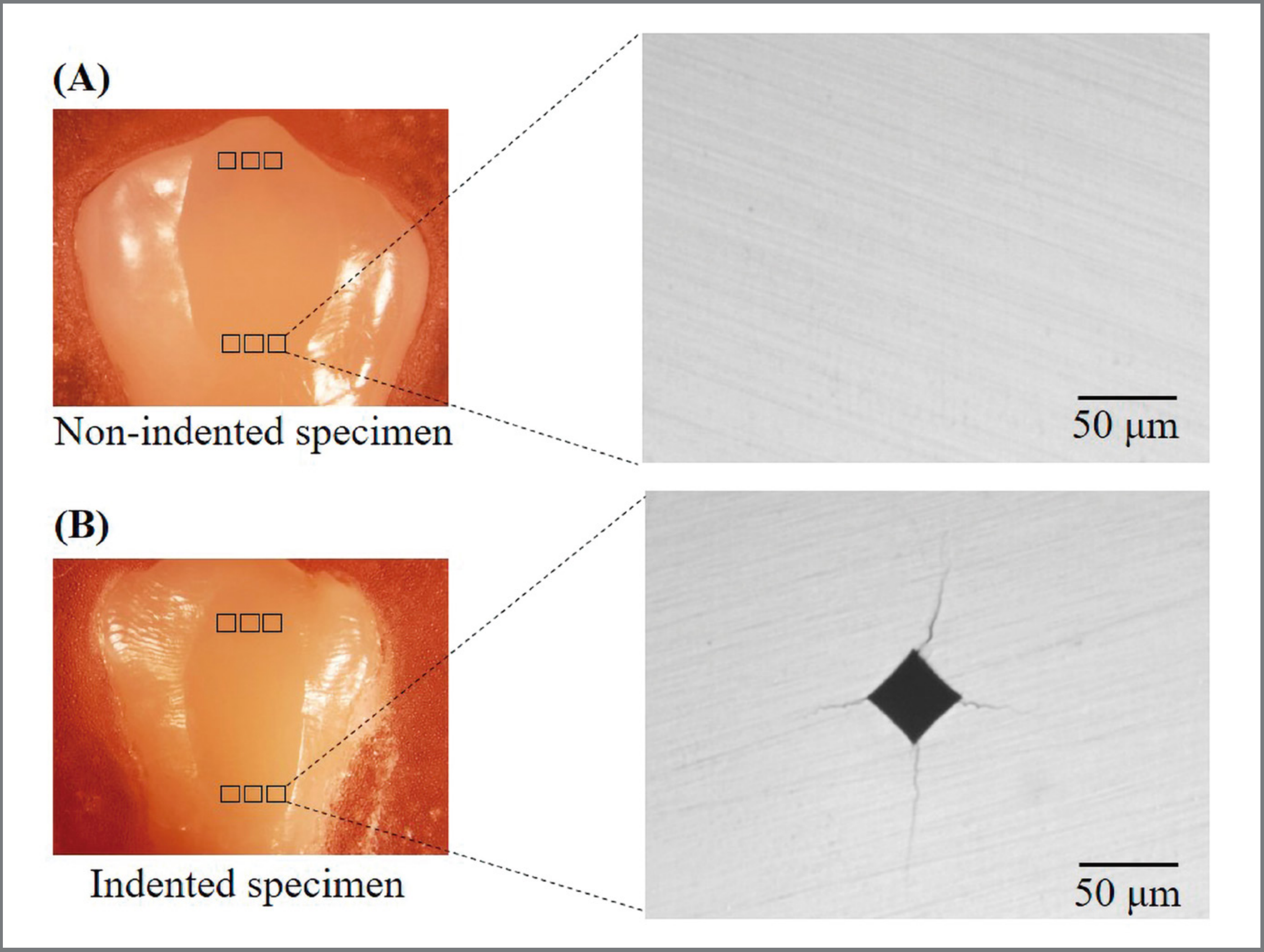

Figure 2: The samples with and without indentation: (**A**) Sample without indentations on polished enamel, (**B**) Sample with indentations on polished enamel.

to the bracket base. Metal (Gemini, 3M Unitek) and ceramic (Clarity, 3M Unitek) brackets of mandibular incisors were used. The brackets were placed and firmly pressed at the center of the polished surfaces. The excess adhesive was removed from the bracket base and light-activated for 3 seconds on each side of the metal bracket and 3 seconds through the ceramic bracket, according to the manufacturer's instructions. After storage of all specimens in water for 24 hours (for complete resin polymerization), each bracket was debonded with a universal testing machine (Instron) with a crosshead speed of 1.0 mm/min, perpendicular to the bracket-enamel interface (Fig 3). The residual adhesive on the enamel surface and bracket base was assessed under a stereomicroscope, according to the modified adhesive remnant index (ARI).[10]

After the final measurement of corner cracks, healing rates in both vertical (R_v) and horizontal (R_h) directions were calculated according to the following equations:

$$R_v = \frac{V_2 - V_1}{t} \quad (1)$$

$$R_h = \frac{H_2 - H_1}{t} \quad (2)$$

where V_1, V_2, H_1, H_2, and t are the initial vertical crack length, final vertical crack length, initial horizontal crack length, final horizontal crack length, and healing time, respectively.

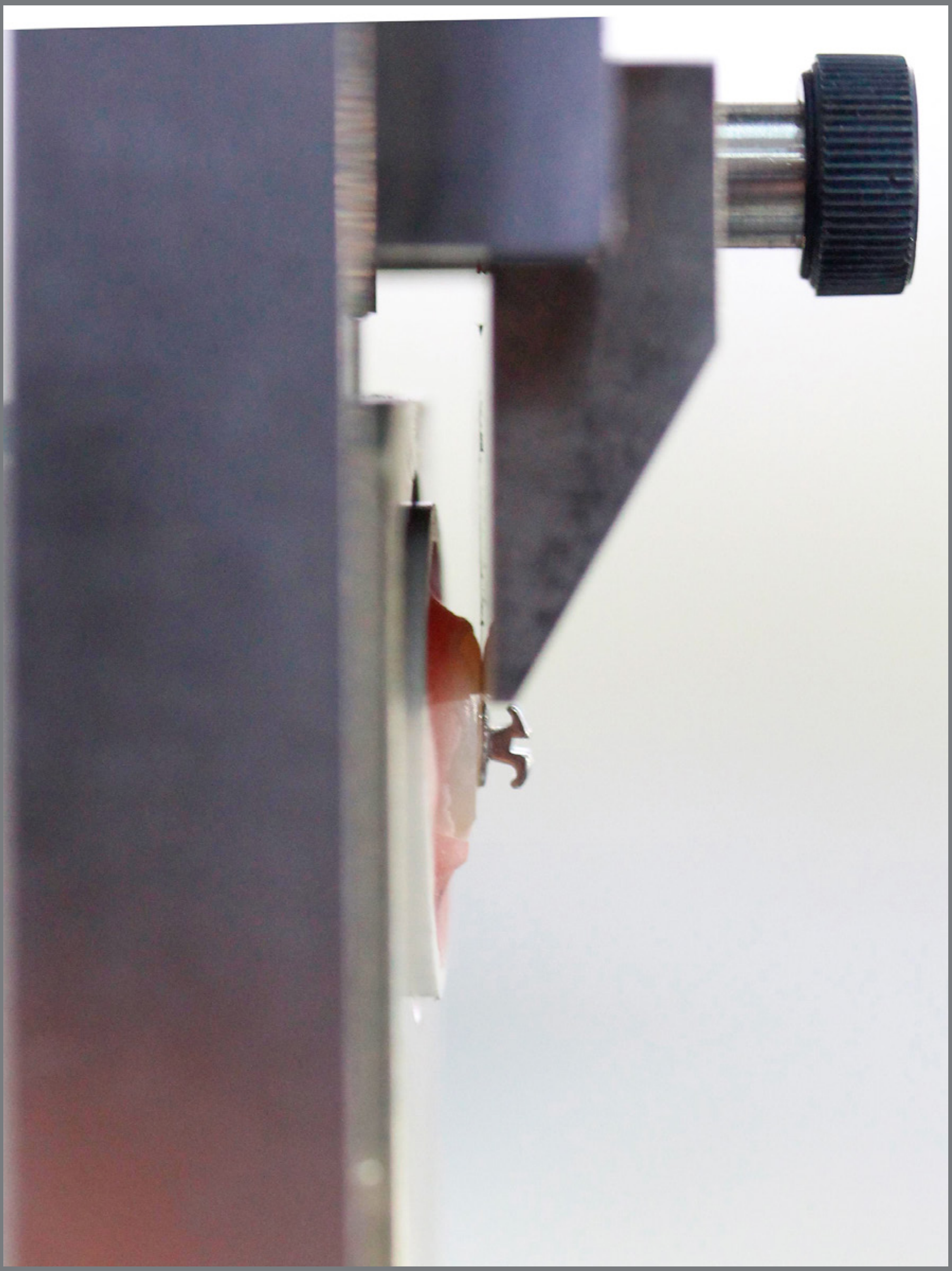

Figure 3: The orientation of a specimen in the universal testing machine.

In addition, the crack length was used to analytically calculate the apparent fracture toughness ($K_{c(app)}$) for each indentation according to the following equation:[11]

$$K_{c(app)} = 0.0084\left(\frac{E}{HV}\right)^{2/5}\left(\frac{2F}{L}\right)\frac{1}{c^{1/2}} \qquad (3)$$

where *HV, F, L*, and *c* are the Vickers hardness, indentation load, average diagonal length, and crack length, respectively. The elastic modulus (*E*) for enamel was obtained elsewhere.[12]

Standard descriptive statistics means and standard deviations were calculated for all parameters. The difference in the debonding strength and degree of crack alteration was compared statistically using a Kruskal-Wallis test. One-way analysis of variance (ANOVA) was used to determine the difference of healing rate of the microcracks and the apparent fracture toughness between groups. Any differences were further investigated using the *post-hoc* test. A statistically significant level was predetermined at 0.05 for all tests.

RESULTS

A comparison of the debonding strengths within groups of similar bracket type and between metal and ceramic bracket groups is presented in Table1. The median debonding strengths of metal and ceramic groups were 23.06 MPa and 37.37 MPa for the non-indented groups, and 20.30 MPa and 31.85 MPa for the indented groups, respectively. There was no statistically significant difference in the strength between non-indented and indented specimens within the similar bracket type. However, ceramic brackets had significantly higher debonding strength than metal brackets ($p < 0.001$).

Alteration of surface indented microcracks between metal and ceramic bracket groups is presented in Table 2. There was some degree of crack healing after removal of both metal and ceramic brackets, which are comparable to that for indentation on the surfaces without brackets. However, there were no statistically significant differences in the healing degree among the groups in both vertical (p=0.852) and horizontal (p=0.071) directions.

Table 3 summarizes ARI scores of the debonded interfaces of all specimens. There were 13 specimens (43.3%) of metal brackets that failed at the enamel-adhesive interface (score 5), and twelve samples (40%) left adhesive on enamel surface more than 10% but less than 90% (score 3). However, there was no adhesive remnant on the enamel surface of the ceramic bracket group (score 5). Additionally, four samples bonded with the ceramic brackets (13.3%) presented enamel chipping.

Table 1: Comparison of average debonding strength between groups after bracket debonding (μm).

Group	Median	Minimum	Maximum	Mean rank
1	23.06	11.73	25.05	19.13[a]
2	37.37	21.77	48.08	46.23[b]
3	20.30	13.32	26.60	14.13[a]
4	31.85	21.61	44.90	42.50[b]

Group 1:Bonding metal bracket on non-indented surface; Group 2: Bonding ceramic bracket on non-indented surface; Group 3: Bonding metal bracket on indented surface; Group 4: Bonding ceramic bracket on indented surface. Similar superscript letter on the column indicates no statistically significant difference.

Table 2: Comparison of average microcrack alteration both in the vertical and horizontal directions between groups after bracket debonding (μm).

Crack directions	Bracket types	Median	Minimum	Maximum	Mean rank
Vertical	Metal	-11.5	-23.6	3.6	21.4[a]
	Ceramic	-8.1	-19.9	5.1	23.8[a]
	No bracket	-9.0	-17.2	-4.7	23.7[a]
Horizontal	Metal	-7.9	-14.5	-2.3	26.9[a]
	Ceramic	-10.5	-16.3	2.9	16.7[a]
	No bracket	-8.4	-13.7	-4.2	25.4[a]

Similar superscript letter on the column indicates no statistically significant difference.

Table 3: Frequency distribution of the adhesive remnant index (ARI scores).

Bracket types	ARI scores					Total
	1	2	3	4	5	
Metal	1	0	12	4	13	30
Ceramic	0	0	0	0	30	30

Adhesive remnant index (ARI scores): 1 = all of the adhesive left on the enamel surface, 2 = more than 90% of the adhesive left on the enamel surface, 3 = more than 10% but less than 90% of the adhesive left on the enamel surface, 4 = less than 10% of adhesive left on the enamel surface, 5 = no adhesive left on the enamel surface.

Comparison of average microcrack healing rates among the groups after bracket debonding is presented in Table 4. No statistically significant difference was found among the groups (p = 0.792 for vertical and p = 0.215 for horizontal directions).

Table 5 exhibits apparent fracture toughness at the initial and the final measurement between groups. Percentage of apparent fracture toughness increased from the initial to the final measurement as follows: 15.17, 14.57, and 11.36 in metal, ceramic, and no bracket groups, respectively.

Table 4: Comparison of average microcrack healing rates between groups after bracket debonding (nm/s).

Bracket types	n	Direction of microcrack	
		Vertical	Horizontal
Metal	15	-0.10 ± 0.07	-0.08 ± 0.04
Ceramic	15	-0.10 ± 0.07	-0.11 ± 0.05
No bracket	15	-0.11 ± 0.04	-0.09 ± 0.03
p-value		0.792	0.215

Table 5: The average of apparent fracture toughness at the initial and final measurement (MPa.m$^{1/2}$).

Bracket types	n	$K_{c(app)}$		
		Initial $K_{c(app)}$	Final $K_{c(app)}$	% increase $K_{c(app)}$
Metal	15	0.87 ± 0.07	1.00 ± 0.11	15.17 %
Ceramic	15	0.85 ± 0.06	0.98 ± 0.09	14.57 %
No bracket	15	0.79 ± 0.07	0.88 ± 0.12	11.36 %

DISCUSSION

Since enamel cracks are difficult to detect clinically, control surface cracks were carried out before bracket attachment, to compare the effect of debonding shear stress on the cracks with both metal and ceramic brackets. However, there still were variations in the length and form of the control microcracks, i.e., crack branching, crack bridging or crack bifurcation in this study, even though the same loading protocol was used. This variation may be a consequence of the complex enamel prism orientations, as well as a range of mechanical behaviors that differ from the dentin-enamel junction to the enamel surface.[9,13]

Regarding shear debonding strength, there was no significant difference between the groups with the same bracket type, suggesting that the presence of surface microcracks on the enamel seems to not affect the bond strength between the bracket's base and the surface enamel. However, for ceramic brackets, the value was significantly higher than for metal brackets and is comparatively higher than the value range of previous studies (from 10.4 ± 4.1MPa to 21.67 ± 5.19 MPa[14-17]) and also the clinically recommended values to resist accidental bracket dislodgement (6 – 8 MPa[18]). The explanation for such high shear strength in this study may be the fact that flattened enamel may expose more enamel rods and thus, improve the bond quality.[19,20] Even though standardization of the surface curvature might not be of clinical relevance, such a procedure was considered necessary to generate controlled straight corner cracks and to reduce uncertainty in the surface topography during the microcrack length measurements.

Interestingly, enamel fracture was observed in 13.3 percent of debonded ceramic brackets (4 out of 30 samples). It is noteworthy that enamel chipping occurred in the samples with an extremely high debonding strength (more than 40 MPa), which exceeded the cohesive strength of enamel.[21] The high shear bond strength observed in this study may be due to the enamel surface preparation. Thus, this *in-vitro* study may represent an extreme situation of the debonding stress that might affect surrounding microcracks. This finding point out that polishing enamel before ceramic bracket installation, or repositioning, should be avoided, which is consistent with the relatively high incidence of enamel fractures that occurred after removing ceramic brackets, but none for metal brackets.[2-4] Such high shear strength of ceramic brackets could lead to enamel surface loss, especially in a tooth with some existing enamel subsurface microcracks, or one previously weakened due to a fatigue response from an extensive restoration, or a tooth with root canal treatment. It has been reported that specimens with a high shear debond strength, of over 30 MPa, are likely to have surface enamel damage.[4] Further research should focus on an optimal removing method for ceramic brackets that can reduce debonding force and protect the surface integrity of enamel.

The cracks partially repaired soon after the removal of the brackets (Fig 4). Interestingly, even with the highest debonding strength observed in the ceramic groups, the same healing rates of the corner cracks as those without brackets could still be found at the bracket's boundary. The stress seems to be limited only to the bonded interface. This finding is consistent with the enamel chipping located on the proximity of incisal or gingival borders of the brackets in the ceramic group (Fig 5), and it is also consistent with a report in which finite element analysis of shear stress distribution in the enamel-adhesive interface was used. The researchers reported a pattern that was quite heterogeneous, and the stress concentration was limited to the upper and lower margins of the brackets.[22]

After indentation with a Vickers microhardness tester on the enamel surface, the length of the diagonal microcracks reduced with time. It has been reported that indented microcracks repaired around 9% of their initial length in the first 24 hours and reached a plateau level (10 % of the initial length) in 48 hours.[9] The repair process may be the consequence of a viscoelastic recovery and extrinsic toughening mechanism of organic protein in enamel.[9] When indentation on the enamel surface and microcrack generated, the crack

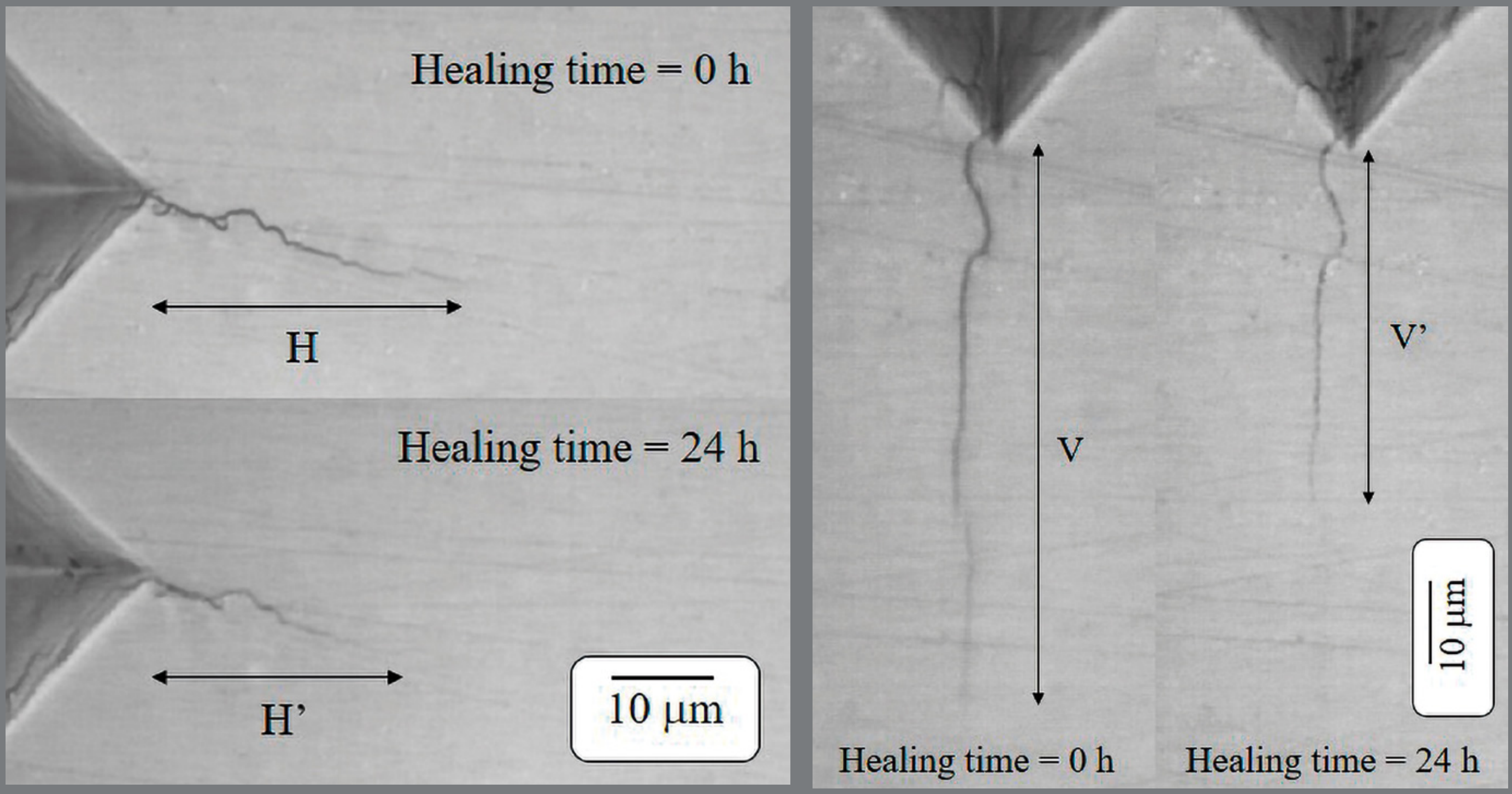

Figure 4: Illustrations of microcrack healing after debonding (H = horizontal crack length immediately after indentation, H' = horizontal crack length 24 hours after bonding, V = vertical crack length immediately after indentation, V' = vertical crack length 24 hours after bonding).

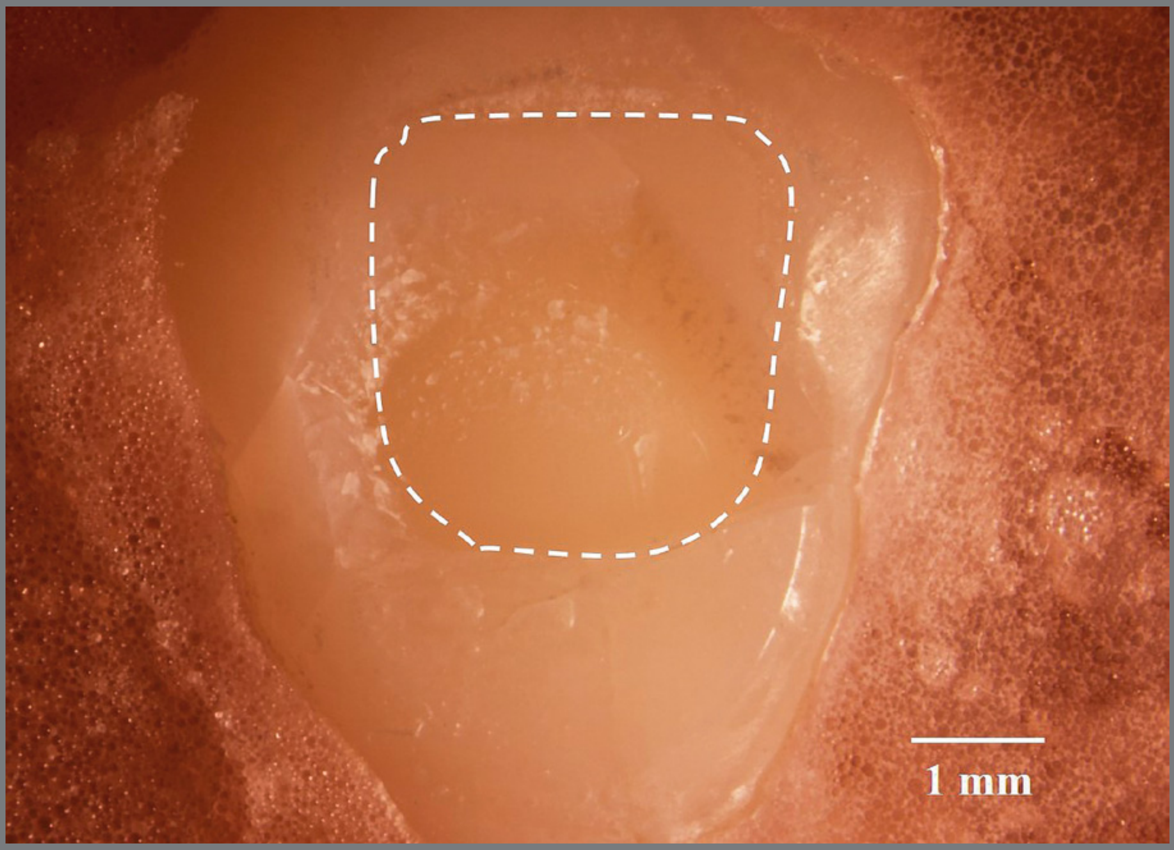

Figure 5: Illustration of enamel chipping after debonding a ceramic bracket (dotted line outlines the bracket bonded area).

does not penetrate the dentin but runs perpendicularly to the interface. The stress intensity initially increases with crack extension and the extrinsic toughening behavior from complex microstructure such as a range of enamel fracture toughness, crack bridging, and deflection act primarily behind the crack tip to reduce the crack-driving force.[23] Soon after the stress intensity reaching the plateaus, the removal of the load and repairing process began. Enamel also exhibits significant viscoelasticity that can dissipate energy during deformation and fracture. During the fracture propagation, the organic protein was in the stretched stage, and created closure stress. Moreover, the importance of enamel protein on both crack resistance and repair was established in a study which found that deproteinization of enamel reduced fracture toughness from 1.23 ± 0.20 MPa $m^{0.5}$ to 0.95 ± 0.20 MPa $m^{0.5}$ (a 25% reduction).[13]

Even though enamel microcracks healing is a normal process on a vital tooth preventing crack propagation to the dentin and dental pulp, this healing process can be found in extracted tooth. According to ISO/TS 11405:2015, the teeth that have been extracted for longer than six months may undergo degenerative changes in enamel and dentinal protein.[24] However, the teeth used in this study have been tested within a month after extraction. Therefore, the remaining organic protein in enamel still had an influence on crack closure stress, and healing process occurred.

Since in this study the corner cracks were remeasured at least 24 hours after indentation, the crack length was a resultant of crack healing combined with the stress at the bracket's boundary. The expected length was then calculated by using a healing degree of 9%, as suggested in the literature.[9] The original and expected 24-hour crack lengths, both in the vertical and the horizontal directions are presented in Figures 6 and 7, respectively. It was observed in this study that the cracks healed slightly more than expected in both directions. Even for the specimens with high debonding strength, such as those with enamel chipping, the stress on the surrounding area during removal of a bracket was minimal and did not extend the microcracks. Additionally, the healing degree in this study might have been more efficient because the outer enamel was polished, since the fracture toughness, as well as the organic content, was found to increase from the surface enamel to the dentin-enamel junction.[9,25]

Comparing the differences between the crack lengths alone might be insufficient to determine the effect of shearing stress on the surrounding microcrack behavior, because of the time lag between each measurement. The average time elapsed between the crack measurement resulting from indentation and the remeasurement after debonding was 26.19 ± 3.69 hours. Although ceramic brackets had higher

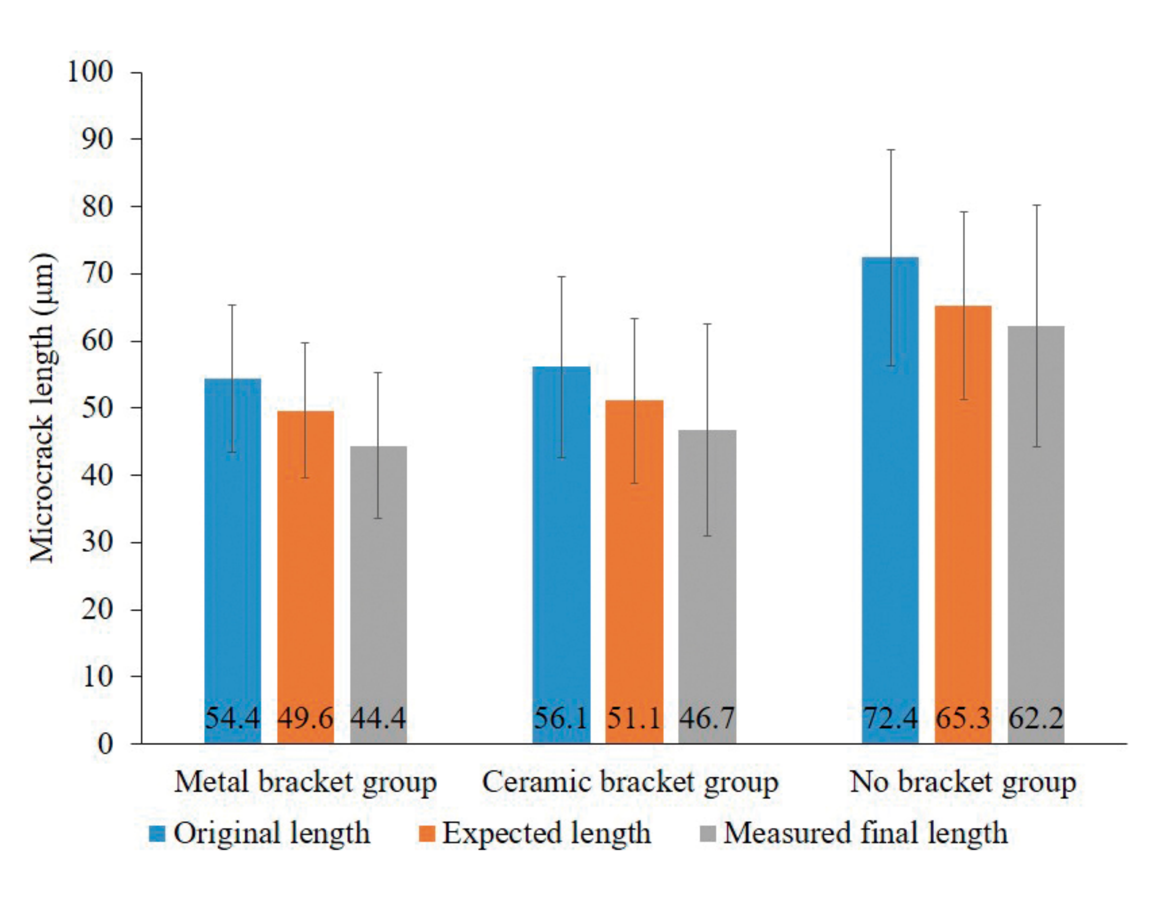

Figure 6: Comparison of 24-hour vertical crack lengths: original length (before bracket removal), final length (after bracket removal) and expected length calculated with original length subtracted from a reported degree of healing.

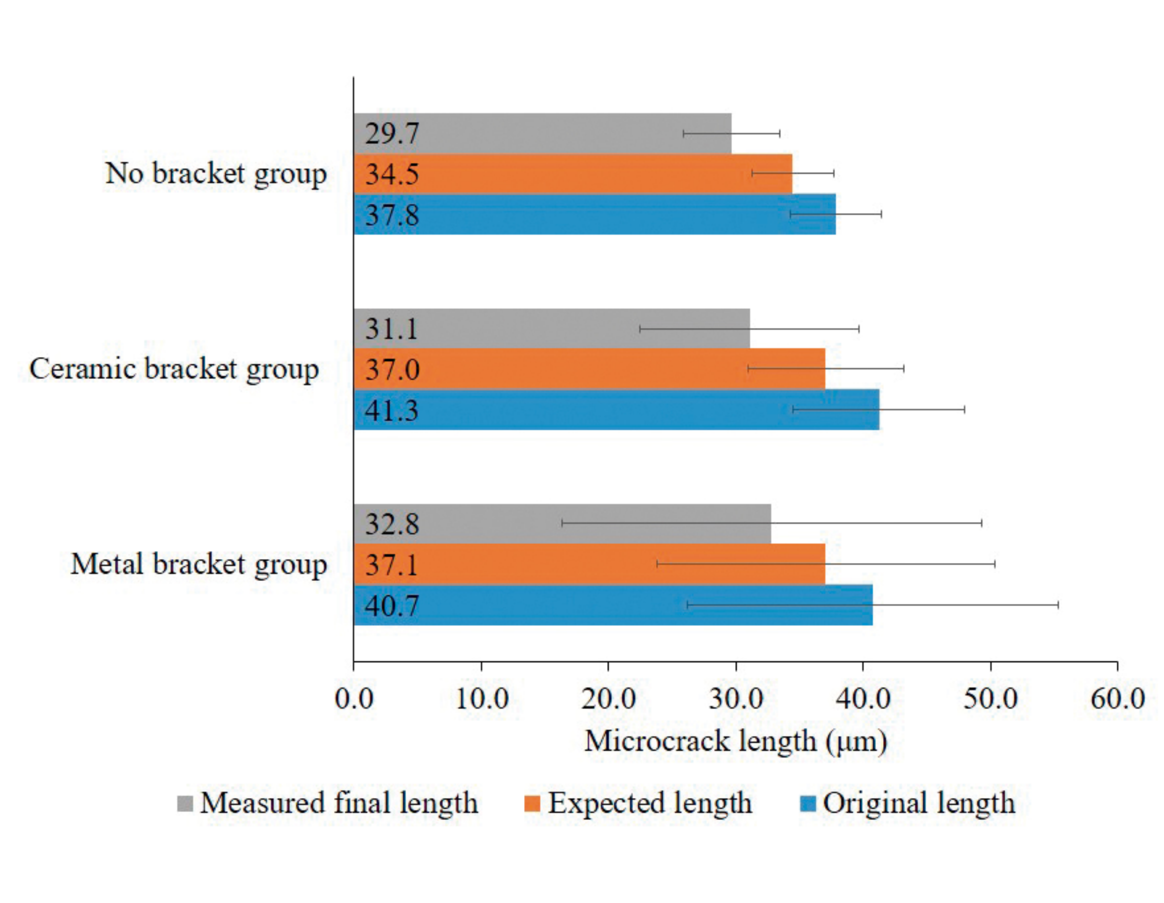

Figure 7: Comparison of 24-hour horizontal crack lengths: original length (before bracket removal), final length (after bracket removal) and expected length calculated with original length subtracted from a reported degree of healing.

debonding strengths compared to metal brackets, there was no significant difference in the degree of healing between the groups. These similar healing rates confirm that bracket removing stress did not affect the healing process of boundary enamel microcracks.

The stress intensity factor (*KI*) is another mechanical parameter used to describe resistance of any material to critical crack growth. The critical value of *KI* or fracture toughness (*Kc*) of enamel can be evaluated by an indentation approach.[25] It has been reported that 10% reduction of the apparent fracture toughness is associated with the degree of microcrack healing in the enamel surface. That reduction in $K_{c(app)}$ is consistent with bridging by the organic matrix in enamel that can be defined as follows:[9]

$$K_{b(protein)} = 2\sigma_b f_b \left(\frac{2l_b}{\pi}\right)^{1/2} \quad (4)$$

where σ_b is the nominal bridging stress on the protein matrix (assumed to be equivalent to the yield strength of protein, f_b is the area fraction of protein matrix bridging ligaments, and l_b is the bridging zone length. For this study, due to the crack reduction, there was an increase in $K_{c(app)}$ from the initial indentation to the final observation, of approximately 15% (Table 4). This higher reduction is probably due to the investigated area on the enamel surface, which was located in the inner part of the buccal enamel, where a greater content of organic matter exists. This layer of enamel may have higher organic bridging stress and bridging zone length, as expressed in equation 3. Consequently, the degree of crack healing in this study is larger than that found by Rivera et al.[9]

For the ARI scores, combination groups of the same bracket type (groups 1 and 3, as well as groups 2 and 4) were performed due to no statistically significant difference of debonding force between groups within similar bracket type. Bond failure for brackets was found to be more prevalent at the enamel-adhesive interface, especially in ceramic brackets (100%) (Table 1). The result might be due to a higher bond strength between the ceramic bracket bases and the adhesive. The predominant failure type of debonded ceramic brackets was found to be at the bracket-adhesive interface.[15,17] This kind of failure is beneficial to the enamel surface because it is left intact, although more time is required to remove the adhesive remnant.[26] On the contrary, there is a higher probability of enamel damage if the unit fails at the enamel-adhesive interface.[27]

All brackets used in this study were subjected to the shear strength test with a universal testing machine to deliver shear force. The unilateral axial load applied to the bonding surface by this testing machine creates pure shear stress, which might differ from removing pliers used clinically.[17] Consequently, the stress generated by a bracket removing plier is not directly comparable to the condition used in this study.[28] Debonding strength exerted by bracket removing plier has been reported to be 30% less than the shear strength delivered by the universal testing machine.[29]

There are some limitations to this study. Firstly, a standardized laboratory setup may be extrapolated to a complex clinical situation, e.g., changes in temperature, humidity, acidity, mechanical and masticatory stress on brackets. Besides, moisture control *in vitro* is superior to *in vivo*. Secondly, the delayed measurement of microcrack length after bracket debonding could not be a real-time crack analysis. Thirdly, the location of the crack tip was difficult to identify by using the microscope, which resulted in an approximate error of 30-70 μm. Lastly, the limited number of crack formations and observation of crack initiation was only located in the surrounding area, which might not represent all the stress conditions within the bonded interface. Finite element analysis, or a real-time crack propagation study, might be used to determine the stress concentration at the crack tip, as well as a microtomography study of the bonded interface immediately after bracket removal.

CONCLUSIONS

Within the limitations of this study, the conclusions are as follows:

Removal of ceramic brackets required a higher debonding strength and was more susceptible to enamel fracture than with metal brackets.

The surrounding cracks partially healed after bracket debonding.

The debonding stress from bracket removal was quite localized and did not affect the healing degree of surrounding microcracks.

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Data acquisition, analysis or interpretation:

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ORIGINAL ARTICLE

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3D technology to measure dental arches and create a template for lingual brackets technique

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ABSTRACT

Objective: This study aims at identifying anatomical dimensions of dental arches, based on landmarks currently used in the lingual orthodontic technique, and create an archwire form template to be used in orthodontic clinics.

Methods: Maxillary and mandibular dental casts of 140 Caucasian individuals with natural and normal occlusion were digitized (3D), and the images were analyzed with Delcam Power Shape™ 2010 software. The dental arch shapes and sizes were obtained from 14 landmarks selected on the lingual surface of the teeth. Points and segments defined by the software were used to create an archwire form template.

Results: Various dental arch patterns were found for both maxilla and mandible. The smallest sizes were found in females, and the largest were found in male subjects. Six categories were defined for each gender, three for the maxilla and three for the mandible (Small, Medium and Large). A template was created with eighteen anatomic lingual archwire designs, nine for the maxilla and nine for the mandible, for both genders.

Conclusions: Landmarks evaluated in this study showed dental arch differences between genders. This information enables making orthodontic lingual archwires that are more compatible with the anatomical forms and sizes of the maxilla and mandible. The findings also allowed the creation of a template for an anatomic lingual metallic archwire form to be used in the lingual technique.

Keywords: Dental arch. Anatomy. Orthodontics.

RESUMO

Objetivo: O presente estudo tem como objetivo encontrar as formas anatômicas e dimensões das arcadas dentárias com base em pontos de referência utilizados na técnica ortodôntica lingual, e criar um diagrama com um maior número de arcos metálicos para serem utilizados na clínica ortodôntica.

Métodos: 140 modelos de indivíduos caucasianos com oclusão normal e natural foram digitalizados (3D) e as imagens, analisadas com o *software* Delcam Power Shape™ 2010. A determinação das formas e tamanhos das arcadas dentárias foi obtida a partir de 14 pontos selecionados na superfície lingual dos dentes. Outros pontos e segmentos foram utilizados, com o auxílio do *software*, para definir um diagrama.

Resultados: Foram encontrados diferentes tamanhos de arcadas dentárias linguais, tanto para a maxila quanto para a mandíbula. Os menores tamanhos foram os femininos, e os maiores, os masculinos. Definiram-se seis tamanhos para cada sexo, sendo três para a maxila e três para a mandíbula, nomeados como P, M e G. Foi criado um diagrama com dezoito desenhos de arcos linguais anatômicos, nove para a maxila e nove para a mandíbula, para ambos os sexos.

Conclusões: A posição dos pontos de referência nesse estudo evidenciou diferenças entre os sexos, o que permitiu a criação de arcos mais compatíveis com as formas e dimensões anatômicas da maxila e mandíbula. A diferença entre os tamanhos das arcadas dentárias linguais possibilitou a criação de um diagrama com formas de arcos metálicos linguais anatômicos para serem utilizados na técnica lingual, para auxiliar o profissional a criar os seus próprios arcos.

Palavras-chave: Arcada dentária. Anatomia. Ortodontia.

INTRODUCTION

In the late 1970s, lingual orthodontics was introduced as a result of conventional appliances bonding to the lingual surfaces of the teeth.[1,2] The first scientific work describing brackets and the mushroom-shape of the lingual archwire was published in 1979.[3]

Striking differences between the lingual and buccal techniques are observed,[4] such as the archwire form used.[5] However, few studies[6-9] have been published attempting to determine the dental arch form in the lingual technique.

Many authors have used cusp tips to outline the archwire forms,[10,11,12] while others used the medial landmarks of the crowns from a buccal perspective on the anterior and posterior teeth as references,[13] as well as lingual and occlusal landmarks, or in the long axial axis of the teeth.[7] Moreover, others researchers[14,15] used landmarks on the lingual surfaces closer to the gingival third because this site showed the smallest difference between the lingual surfaces of canines and premolars.[16]

Despite the fact that there are several ways to define dental arch forms, in the lingual technique, the inter-canine distances vary substantially,[16] making it difficult to determine how many sizes of mushroom-shaped lingual archwires might exist.[3] Therefore, some authors developed the straight-wire concept in lingual orthodontics, seeking to streamline the work of the professional.[16,17]

They also proposed[18] that brackets should be bonded with auxiliary blades in order to enable the use of archwires without curvatures, whereas other authors[14,15] devised a more square-shaped archwire, allowing use of a lingual straight archwire.

A previous study analyzing the shapes and dimensions of dental arches in digital 3D models for the use in lingual straight-wire technique showed that more cervical archwire setting promotes smaller inter-bracket distance.[15]

Although this strategy allowed reduction of the typical insets and offsets of the dental arch lingual surfaces, it hampers orthodontic mechanics in certain movements[19,20] and may cause gingival inflammation.[21] Furthermore, a specific assembly with resin pads is required to compensate the distance between the lingual surface and the base of the bracket.[4,5] In areas where compensations are made, the brackets advance more into the space occupied by the tongue, resulting in patient discomfort.[21] Furthermore, low bracket profile enables less invasion to the lingual space, therefore providing better adaptation for the patient in terms of speech and comfort.[22]

In this context, the present study evaluated the dental arch shapes and sizes that are formed when the brackets are placed farther from the cervical margin of the teeth,[15] in region that keep the concave and convex form in the lingual surface, but more distant from the cervical area, to avoid gingival inflammation.

The forms and sizes of archwires for the lingual technique were also defined, and a template was created. It is believed that there is a difference in dental arch forms between genders. Orthodontists should benefit from different sizes and shapes of archwires to perform treatments, and not be limited to a number of prefabricated archwires that are usually dictated by wire and bracket manufacturers. Using the template, the professional may choose the appropriate archwire form.

MATERIAL AND METHODS

This study is an analytical observational research of patient records from Faculty of Health, UMESP, São Bernardo do Campo, SP, Brazil. The protocol of this study was approved by the Ethics Committee from, Federal University of São Paulo – UNIFESP, number 0388/2016.

The sample included maxillary and mandibular dental casts of 70 Caucasian Brazilian individuals (28 men and 42 women), minimum 15.0 years old and maximum of 21.3 years old (average 16.4 ±1.3 years old).

Sample inclusion criteria were defined as follows: cast models from individuals with normal occlusion and no odontogenic abnormalities; complete full dentition, except for third molars; and all permanent teeth in occlusion according to the following keys for occlusion of Andrews :[23] Angle Class I molar relationship, angulation and inclination of the crowns (considering the long axis of the teeth) and the flat curve of spee.[23] Rotations of up to 3 degrees and diastema up to 0.5 mm were accepted.

Sample exclusion criteria were: odontogenic abnormalities, incomplete dental eruption, and presence of erupted third molars.

Seventy pairs of cast models were digitized with a 3D Dental Wings™ scanner (model DW5-140, Montreal, Quebec, Canada). Images were analyzed by Delcam Power SHAPE™ software (2010, Birmingham, UK).

To standardize the position of the models and to avoid measurement distortions, landmarks were set on the canine's incisal and on the first molar's mesiobuccal cusp,[10] creating a trapezoid form and a grid of coordinates in the X, Y, and Z axes, allowing the rotation of the models in several positions, without changing the proportion of the measures executed during the study.[15]

DETERMINING THE LANDMARKS AND DEFINING THE SHAPE AND SIZE OF THE ARCH

Lingual surface landmarks were determined with the Delcam Power SHAPE™ 2010 software program. The landmarks chosen represented the location where the brackets would be placed on the lingual surface of each tooth, and where the archwires would pass inside the bracket slot.

The location of the points was defined as follows: In the maxillary and mandibular anterior teeth, the reference point was located at the intersection of the line passing through the long axis of the tooth in the vertical plane and the line passing through the center of the clinical crown of the horizontal axis (the deepest point of the concavity of palatal surface). In the maxillary and mandibular premolars, the reference point was also located at the intersection of the line passing through the long axis of the tooth in the vertical plane and the line passing through the middle third of the lingual surface (the most prominent convex point of the lingual surface). In the first and second upper and lower molars, the reference point was located in the intersection of the line that passes the long axis of the mesio-lingual cusp in the vertical plane and the line passing through the middle third of the lingual surface (most prominent point of the lingual surface of these teeth).

The model was rotated on the computer screen in a way that the lingual surfaces could be seen with a frontal view and the operator could define and locate where the marked landmarks should be placed.

By means of the X, Y, and Z coordinates, two planes were established. The X and Y axes established the horizontal plane, whereas the Y and Z axes established the vertical plane, corresponding to the median sagittal plane that passes between the central incisors and divides the model into two halves, left and right (Fig 1).

The fourteen united landmarks defined the curvature and shape of the dental lingual archwire[11] using Delcam Power SHAPE™ 2010 tools (Fig 2).

The previously chosen points were plotted in the XY plane, such that the Z axis was reset, and it was possible to obtain the XY coordinates of each landmark (Fig 2).

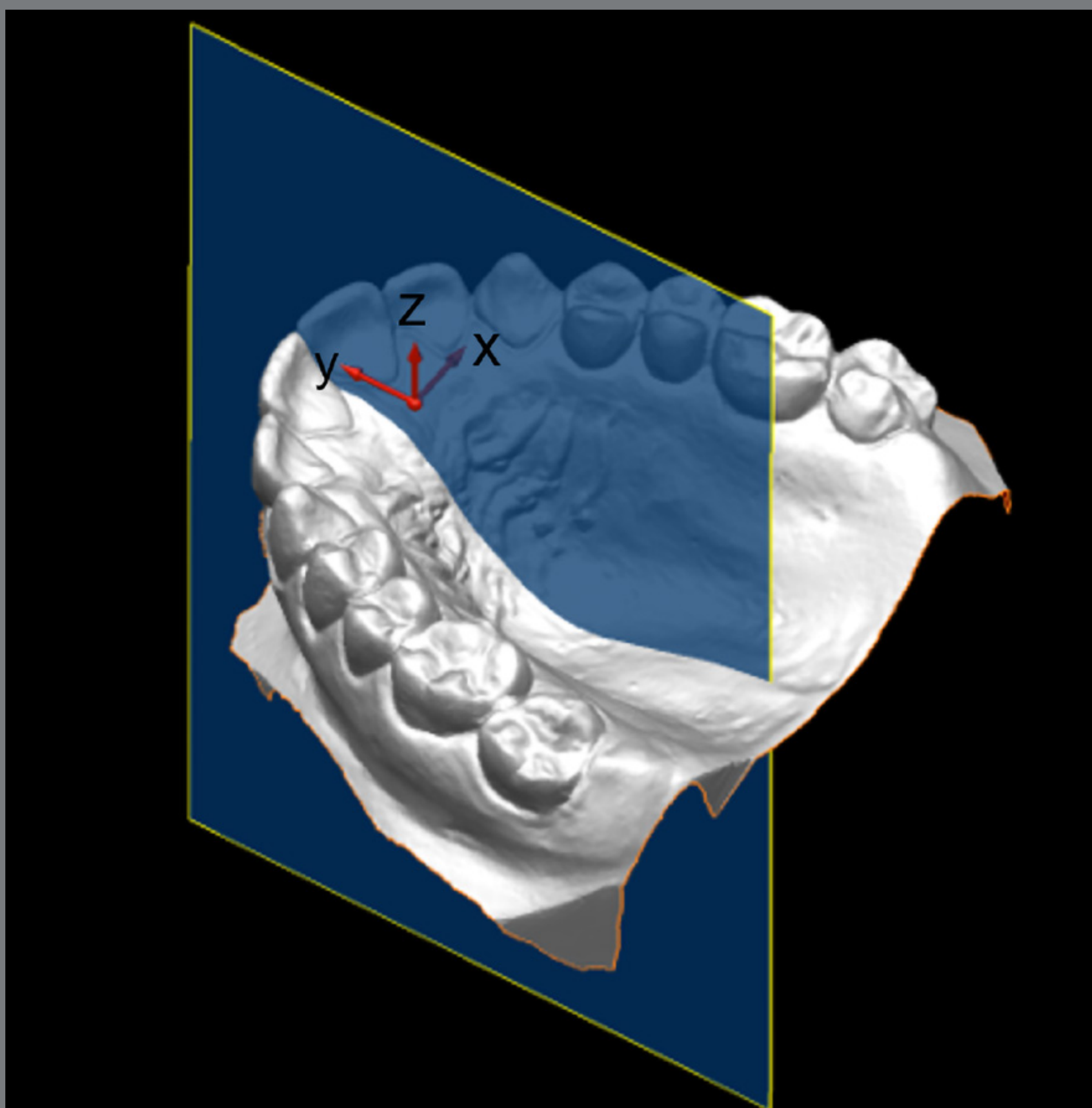

Figure 1: Digitalized model, with the X, Y, and Z coordinates.

For determining fourteen measurements (ten horizontal and four vertical),[10,15] Delcam Power SHAPE™ 2010 program was used as well.

The horizontal measurements corresponded to the distances between the landmarks chosen in the molars, premolars and canines in relation to the Y axis; and the vertical measurements, to the central and lateral incisors in relation to the X axis (Fig 2).

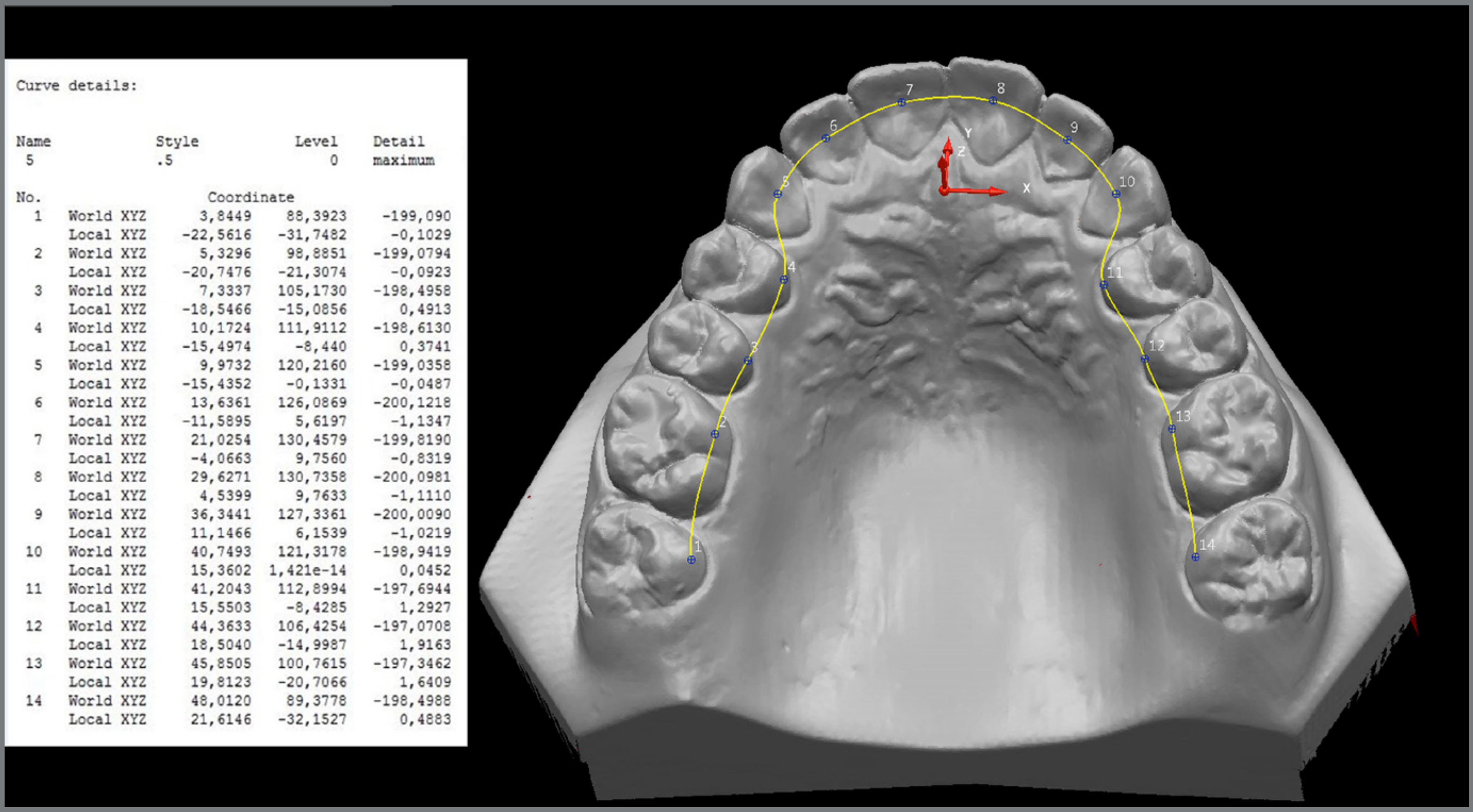

Figure 2: Image obtained from Delcam Power SHAPE™ 2010 software model, with points determined on the lingual surface and arch shape formed with measurements obtained from each key-point related to the coordinates (X, Y, and Z).

The program provided linear measurements, in millimeters, of the coordinates of the points in relation to the work plane, indicating a satisfactory degree of accuracy (Fig 2).

DETERMINING ARCHWIRE TEMPLATE

For the construction of the archwire template, the Delcam Power SHAPE™ 2010 program was used in the previously digitized models. Points were created on the cusp tips of the canines and first left and right premolars, and then points on the cusp tips of the second premolars and left and right first molars, and these points were united two-by-two, forming small straight line segments. Previously defined points were also used on the lingual surface of the 3D model of the first and second left and right molars, and the first and second left and right premolars, which were joined two-by-two, respectively, forming small straight line segments (Fig 3).

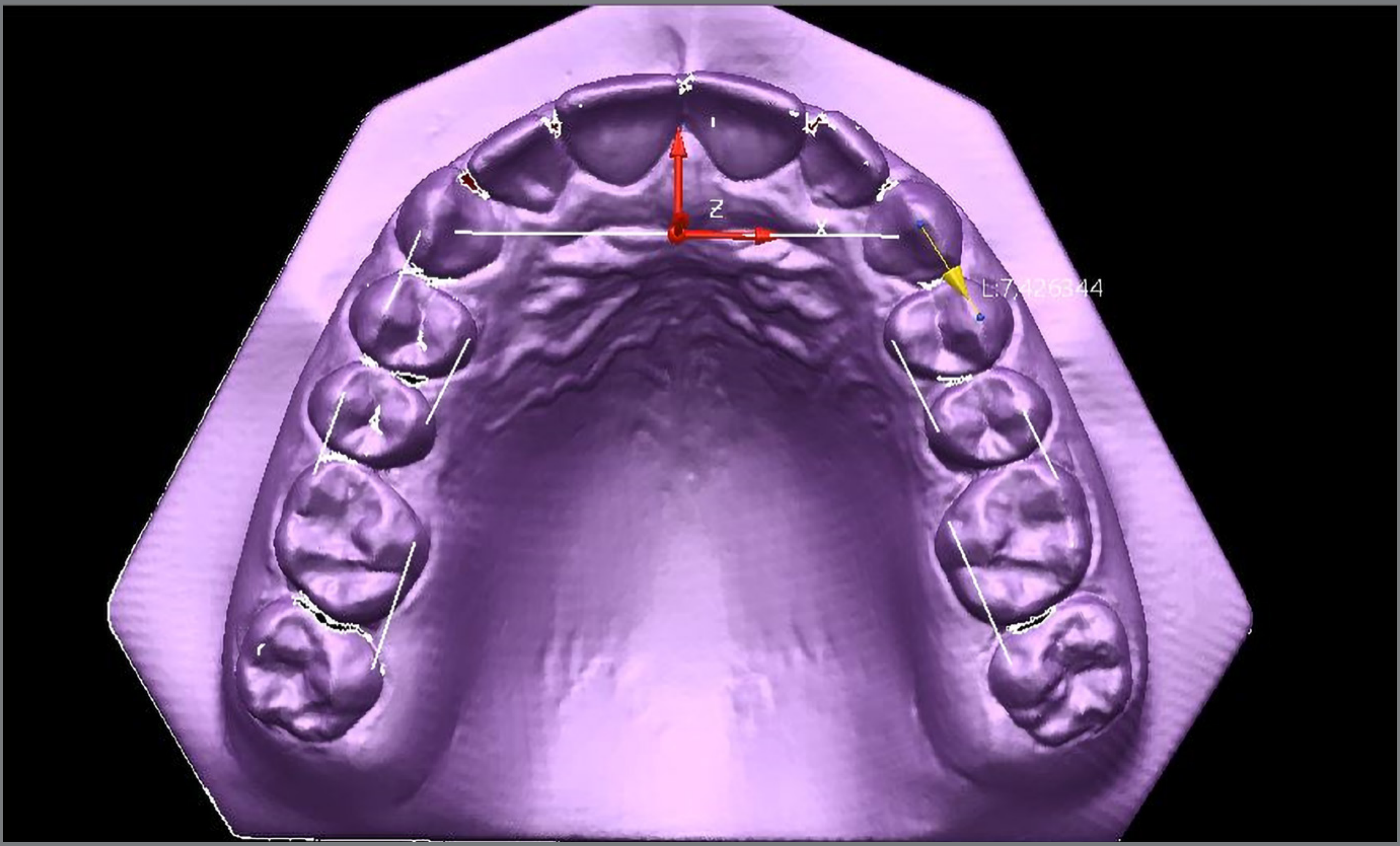

Figure 3: Eight straight wire segments defined by the landmarks and cuspid tips.

Perpendicular segments were drawn to the straight line segments previously created, and then the model was removed from the computer screen. An extension of all the lines was made until they crossed each other. The initial 3D model was reinserted, and perpendicular line extensions were found to pass through the interdental embrasure ridge of the respective teeth in question. That was also done in the mandibular model, and the measurements obtained were all flattened in the Z axis, so that a flat archwire could be constructed, because the models were in a three-dimensional space. At this stage, a curve (red line in Fig 4) was created from the point of the left canine to the point of the right canine, passing through a point between the central incisors, as the anterior limit of the curvature.

The program has a tool in the form of scissors that allowed for all the extensions to be cut, thereby obtaining the final designs of the maxillary and mandibular archwires of each of the models (Fig 5). The templates with eighteen archwires, nine maxillary and nine mandibular, were built from the coordinates (X and Y) of the eleven points, which defined the design of the metallic archwires mentioned in Figure 5.

Percentiles 5, 15, 25, 40, 50 (medium), 60, 75, 85 and 95 were taken from the coordinates (X and Y) measurements of each point, and then the mean between both sides was symmetrical.

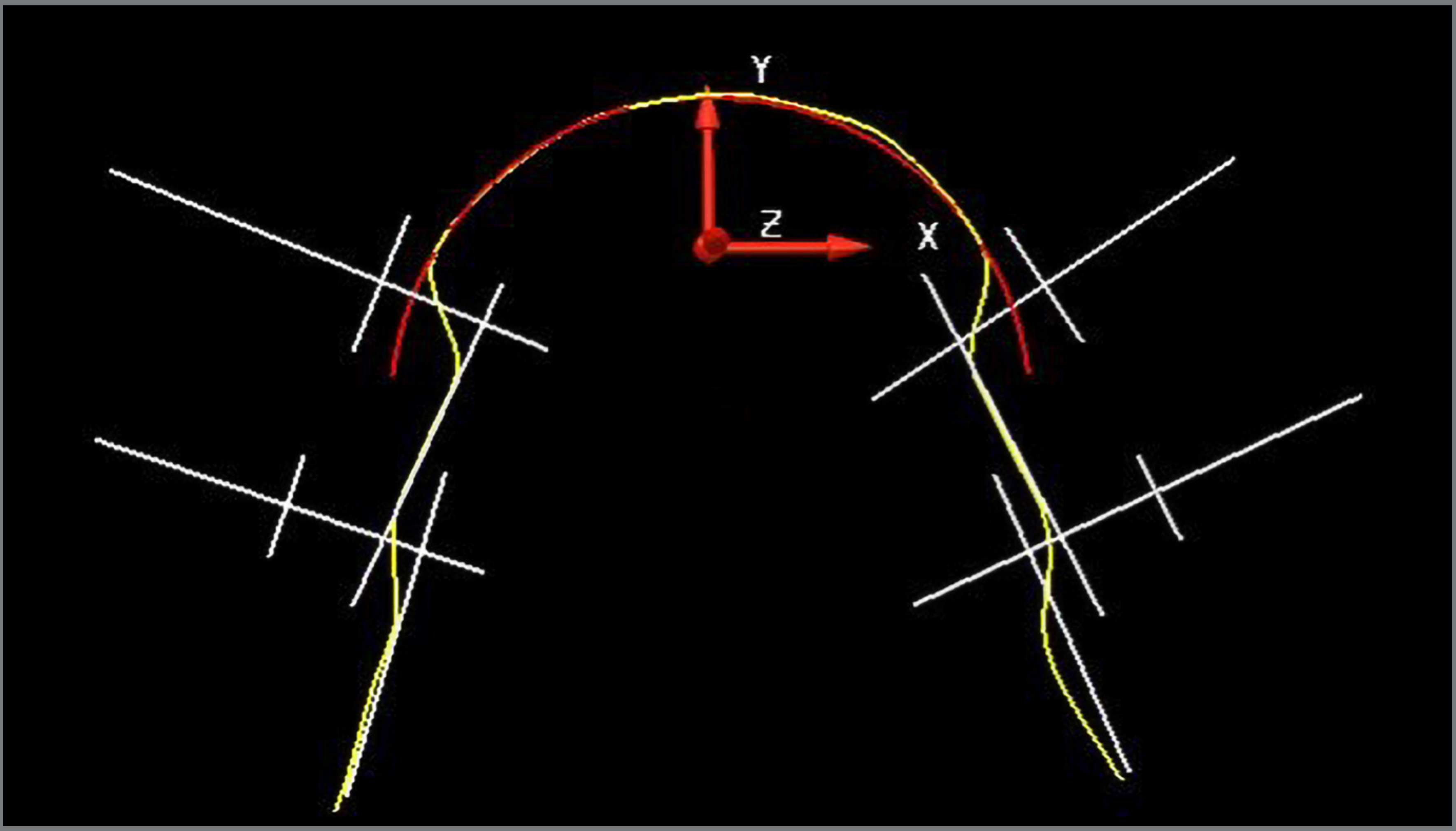

Figure 4: Lines and curves to define the archwire shapes for the template.

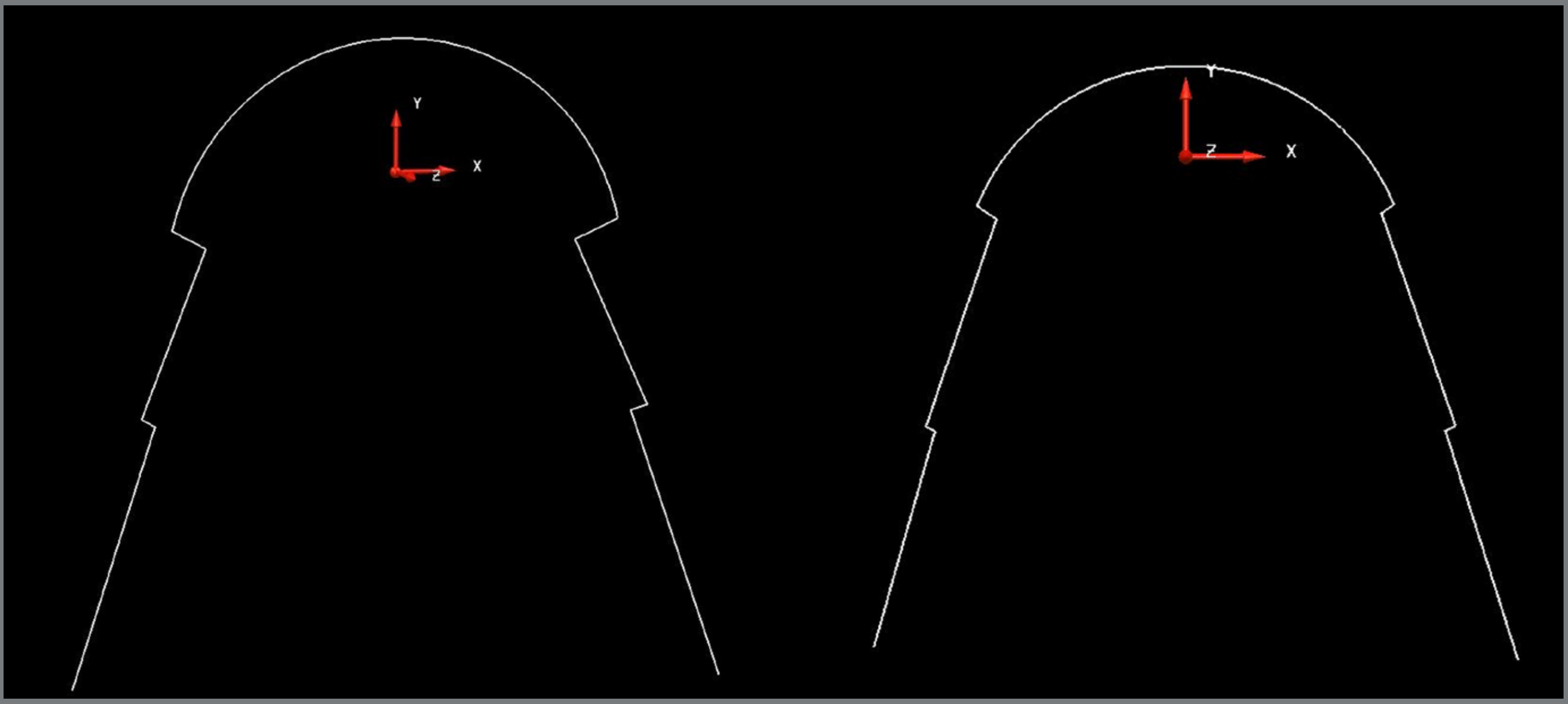

Figure 5: Maxillary and mandibular dental arches obtained by the Delcam Power SHAPE™ 2010 software.

These data can be observed in Tables 1 and 2, and the illustration is represented by Figures 6 and 7.

After completing all these steps, 0.5 mm was deducted to compensate for the base of the lingual bracket, and the final result with the template of anatomical lingual archwires can be seen in Figure 8.

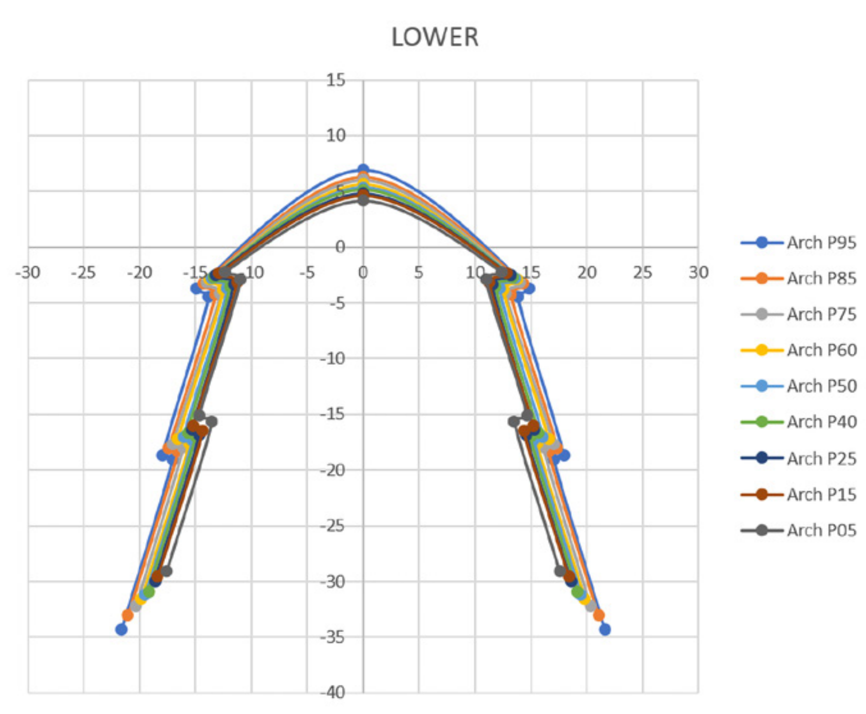

Figure 6: Illustration of the archwires' points and the percentiles of the mandible.

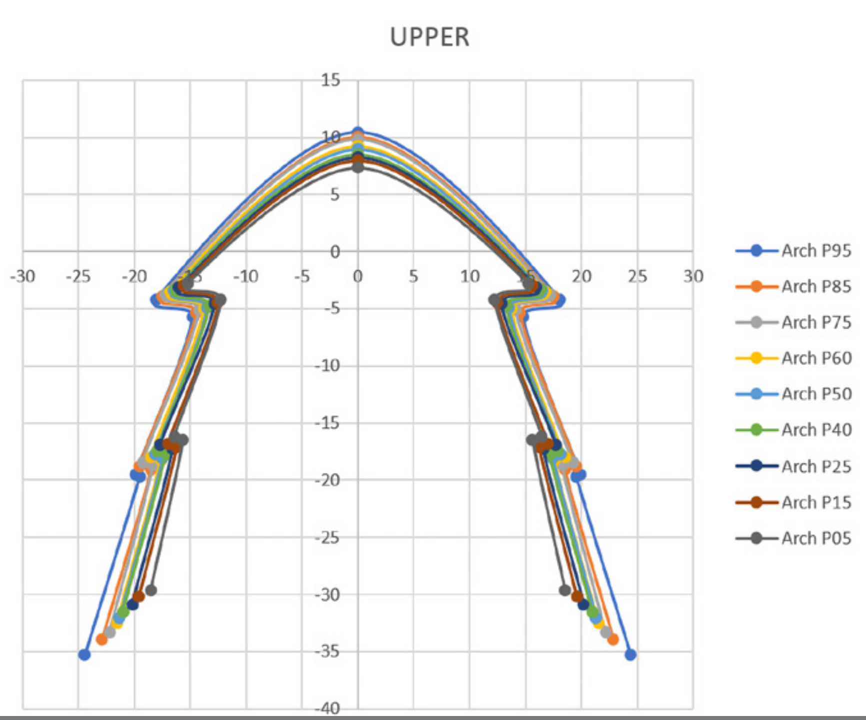

Figure 7: Illustration of the archwires' points and the percentiles of the maxilla.

Table 1: Coordinates measurements of each point, to set up the template of the mandibular metallic archwire.

Arch		Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10	Pt 11
P95	x	-21.6	-17.1	-18.0	-13.8	-14.9	0.0	14.9	13.8	18.0	17.1	21.6
	y	-34.3	-19.0	-18.7	-4.4	-3.7	6.9	-3.7	-4.4	-18.7	-19.0	-34.3
P85	x	-21.0	-16.6	-17.4	-13.2	-14.3	0.0	14.3	13.2	17.4	16.6	21.0
	y	-33.1	-18.4	-18.1	-4.3	-3.2	6.3	-3.2	-4.3	-18.1	-18.4	-33.1
P75	x	-20.3	-16.1	-17.0	-12.8	-14.0	0.0	14.0	12.8	17.0	16.1	20.3
	y	-32.2	-17.9	-17.7	-4.1	-3.1	6.0	-3.1	-4.1	-17.7	-17.9	-32.2
P60	x	-19.8	-15.6	-16.6	-12.5	-13.7	0.0	13.7	12.5	16.6	15.6	19.8
	y	-31.6	-17.6	-17.2	-3.8	-2.9	5.7	-2.9	-3.8	-17.2	-17.6	-31.6
P50	x	-19.5	-15.3	-16.1	-12.2	-13.6	0.0	13.6	12.2	16.1	15.3	19.5
	y	-31.2	-17.3	-17.0	-3.7	-2.8	5.3	-2.8	-3.7	-17.0	-17.3	-31.2
P40	x	-19.2	-15.0	-15.7	-11.9	-13.4	0.0	13.4	11.9	15.7	15.0	19.2
	y	-30.9	-17.1	-16.7	-3.6	-2.7	5.1	-2.7	-3.6	-16.7	-17.1	-30.9
P25	x	-18.6	-14.6	-15.3	-11.6	-13.2	0.0	13.2	11.6	15.3	14.6	18.6
	y	-30.0	-16.8	-16.4	-3.3	-2.5	4.8	-2.5	-3.3	-16.4	-16.8	-30.0
P15	x	-18.4	-14.4	-15.2	-11.3	-12.9	0.0	12.9	11.3	15.2	14.4	18.4
	y	-29.6	-16.5	-16.0	-3.2	-2.3	4.6	-2.3	-3.2	-16.0	-16.5	-29.6
P05	x	-17.6	-13.5	-14.7	-11.0	-12.4	0.0	12.4	11.0	14.7	13.5	17.6
	y	-29.1	-15.7	-15.1	-2.9	-2.2	4.2	-2.2	-2.9	-15.1	-15.7	-29.1

Table 2: Coordinates measurements of each point, to set up the template of the maxillary metallic archwire.

Arch		Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10	Pt 11
P95	x	-24.4	-19.5	-19.9	-14.8	-18.1	0.0	18.1	14.8	19.9	19.5	24.4
	y	-35.3	-19.7	-19.5	-5.7	-4.2	10.5	-4.2	-5.7	-19.5	-19.7	-35.3
P85	x	-22.9	-18.5	-19.5	-14.5	-17.5	0.0	17.5	14.5	19.5	18.5	22.9
	y	-33.9	-19.1	-18.8	-5.4	-3.9	10.0	-3.9	-5.4	-18.8	-19.1	-33.9
P75	x	-22.2	-18.3	-19.2	-14.2	-17.3	0.0	17.3	14.2	19.2	18.3	22.2
	y	-33.3	-18.7	-18.5	-5.1	-3.7	9.8	-3.7	-5.1	-18.5	-18.7	-33.3
P60	x	-21.5	-17.6	-18.5	-13.8	-16.8	0.0	16.8	13.8	18.5	17.6	21.5
	y	-32.5	-18.3	-18.0	-5.0	-3.5	9.2	-3.5	-5.0	-18.0	-18.3	-32.5
P50	x	-21.3	-17.5	-18.1	-13.5	-16.5	0.0	16.5	13.5	18.1	17.5	21.3
	y	-32.0	-18.1	-17.7	-4.9	-3.4	9.0	-3.4	-4.9	-17.7	-18.1	-32.0
P40	x	-21.0	-17.2	-17.9	-13.3	-16.3	0.0	16.3	13.3	17.9	17.2	21.0
	y	-31.5	-17.7	-17.4	-4.8	-3.3	8.5	-3.3	-4.8	-17.4	-17.7	-31.5
P25	x	-20.2	-16.6	-17.7	-12.8	-16.0	0.0	16.0	12.8	17.7	16.6	20.2
	y	-30.9	-17.3	-16.9	-4.6	-3.1	8.2	-3.1	-4.6	-16.9	-17.3	-30.9
P15	x	-19.6	-16.2	-17.0	-12.5	-15.6	0.0	15.6	12.5	17.0	16.2	19.6
	y	-30.2	-17.1	-16.8	-4.4	-2.9	8.0	-2.9	-4.4	-16.8	-17.1	-30.2
P05	x	-18.5	-15.6	-16.4	-12.2	-15.2	0.0	15.2	12.2	16.4	15.6	18.5
	y	-29.7	-16.5	-16.2	-4.2	-2.8	7.3	-2.8	-4.2	-16.2	-16.5	-29.7

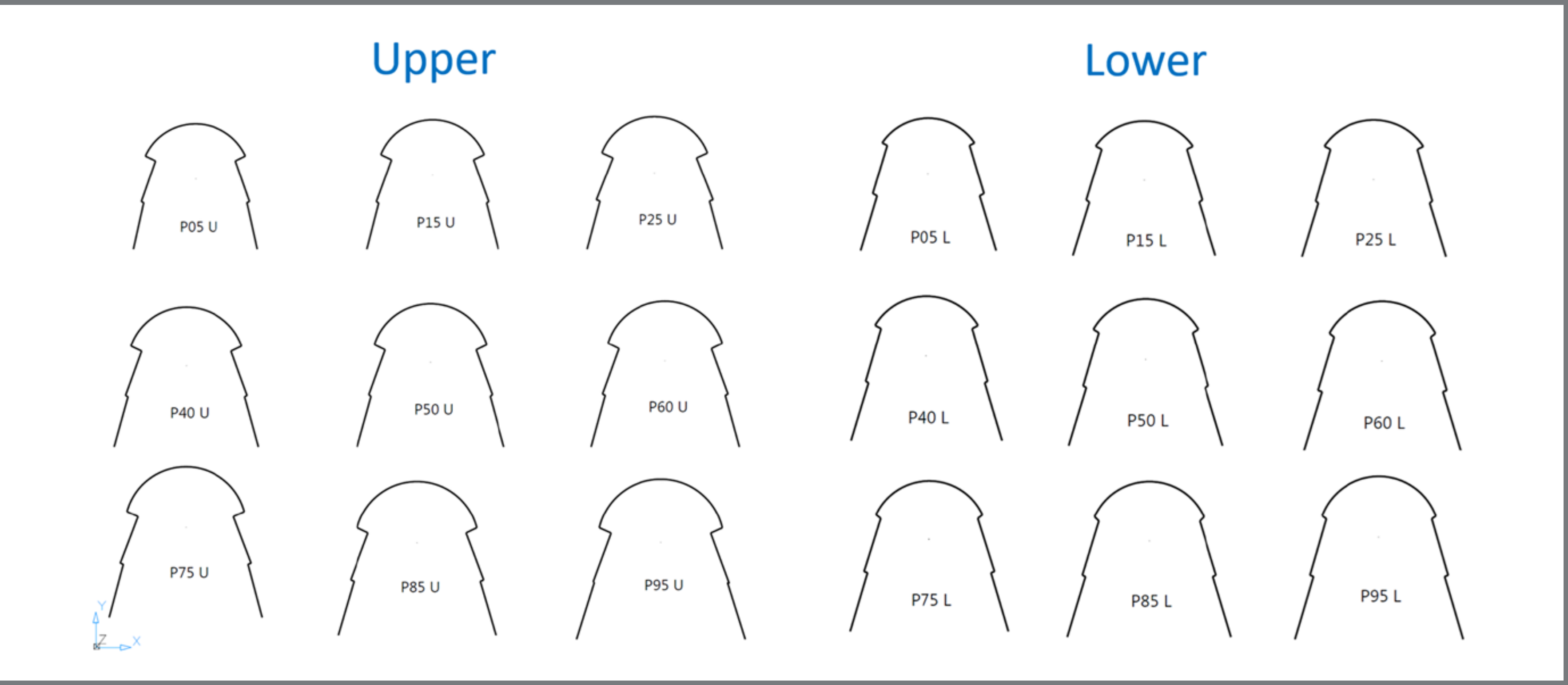

Figure 8: Template with eighteen anatomic lingual archwires.

DATA ANALYSIS AND RESULTS

In the distribution of the models analyzed in the sample, 40% were from male and 60%, from female patients. The Shapiro-Wilk test showed that the data had a normal distribution and that all measurements passed the criterion of normality. Student's *t*-test was used to compare differences between the genders and to define the measurements. As seven measurements were made in each arch, to maintain the global significance level at 0.05, Bonferroni correction (0.05/7) was used, so the difference was considered statistically significant when $p < 0.007$.

Method error was performed after 30 days, and we repeated setting the landmarks in 30% of the sample. The Intraclass Coefficient Correlation (ICC) showed that the measurements varied from 0.98 to 1.00, and the Bland-Altman plot showed that the largest mean variation was 0.08 mm (-0.06 to 0.23), which occurred in the measurement of the second left molars.

Table 3: Comparison between the male and female genders (mm)

Measurement		Female		Male		diff.	p
		mean	SD	mean	SD		
Mandible	CI	5.05	0.85	5.29	0.78	0.24	0.241
	LI	3.56	0.62	3.73	0.56	0.17	0.248
	C	23.20	1.17	23.71	1.28	0.51	0.090
	PM1	26.44	1.61	27.27	1.66	0.83	0.041*
	PM2	29.96	1.93	30.88	1.70	0.91	0.046*
	M1	32.27	2.18	33.60	1.81	1.33	0.010*
	M2	38.42	2.45	39.89	2.07	1.47	0.011*
Maxilla	CI	8.38	1.00	8.53	0.97	0.15	0.531
	LI	5.39	0.58	5.52	0.71	0.12	0.436
	C	29.90	1.43	31.28	1.49	1.38	<0.001*
	PM1	28.74	1.69	29.95	1.64	1.21	0.004*
	PM2	33.77	2.10	35.23	1.91	1.45	0.004*
	M1	36.37	2.38	38.35	1.96	1.98	0.001*
	M2	41.67	2.84	43.70	2.57	2.02	0.003*

* Statistically significant difference $p<0.007$. CI = central incisor, LI = lateral incisor, C = canine, PM1 = first premolar, PM2 = second premolar, M1 = first molar, M2 = second molar.

Table 3 shows the comparison between the means of vertical and horizontal linear measurements between the genders. In the maxilla, we observed differences between the genders in molars, premolars and canines, whereas in the mandible, differences were observed only in the measurements of the molars and premolars.

To define the measures of the average arch, the mean was used: the 25th percentile (P25%) was used for the small arch and the 75th percentile (P75%) was used for the large arch for both males (Table 4) and females (Table 5).

Table 4: Measurements for the male gender (mm).

Measurement		Mean	SD	median	minimum	maximum	P25%	P75%
Mandible	CI	5.3	0.8	5.4	3.3	6.8	4.7	5.9
	LI	3.7	0.6	3.8	2.0	4.6	3.3	4.2
	C	23.7	1.3	23.8	21.1	25.7	22.7	24.6
	PM1	27.3	1.7	27.2	24.0	30.2	26.4	28.3
	PM2	30.9	1.7	31.1	27.5	34.2	29.5	31.9
	M1	33.6	1.8	33.6	30.3	37.4	31.9	34.9
	M2	39.9	2.1	40.0	35.4	42.8	38.1	42.1
Maxilla	CI	8.5	1.0	8.5	6.2	10.6	8.1	9.2
	LI	5.5	0.7	5.5	4.3	7.0	4.8	6.1
	C	31.3	1.5	31.5	28.9	35.3	30.1	31.9
	PM1	30.0	1.6	30.0	27.1	33.7	28.7	31.2
	PM2	35.2	1.9	35.2	32.0	39.6	33.6	36.5
	M1	38.4	2.0	38.2	34.1	41.8	37.0	40.0
	M2	43.7	2.6	43.4	36.6	48.7	42.4	45.7

SD= standard deviation. CI = central incisor, LI = lateral incisor, C = canine, PM1 = first premolar, PM2 = second premolar, M1 = first molar, M2 = second molar.

Table 5: Measurements for the female gender (mm).

Measurement		Mean	SD	median	minimum	maximum	P25%	P75%
Mandible	CI	5.1	0.9	4.9	3.7	7.3	4.5	5.5
	LI	3.6	0.6	3.6	2.5	5.1	3.1	4.0
	C	23.2	1.2	23.1	21.2	25.9	22.6	23.7
	PM1	26.4	1.6	26.2	22.8	29.9	25.2	27.2
	PM2	30.0	1.9	29.5	25.5	34.5	28.8	31.7
	M1	32.3	2.2	32.2	28.1	36.3	31.1	33.6
	M2	38.4	2.4	38.4	33.6	43.9	36.8	39.9
Maxilla	CI	8.4	1.0	8.2	6.8	10.4	7.5	9.2
	LI	5.4	0.6	5.3	3.6	6.4	5.1	5.6
	C	29.9	1.4	29.7	27.4	33.1	28.9	30.8
	PM1	28.7	1.7	28.5	25.6	32.2	27.4	30.3
	PM2	33.8	2.1	33.5	29.5	38.2	32.2	35.7
	M1	36.4	2.4	36.3	32.0	42.2	34.9	37.4
	M2	41.7	2.8	42.5	35.5	49.0	39.2	43.7

SD= standard deviation. CI = central incisor, LI = lateral incisor, C = canine, PM1 = first premolar, PM2 = second premolar, M1 = first molar, M2 = second molar.

Figures 9 and 10 illustrate the shapes and sizes of the arches of the two genders, for the mandible and maxilla, respectively, from the values of Tables 4 and 5. P25% values were considered small size (S), P75% values were considered large size (L), and means were used to define medium size (M). The determination of S, M and L was done separately for each gender, with pink representing the female gender and blue representing the male gender, showing twelve sizes of dental arches, six for the maxilla and six for the mandible.

Figure 8 illustrates the template with the design of eighteen archwires, with nine maxillary and nine mandibular lingual archwires.

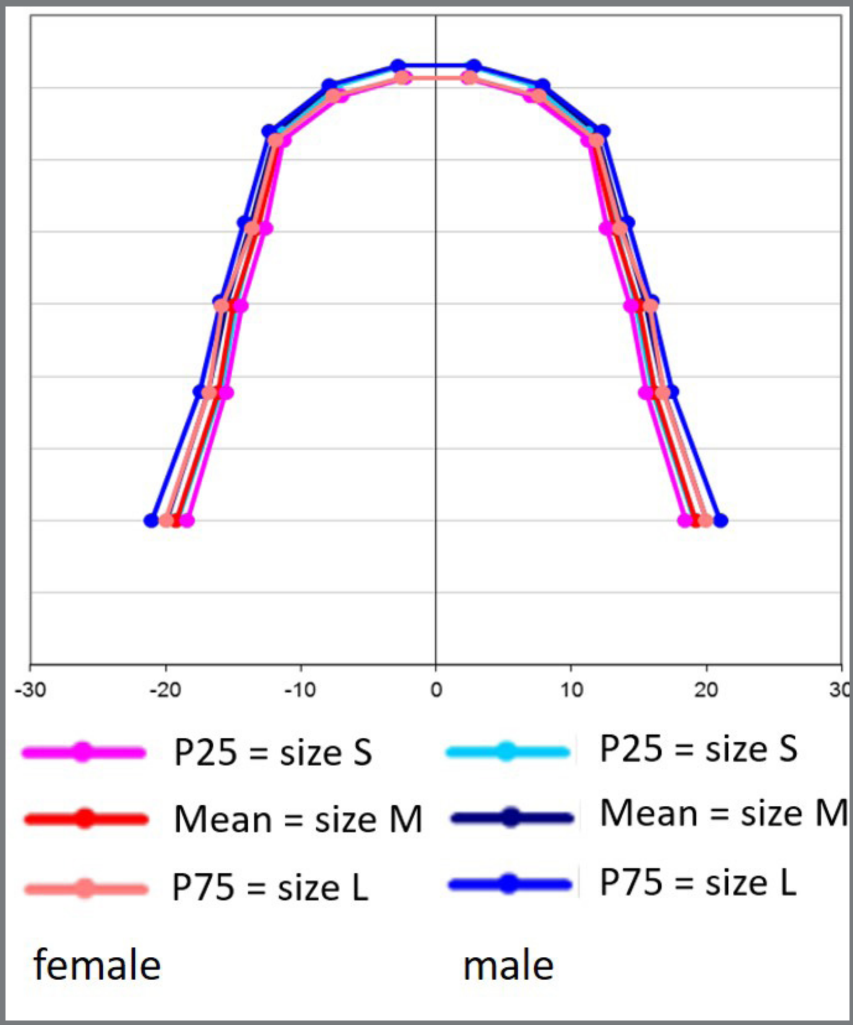

Figure 9: Shape and sizes of mandibular dental arches for both genders.

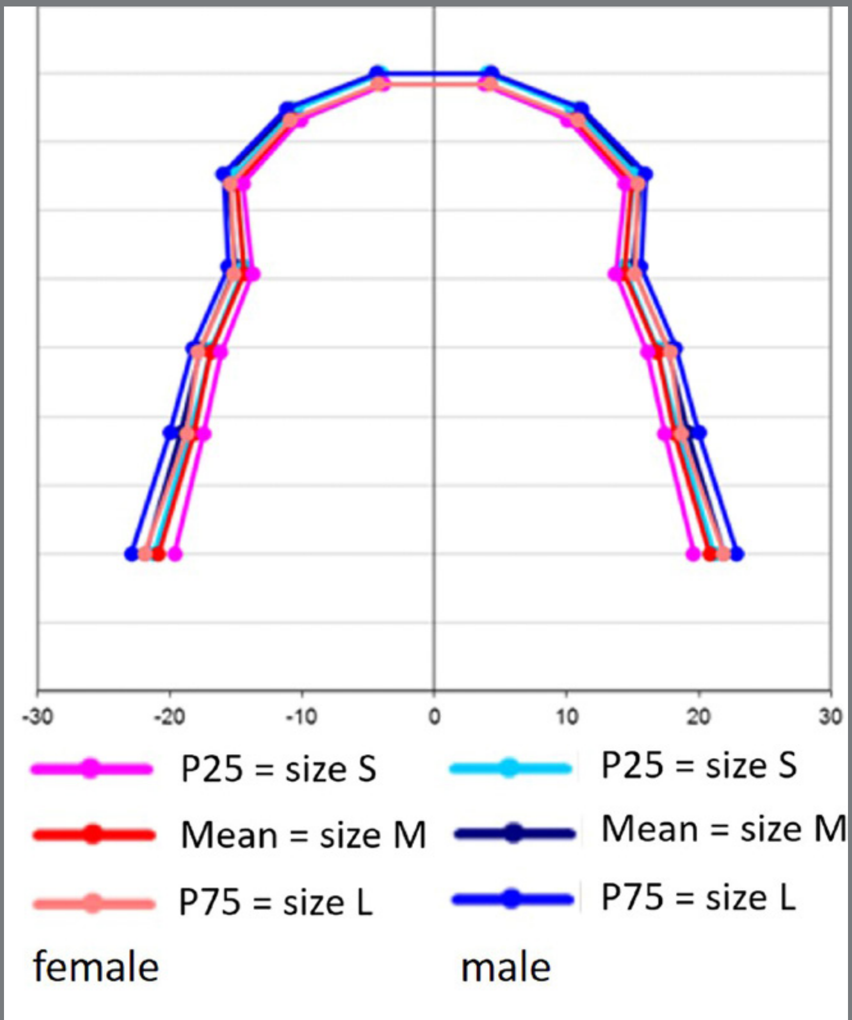

Figure 10: Shapes and sizes of maxillary dental arches for both genders.

DISCUSSION

This study aimed at identifying the shapes and sizes of lingual dental arches from digitized models, as well as the probable difference between genders, from the point of view of the lingual orthodontic technique. It was found that there was a difference between the lingual sizes of the maxillary and mandibular arches, which allowed to define six sizes of lingual dental arches for the maxilla and six for mandible. Three of those for females and three for males, described as S, M and L.

Another purpose was to create arch templates to assist orthodontists in bending archwires themselves and not to depend on prefabricated archwires that might not meet their needs in daily practice. It was possible to create a template composed of eighteen archwire sizes, nine for the maxilla and nine for the mandible.

3D images digitized from cast models were used, in agreement with other authors,[15,24-29] because they allow simultaneous visualization in three dimensions (horizontal, sagittal and vertical). 3D technology is currently used in several areas of Dentistry,[30,31] allowing professionals to develop studies using the same sample. Since it can be inserted in any computer compatible with the program that was used, it is maintained over time and does not occupy a physical space, in addition to the great accuracy given by the software that is needed when using several pieces of numerical data.

One of the limitations of this study was the average age of 16.4 years, because the cast models available for digitization came from a sample of individuals aged 15 to 21.3 years old. However, this average age allows consideration of individuals without growth, since the dental arch has greater growth from 12 to 15 years old, showing a small reduction in width and depth between the ages of 15 and 26 years in both arches.[32]

To guarantee that the measurements remained proportional, regardless of the position of the digital models, the X, Y and Z axes were used in this study, as well as some previous studies,[15,24] allowing the reference points to be positioned in the three dimensions. However, some other studies[13,14] used only two (X and Y) coordinates, not allowing the models to be moved due to the lack of a third axis, since the Z axis does not exist in 2D models.

Fourteen points were chosen on the lingual surfaces because they would represent the place where the brackets would be placed on the lingual surfaces of the teeth, and where the orthodontic wires or metallic archwires pass into the slot of these brackets. The height chosen for these points took into consideration the most concave and convex parts of the lingual surfaces, to represent the anatomical shape of the dental arches as much as possible. From these points, the measurements were obtained to define the shapes and sizes of the arches.

To accomplish this, several authors[13,14,27,33] used polynomial functions; others chose linear measurements.[12,15] In this study, fourteen linear measurements (ten horizontal and four vertical) were used to define the shapes and sizes of the dental arches, similar to an earlier study,[15] while others used four linear measurements[12] (two horizontal and two vertical). Few studies combined the two forms together, that is, polynomial functions and linear measurements: ten linear measurements (five horizontal and five vertical),[7] six horizontal linear measurements,[10] and six linear measurements (three horizontal and three vertical).[34]

The linear measurements of this study were automatically defined by Delcam Power SHAPE™ 2010 software and therefore they were obtained with great precision. With this method, using methodology similar to an earlier study,[15] we noticed a difference between the measurements when points were used more at the center of the clinical crown than when these points were positioned more in the cervical region of the clinical crown. Therefore, as shown in Table 4, the male measurements of the vertical distances of the mandibular central incisors (CI, 5.3 mm), mandibular lateral incisors (LI, 3.7 mm) and horizontal distances of mandibular canines (C, 23.7 mm) were different from those of a previous study[15] (4.7 mm for CI, 3.3 mm for LI and 22.7 mm for C). The measurements of the distances for the maxillary central incisors (CI, 8.5 mm) and maxillary canines (C, 31.3 mm) were also different when compared with the previous report (7.5 mm for CI and 29.2 mm for C).

The same was observed with the results obtained from female samples, as shown in Table 5. It was shown that the measurements of the vertical distances of the mandibular central incisors (CI, 5.1 mm), mandibular lateral incisors (LI, 3.6 mm) and horizontal distances of the mandibular canines (C, 23.2 mm) were different from those of the previous study[15] (4.6 mm for CI, 3.1 mm for LI, and 22.1 mm for C), The measurements of the distances for the maxillary central incisors (CI, 8.4 mm) and maxillary canines (C 29.9 mm) were also different when compared with the previous report (7.3 mm for CI and 27.9 mm for C). The differences that were found in the distance measurements are important because they change the final shape of the dental arches.

The accuracy of the digital technique was confirmed by the usage of the Shapiro-Wilk test on the measurements obtained. And as all data passed the normality criterion, even though the sample pool was composed by 40% male and 60% female models, it was possible to apply Student's *t* test and Bonferroni test on the measures found, allowing the creation of two tables (Tables 4 and 5), showing the measures of the female and male casts separately.

Some studies[13,14,27,28,35] were not able to identify differences between the genders. It is anthropologically known that the sizes of the male dental arches are larger than those of females,[24] although in this study there were females with broader arches and males with narrow arches. This can be explained by the choice of reference points and the number of measurements applied.[15]

From the measurements obtained, three sizes of dental arches were identified: S, M, and L. In another study,[14] median measurements were applied, unlike the averages found in this study and those of other authors.[15] In this way, the mean, and not the median, was used to obtain the final measurements, because mean measurements were more accurate than the medians.

In the mandible, the shape of the dental arch resembles a parabola, with a more rounded form in the anterior portion, and the posterior side is more like a straight line, with a slight deviation in the region of the premolars and molars. In the maxilla, the shape of the dental arch also resembles a parabola, with the rounded anterior portion with more pronounced curves in the canine region, and a segment of a line, with deviations, in the region of the premolars and molars (Figs 9 and 10). In other studies,[14,15] the parabola was flatter, with less prominent curve in the anterior region, mainly due to the location of the points that were selected. In our study, those points were placed more occlusally, to allow a better adaptation to the anatomical form of the dental arch, compared to previous studies in which the placement of the points was more cervical.

As stated in a previous study,[36] to perform orthodontic treatment orthodontist should have an understanding about the shape of the dental arch. It has been observed for years that many professionals sought to find a method to reliably copy the shape of the dental arch and apply it for orthodontic treatment.

For this purpose, the first diagram in orthodontics was created by the millimeter paper method.[37] Over the years, other diagrams have emerged,[38-41] with the intention of preserving stability and individualizing treatment, allowing coordination of archwires to facilitate the professional's work. Some are more accurate and use their own initial model as a reference;[36,38] others look for diagrams with the possibility of several sizes of archwires,[40,41] which is possible in regard to making metal archwires.

Some studies[42,43] have shown that professionals have a concern regarding maintenance of the dental arch shape. Perhaps because the prefabricated archwires mostly do not correspond to the size and shape of the arches in a normal occlusion.[26] Nevertheless, it should be noted that prefabricated light alloy archwires (mainly nickel and titanium) cannot substantially alter the shape of the dental arch;[25] however, they assist in the initial stages of treatment and are necessary for current orthodontics.[26]

In lingual orthodontics, diagrams were proposed from photocopied models,[6] and others through computerized programs,[9,14,15,44] to allow the manufacture of individualized orthodontic archwires, because in lingual orthodontics the coordination of the archwires is a difficult or almost impossible task.

Therefore, considering that dental human arches are asymmetrical and that this characteristic is more a rule than an exception,[45] the construction of symmetrical archwires results in smaller errors than if the asymmetries are obeyed,[39] and the measures resulting from this work are adequate to define the shapes of anatomical arches. It is possible to determine a diagram to obtain lingual archwires that could help lingual orthodontics in the definition of prefabricated archwires.

There is controversy regarding the various types of archwires used in the lingual technique. Some authors[14-18] suggest using straight archwire as a facilitator of the technique, even aware of the need for making bends for finishing and detailing. A group of authors[1,2,3] have advocated the lingual technique using mushroom archwires, and others[6] advocated metallic archwires to be used in the lingual technique resembling a Christmas tree-shaped archwire.

It is known that there are differences between one archwire type and another, and it is important to remember that in clinical practice, the mechanical aspect must also be considered. Therefore, authors who compared *in vitro* the two types of mushroom and straight archwire observed that the advantages and disadvantages of some orthodontic movements varied for each archwire according to the treatment phase.[19,20]

We believe that more studies on archwire shape should be performed (*in vitro* and *in vivo*) because it is still not possible to state which archwire shapes —mushroom, straight wire, Christmas tree or anatomical (the forms found in this study)— will be more suitable for treatment with the lingual technique. Therefore, the professional will have the opportunity to choose the shape of the archwire that better suits according to the clinical case being treated and, if possible, a template to assist in the orthodontic treatment.

CONCLUSION

In this study, we were able to define twelve sizes of lingual dental arches by altering the reference points: six sizes for the maxilla, with three for females (S, M, L) and three for males (S, M, L); and six sizes for the mandible, with three for females (S, M, L) and three for males (S, M, L).

It was also possible to create an anatomical template representative of anatomical arch shapes, allowing construction of lingual metallic archwires to be used in the lingual technique that are more compatible with the reality of the anatomy of the dental arches.

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ORIGINAL ARTICLE

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Extended-pour and conventional alginates: effect of storage time on dimensional accuracy and maintenance of details

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ABSTRACT

Objective: This study aimed to evaluate the dimensional stability and maintenance of details of conventional and high stability alginates up to 5-day storage.

Methods: Two types of alginates were selected (n=10) for this study, conventional (Hydrogum) and high stability alginates (Hydrogum 5), which were produced with the aid of a cylindrical metal block and a ring-shaped metal mold (Specifications 18, 19, and 25, ANSI/ADA). Ten images were obtained from the molds for the dimensional stability test, which were taken immediately after their production and at each different storage periods (15 min, 24 h, 48 h, 72 h, 96 h, and 120 h) by a digital camera. The specimens were kept hermetically sealed in plastic bags (23°C) and then used to obtain 140 (n=70) dental stone models, used in the detail reproduction test, in which the angular accuracy of three grooves (20 µm, 50 µm, and 75 µm) was observed at each period. The details reproduction accuracy was classified using a predetermined score classification. Measurements of dimensional changes were made in the Corel DRAW X6 program. The data were submitted to the Student's t-test ($\alpha = 0.05$).

Results: A statistically significant difference concerning the size of the matrix was observed after 24h for both alginates, and a statistically significant negative linear dimensional change (contraction) was verified after 24 h of storage (1.52% for the high stability alginate, and 1.32% for the conventional alginate). The high stability alginate kept the full details for 72 hours, while the conventional alginate, for 24 h. Both alginates reproduced the 75 µm groove at all storage periods.

Conclusion: Impressions made with both alginates presented satisfactory clinical results when the alginates were immediately poured.

Keywords: Dimensional measurement accuracy. Alginates. Dental impression materials.

RESUMO

Objetivo: O presente estudo teve como objetivo avaliar a estabilidade dimensional e manutenção de detalhes de alginatos convencionais e de alta estabilidade por até 5 dias de armazenamento. **Métodos:** Para esse estudo, foram selecionados dois tipos de alginatos: convencional (Hydrogum) (n = 10) e de alta estabilidade (Hydrogum 5) (n = 10), sendo produzidos com o auxílio de um bloco metálico cilíndrico e um molde metálico em forma de anel (especificações 18, 19 e 25, ANSI/ADA). Para o teste de estabilidade dimensional, dez imagens foram obtidas imediatamente e para cada tempo de armazenamento (15 min, 24, 48, 72, 96 e 120 horas), realizadas por câmera digital. As amostras foram mantidas hermeticamente fechadas em sacos plásticos (23°C). Para o teste de reprodução de detalhes, as amostras foram utilizadas para obter 140 (n = 70 por grupo) modelos de gesso, sendo observada a precisão angular de três sulcos (20 μm, 50 μm e 75 μm) para cada período. A precisão da reprodução de detalhes foi classificada usando uma classificação de pontuação predeterminada. As medições das mudanças dimensionais foram feitas no programa Corel DRAW X6. Os dados foram submetidos ao teste *t* de Student (α = 0,05). **Resultados:** Foi observada diferença estatística em relação à matriz após 24h para ambos os alginatos. Uma mudança dimensional linear negativa estatisticamente significativa (contração) foi verificada após 24 h de armazenamento (1,52% para alginato de alta estabilidade; 1,32% para alginato convencional). O alginato de alta estabilidade manteve os detalhes completos por até 72 horas, enquanto o alginato convencional, por 24 horas. Os alginatos reproduziram o sulco de 75 μm para todos os períodos. **Conclusão:** As impressões feitas com ambos os alginatos devem ser imediatamente vazadas para se ter resultados clínicos satisfatórios.

Palavras-chave: Precisão de medição dimensional. Alginatos. Materiais de impressão dentária.

INTRODUCTION

Optimal dental impression material should have dimensional stable performance over time and allow the pouring of the dental stone according to the convenience of the operator.[1] Hydrocolloids and synthetic elastomeric polymers are the most frequently used materials to obtain dental impressions. When higher precision is required, some nonaqueous elastomeric impression materials can be used, like polysulfides, polyethers, and condensation or addition silicones.[2] However, alginate is one of the most used impression materials, especially due to its satisfactory technical properties and low cost.

Their details reproduction allows creating stone cast models with good details of accuracy when correctly used. However, it is a very sensitive material, requiring a strict protocol of use. Certainly, one of the main causes of clinical failure when using alginate is its tendency to experience syneresis and imbibition, often as a result of mold storage issues, long time between molding and casting, and insufficient disinfection procedures.[3-6] Alginate has poor detail reproduction and dimensional instability when stored for long periods.[5,6] Therefore, its immediate pouring or right after disinfection is recommended. New products have been launched in the dental market to overcome some of these disadvantages inherent to the material composition, claiming to be dimensionally stable for up to 5 days (extended-pour alginates), being known as new generation of alginates due to their high stability.[3,7-10]

Dimensional stability is one of the most important properties of impression materials to obtain accurate dental stone models.[11] The main limitation of alginate is its dimensional change after being removed from the mouth and stored for periods over 15 min.[12] Thus, the analysis of dimensional stability and maintenance of details of these new high stability products is required, since the immediate pouring of the impressions may not always be possible, especially if the impression needs to be sent to a dental laboratory.[7] Although this material is generally used to obtain diagnostic casts, it is frequently used during the manufacturing of the partially removable dental prostheses.[6,11] Therefore, the knowledge about the dimensional behavior of impression materials is of utmost importance, and this study aimed to provide new information to the clinician about the different products available in the market, providing scientific support to the selection of the best materials.

This study aimed to evaluate the influence of 5-days storage on the dimensional stability and maintenance of details of molds obtained from two types of alginate (conventional and high stability). Two null hypotheses were tested, in which there was no statistically significant difference between both alginates, regarding their dimensional stability; and that the dimensional stability and maintenance of details would not be affected by the storage time.

MATERIAL AND METHODS

Two types of alginates were used to make the test specimens, the conventional and high stability alginates (Hydrogum® and Hydrogum 5®, Zhermack Spa, Badia Polesine, Italy). The test specimens were prepared according to ANSI/ADA specifications#18, 19, and 25,[13-15] using a cylindrical metal block and a ring-shaped metal mold (Fig. 1) in order to test their dimensional stability and maintenance of details. The ring-shaped metal mold was adapted to the upper part of the cylindrical metal block, to leave a space where the material was placed.

The alginates were manipulated according to the instructions of the manufacturer at 23 ± 2°C and at relative humidity of 50 ± 10%. After manipulation, the material was placed in the mold using a spatula. After insertion, a polyethylene strip was laid, followed by a glass plate. A 1,500 g load was placed on the glass plate to extrude the excess of impression material, and kept under pressure. Subsequently, the material was immersed in distilled water at 35 ± 1°C and kept in an incubator

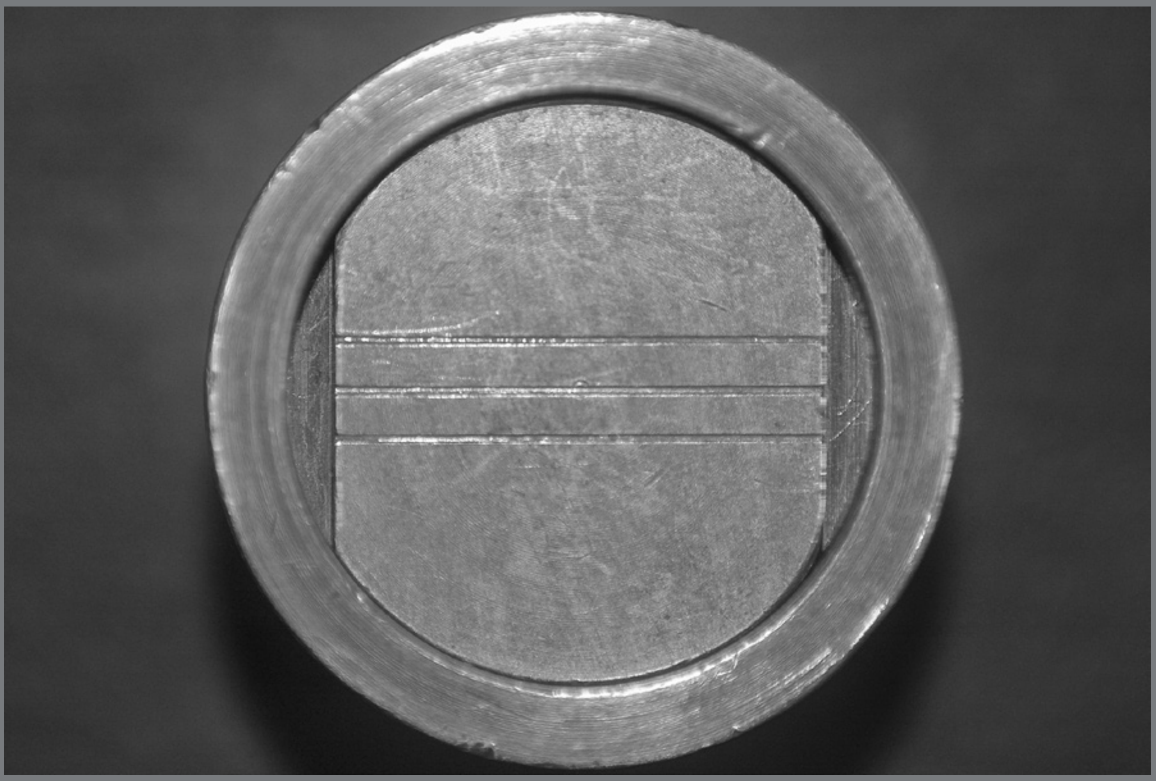

Figure 1: Metallic cylindrical matrix.

for three min longer than the minimum time recommended by the manufacturer. After this time, the set was removed from the incubator, the mold separated from the metal matrix, and the specimens were carefully removed to avoid distortions.

LINEAR DIMENSIONAL CHANGE TEST

Twenty specimens (n=10) were made and, since the same test specimen was used for the different storage times, variables such as water/powder ratio, hand spatulation time, etc, were excluded. Photos were taken using a digital camera (Nikon D50) with a macro lens and a ring flash, mounted on the stand (Asahi Pentax), with the camera distance/object determined and maintained equal for all specimens. Along with the specimen, a 10 x 10 mm metal block was placed (a metallic reference standard) to determine the true magnitude of the picture, enabling to scale the values obtained in actual numbers (Fig. 2A and B). Each specimen (n=10) was photographed immediately after its removal from the matrix and at each storage period (15 min, 24 h, 48 h, 72 h, 96 h, and 120 h).

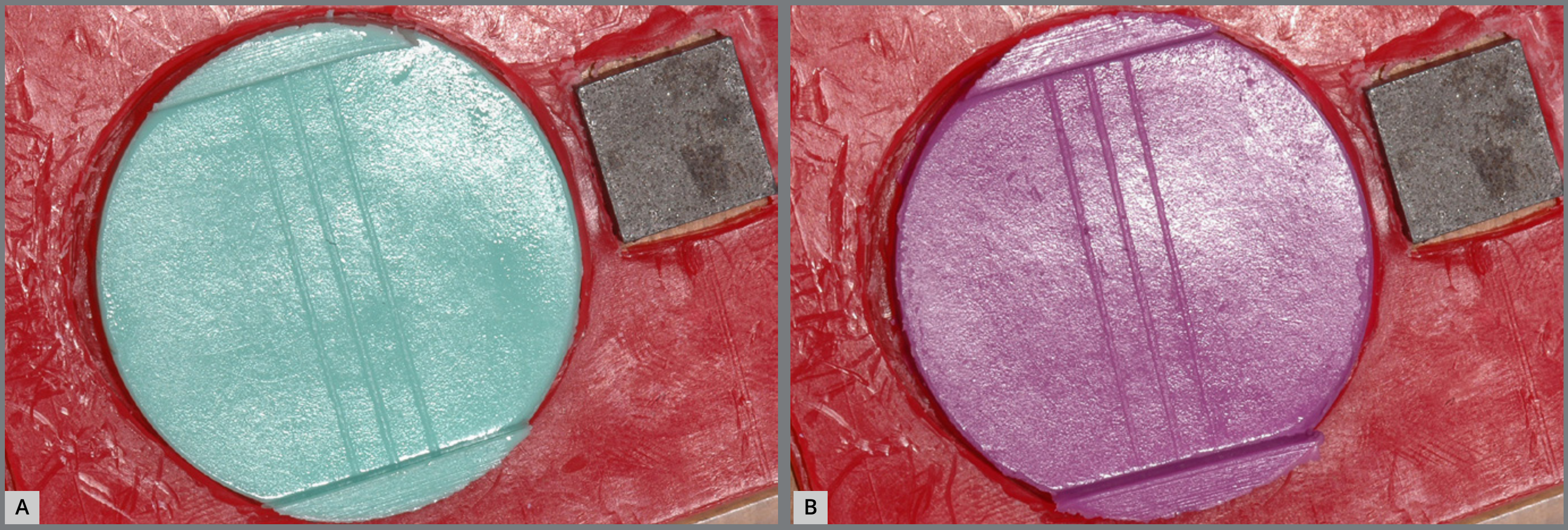

Figure 2: Specimens of conventional Hydrogum® (**A**) and Hydrogum 5® (**B**).

The specimens were stored according to the instructions of the manufacturer in hermetically sealed plastic bags at room temperature (23°C), placed at the laboratory bench during all the experimental periods. Ten images were obtained for each time of storage for each material, divided into seven groups. After the image capture, the specimen returned to the hermetically sealed plastic bag and the process was repeated for each storage time. The linear dimensional alteration was analyzed based on the distance between edges C' and D', measured in the pictures taken, using a computer program (Corel DRAW X6, Corel Corporation). The original distance between these edges was of 25 mm (Fig. 3, the original distance of the matrix). The measurement of each image was repeated three times to obtain an average value (Fig. 4). The percentage of dimensional change of the alginate molds tested was calculated using the formula expressed below:

Dimensional change (%) = (B – A) / A × 100
A = original distance of the block between edges C and D = 25 mm.
B = distance between edges C' and D' in the test specimens, after storage periods.

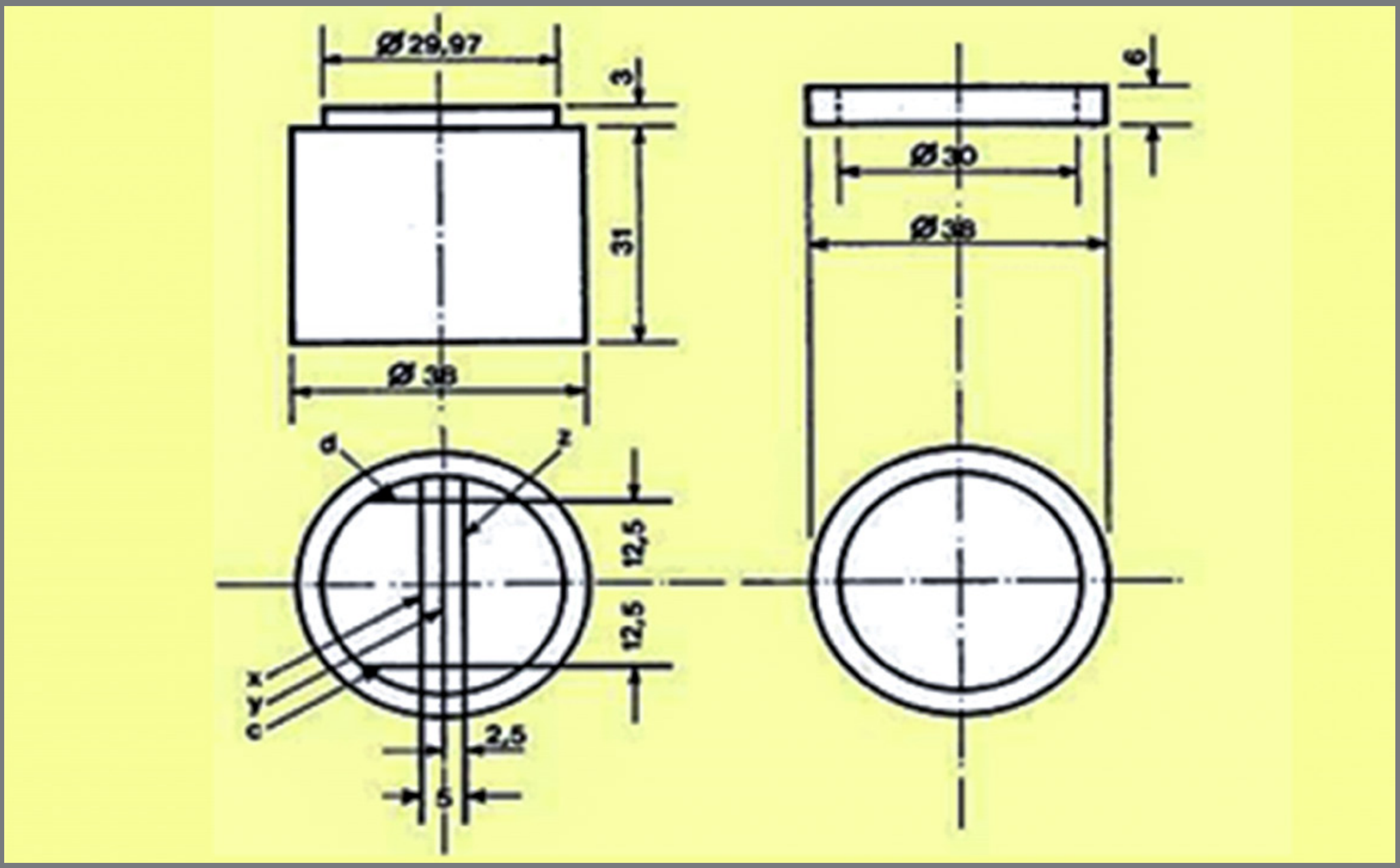

Figure 3: Schematic drawing of the matrix.

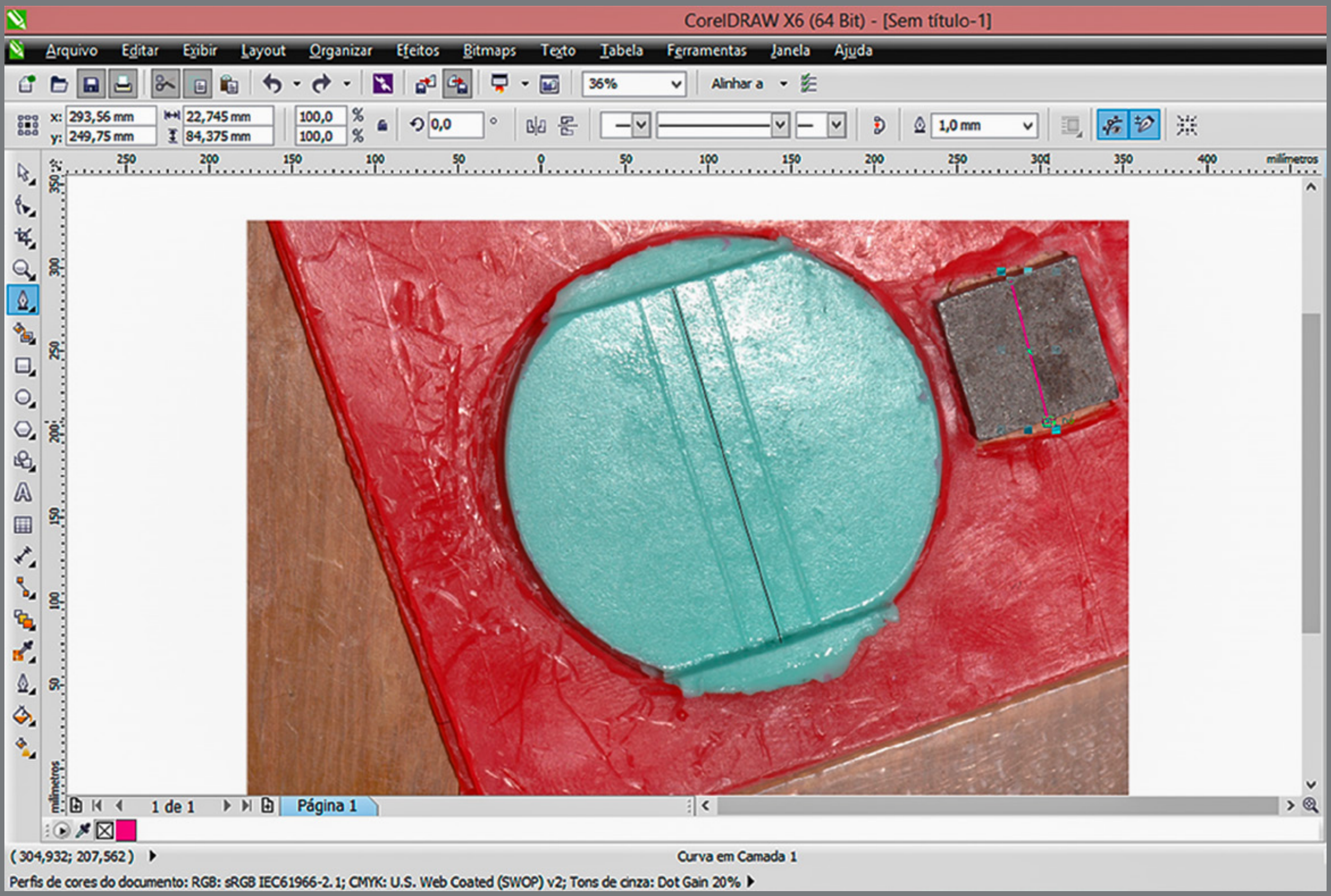

Figure 4: Image measurement in the Corel DRAW X6 program.

MAINTENANCE OF DETAILS TEST

A total of 70 specimens for each alginate mold (n=10) were prepared and divided according to the storage period (immediately, 15 min, 24 h, 48 h, 72 h, 96 h, and 120 h) for the maintenance of details test. After each storage period, the molds were inserted in a frame and the pouring of the dental stone type IV (Durone, Dentsply, Petrópolis, Brazil) occurred under mechanical vibration after the proportioning and vacuum tooling, according to the manufacturer, which were separated 1 hour after the pouring.

The maintenance of details of the dental stone models was tested in a stereomicroscope (Olympus) under a low-angle illumination at 13× magnification. In the detail reproduction test, the angular accuracy of three grooves ($x = 50 \pm 5$ μm; $y = 20 \pm 5$ μm; $z = 75 \pm 5$ μm) molded in each sample was recorded, obtained after the following storage periods: 15 min, 24, 48, 72, 96 and 120 h. To classify the detail reproduction accuracy, the scores suggested by Goiato et al.[16] were used, as follows: 0 – full reproduction of two of the three grooves; 1 – full reproduction of the three grooves, with inaccurate angles; 2 – full reproduction of the three grooves, with accurate angles.

STATISTICAL ANALYSIS

All the photos were taken by a single examiner and under the same camera setup, to avoid discrepancies between the images. After capturing the images, they were transferred to the computer and analyzed using the Corel DRAW software. The measurements were repeated twice after a two-days interval, to examine the reproducibility of the method, by statistical analysis; and for intraclass evaluation. After performing two measurements every two days between them, the average result obtained was CCI = 0.90 (F = 17.91; $p = 0.0001$), indicating reproducibility of the method.

The data were submitted to statistical analysis using the Student's t-test (paired samples), and the two alginates were compared using the Student's t-test (SPSS 20.0, IBM), at the level of confidence of 95% ($p < 0.05$).

RESULTS

LINEAR DIMENSIONAL CHANGE RESULTS

The frequency distribution of each measurement was analyzed for the assumption of normality, which was confirmed for the quantitative data. Table 1 shows the mean values and standard deviations of the dimensional changes that occurred in the conventional and high stability alginates during all the storage period. The results showed that there was no significant difference regarding the C and D dimensions of the metal matrix (25 mm), immediately after its production and at the 15 min storage time (Table 1). Both alginates presented a negative linear dimensional change (contraction) statistically significant after 24 h of storage (1.52% for the high stability alginate and 1.32% for the conventional alginate).

There was no statistically significant difference for the high stability alginate from 24 h to 96 h of storage time. After the maximum period of time recommended by the manufacturer for the storage of the material (120 h), the high stability alginate suffered an average contraction of 1.56%. Regarding the conventional alginate, there were no statistically significant difference between the storage periods of 24 h and 48 h and between 48 h to 120 h. Further, there was no statistically significant difference between the alginates, regardless of storage periods (Fig. 5).

Table 1: Mean values (SD) of dimensional change of conventional and high stability alginates at different storage periods (mm and %).

Storage periods	Conventional		High stability	
Control (matrix)	25.00 (0)[Aa]	0	25.00 (0)[Aa]	0
Immediate	25.01 (0.23)[Aa]	+0.04	25.01 (0.18)[Aa]	+0.04
15 min	25.08 (0.31)[Aa]	+0.32	25.13 (0.37)[Aa]	+0.52
24 hours	24.67 (0.24)[Ba]	-1.32	24.62 (0.51)[Ba]	-1.52
48 hours	24.35 (0.39)[BCa]	-2.60	24.32 (0.4)[BCa]	-2.72
72 hours	24.34 (0.35)[Ca]	-2.64	24.54 (0.51)[BCa]	-1.84
96 hours	24.30 (0.4)[Ca]	-2.80	24.29 (0.22)[BCa]	-2.84
120 hours	24.41 (0.43)[BCa]	-2.36	24.35 (0.47)[Ca]	-2.60
General average	24.59 mm (-1.62%)	-1.62%	24.61 mm (-1.56%)	-1.56%

Means followed by the same capital letters in the column and the same lowercase letters in the row did not differ statistically from each other at the level of 95% reliability ($p<0.05$).

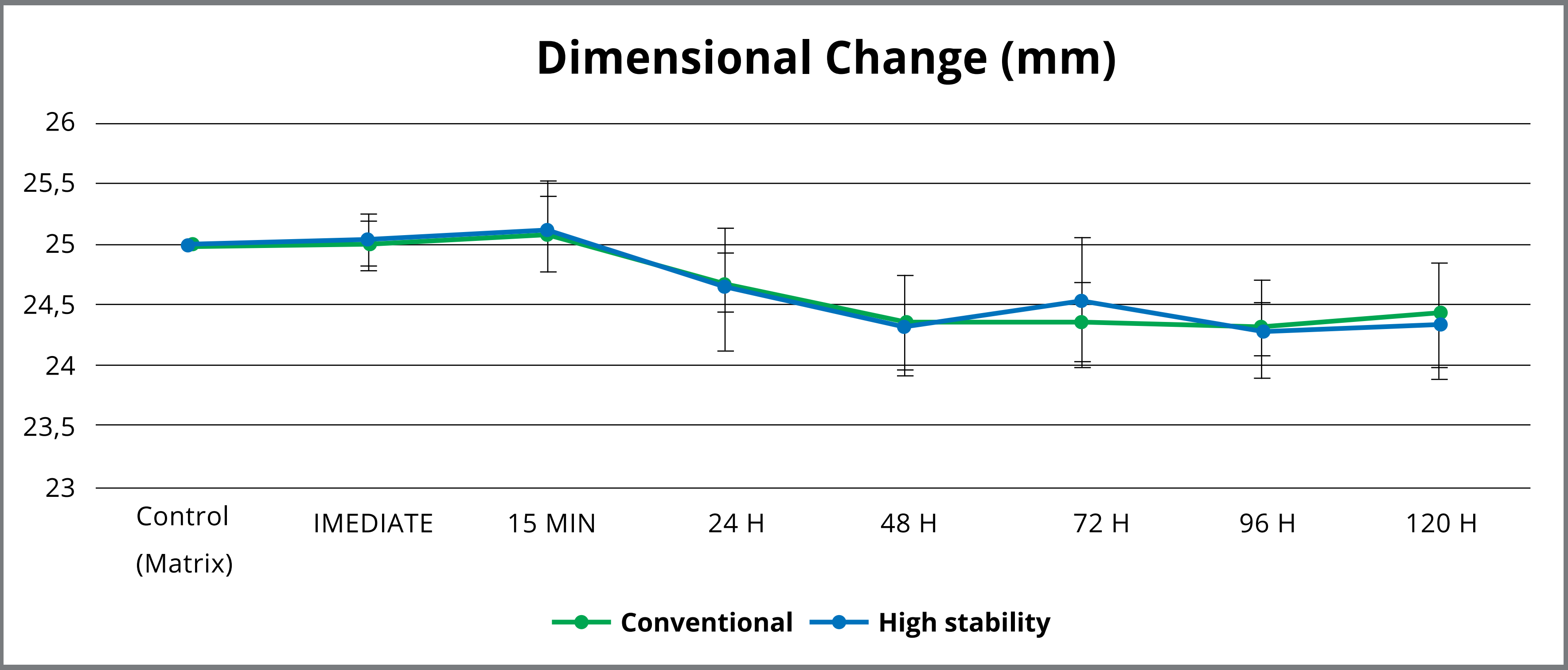

Figure 5: Line graph of the dimensional change (mm) in all the periods evaluated.

MAINTENANCE OF DETAILS

Tables 2 and 3, and Fig. 6 (A and B) show the results of the maintenance of details test for the two alginates, depending on the storage time, according to the classification of Goiato et al.[16] In this scale, score 0 is assigned to full reproduction of two of the three grooves; score 1, to full reproduction of the three grooves, without accurate angles; and score 2, to full reproduction of the three grooves, with accurate angles.

In the high stability alginate (Table 2), the maintenance of details test presented a score 2 (full reproduction of the three grooves, with accurate angles) for 100% of the specimens for the storage time of 15 min, 24 h, 48 h, and 72 h. The same score was obtained for 80% of samples for the groups subjected to storage periods of 96 h and 120 h.

Regarding the conventional alginate (Table 3), the maintenance of details presented a score 2 (total reproduction of the three grooves, with accurate angles) in 100% of the samples for storage periods of 15 min to 24 h. The groups subjected to storage periods of 48 h, 72 h, 96 h, and 120 h, the same score was obtained in 80%, 50%, 50%, and 0% of the samples, respectively (Fig. 7). Following the ADA specification #18,[13] both alginates reproduced the groove of 75 μm in width, fulfilling properly this requirement.

Table 2: Scores of maintenance of details for casts obtained from high stability alginates, as a function of the storage time.

SCORE CLASSIFICATION						
Stone cast models	**15 min**	**24 hours**	**48 hours**	**72 hours**	**96 hours**	**120 hours**
Specimen 1	Score 2	Score 2	Score 2	Score 2	Score 2	Score 2
Specimen 2	Score 2	Score 2	Score 2	Score 2	Score 2	Score 2
Specimen 3	Score 2	Score 2	Score 2	Score 2	Score 2	Score 2
Specimen 4	Score 2	Score 2	Score 2	Score 2	Score 1	Score 2
Specimen 5	Score 2	Score 2	Score 2	Score 2	Score 1	Score 2
Specimen 6	Score 2	Score 2	Score 2	Score 2	Score 2	Score 2
Specimen 7	Score 2	Score 2	Score 2	Score 2	Score 2	Score 1
Specimen 8	Score 2	Score 2	Score 2	Score 2	Score 2	Score 2
Specimen 9	Score 2	Score 2	Score 2	Score 2	Score 2	Score 1
Specimen 10	Score 2	Score 2	Score 2	Score 2	Score 2	Score 2
Score 2 reproduction	100%	100%	100%	100%	80%	80%

Table 3: Scores of maintenance of details for casts obtained from conventional alginates, as a function of the storage time.

SCORE CLASSIFICATION						
Stone cast models	**15 min**	**24 hours**	**48 hours**	**72 hours**	**96 hours**	**120 hours**
Specimen 1	Score 2	Score 2	Score 2	Score 2	Score 2	Score 1
Specimen 2	Score 2	Score 2	Score 2	Score 2	Score 2	Score 1
Specimen 3	Score 2	Score 2	Score 2	Score 2	Score 1	Score 1
Specimen 4	Score 2	Score 2	Score 2	Score 2	Score 1	Score 1
Specimen 5	Score 2	Score 2	Score 2	Score 1	Score 2	Score 1
Specimen 6	Score 2	Score 2	Score 2	Score 1	Score 1	Score 1
Specimen 7	Score 2	Score 2	Score 2	Score 1	Score 2	Score 1
Specimen 8	Score 2	Score 2	Score 1	Score 1	Score 1	Score 1
Specimen 9	Score 2	Score 2	Score 1	Score 1	Score 1	Score 1
Specimen 10	Score 2	Score 2	Score 2	Score 2	Score 2	Score 1
Score 2 reproduction	100%	100%	80%	50%	50%	0%

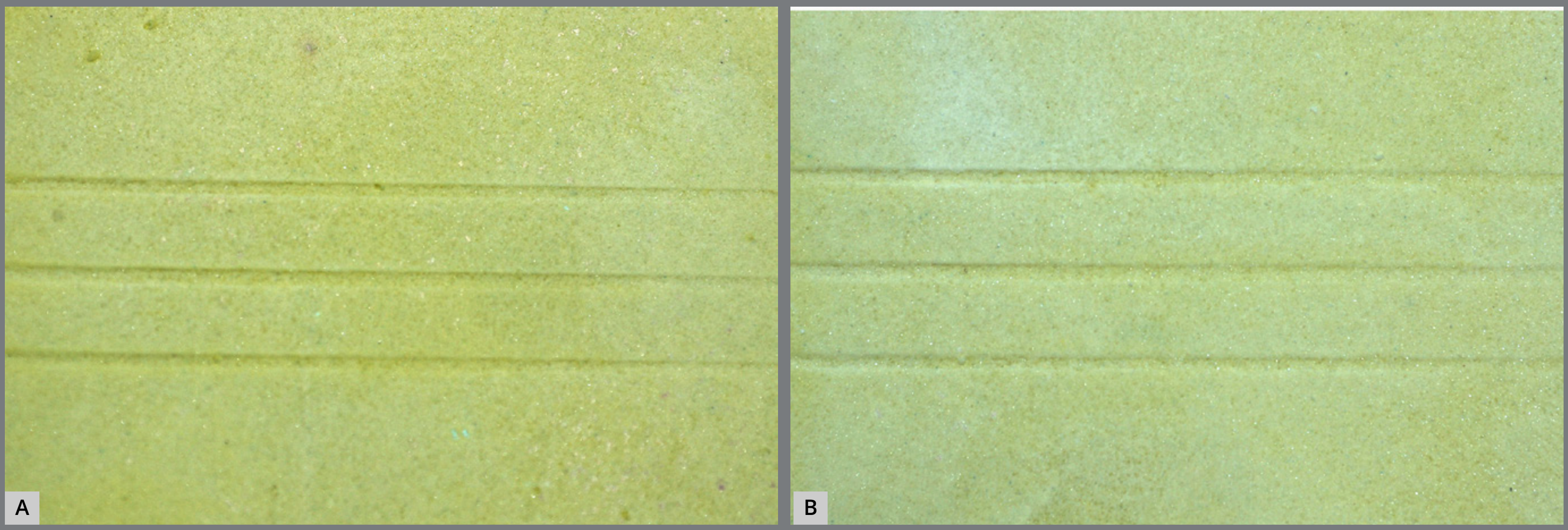

Figure 6: Stone cast models with a reproduction of the 75 µm groove: **A)** high stability and **B)** conventional alginate.

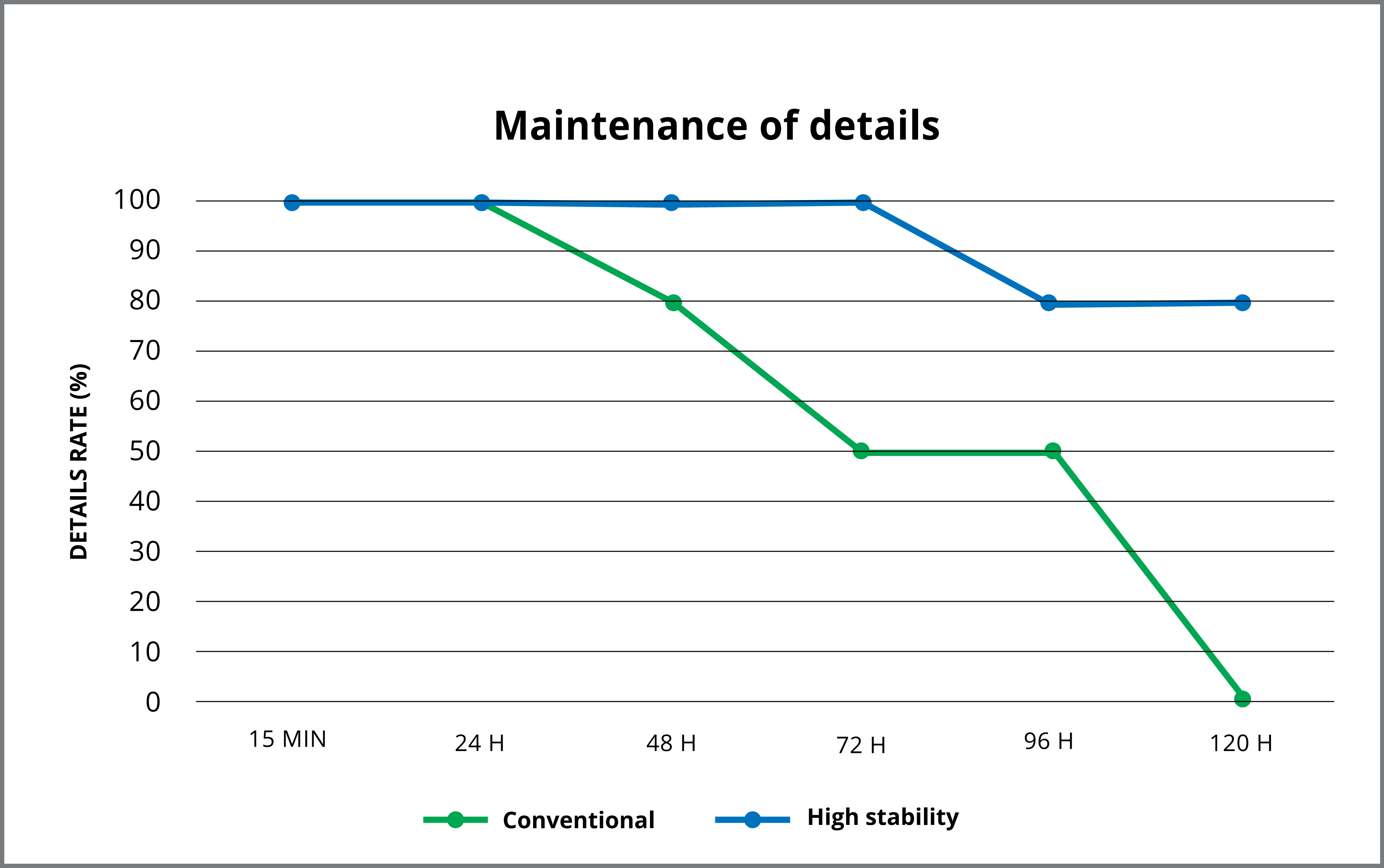

Figure 7: Line graph of the rate of maintenance of the details (%).

DISCUSSION

Alginates are used currently, day after day at dental offices, especially due to their several advantages. They present low cost, well acceptability by the patient, easy manipulation and execution technique, as well the possibility of achieving a detailed impression all in a single step, being outstanding for primary prosthetic, orthodontic and design imprints. However, alginates present some disadvantages like lower accurate reproduction than elastomeric impression materials, and poor dimensional stability for complex cases.[17]

In this study, the linear dimensional change (% mean) for high stability alginate and conventional alginate at 24 h of storage was of -1.52% and -1.32%, respectively (Table 1). The values were statistically different from the immediate period after mold production and at 15 min of storage. These data revealed that the alginate molds, once removed from the mouth, experience some contraction associated with syneresis and evaporation.[11] According to the manufacturer, if the gypsum can not be immediately poured, the impression should be stored in a bag sealed at room temperature (23°C), and delayed for up to 5 d after taking the impression. In this study, however, the molds of high stability alginate remained dimensionally stable only in the first 15 min. The same result was obtained with the conventional alginate.

In the methodology used in this study, the molds were stored in sealed bags without relative humidity, following the recommendations of the manufacturer. According to literature guidelines,[11] when they need to be stored, this must be done in containers with a relative humidity of 100%. This factor might explain the unsatisfactory or less than expected results obtained.

The ADA specification #18[13] does not stipulate a maximum clinically acceptable value for the dimensional changes of alginates.[3,9,18,19] However, for the elastomeric materials, these values are well defined in the literature and may not exceed 1%, according to the ANSI/ADA specification #19.[14] The polysulfides present a shrinkage percentage in 24 h that vary from 0.4% to 0.45%; condensation silicones, from 0.38% to 0.6%; addition silicones, from 0.14% to 0.17%; and polyethers, from 0.19% to 0.24%.[11] There are controversies regarding the dimensional change values considered clinically acceptable for alginates, ranging from 0.1% to 0.8%.6 According to Imbery et al.[3] and Rohanian et al.,[9] for a plaster model to be considered clinically acceptable, it should not present a discrepancy higher than 75 μm from the originally intended size. The authors considered as a clinically acceptable value the amount of 0.5% dimensional change for alginates.

Although dentists do not use alginates to obtain impressions for fixed partial denture, *in vitro* and *in vivo* studies determined that the misfit of the prosthetic crown should not exceed the range of 25-80 µm, approximately.[11,20-22] However, there is no consensus in the literature about the acceptable values for this maladjustment. According to the ADA specification #8,[23] the marginal crown adaptation in the cementing procedure should be within the range of 25 µm, although many studies reported as clinically acceptable values less than or equal to 120 µm for the good performance of these crowns.[24,25]

In this study, for high stability alginate, after 24 h of storage, the mean linear dimensional change was 24.62 mm, with an inaccuracy of 0.38 mm (380 µm) concerning the value of the matrix (25 mm). The highest mean value of dimensional change in this material was observed in the group that remained stored for 96 h (24.29 mm), presenting an inaccuracy of 0.71 mm (710 µm). The high stability alginate showed a mean linear shrinkage of 1.56% (24.61 mm), which in numerical terms was equivalent to a discrepancy of 0.39 mm (390 µm), well above the acceptable for its use as a molding material for FPD.

Therefore, this study showed that alginate, regardless of its high dimensional stability, does not present enough accuracy to be used in impressions that require a high accuracy level, unless the dental stone is poured within 15 min. This fact is predictable given that this type of material is not designed to be stored for long periods. Most authors recommend to pour the dental stone immediately or at the most in 15 min,[13] since the accuracy of the mold may easily change due to syneresis and imbibition. On the other hand, different results are found in the literature regarding the high stability alginates. In the study of Imbery et al.,[3] the high stability alginate investigated (Cavex Color change) showed a dimensional change from 0.16% to -0.49% during the 5 days of storage. The authors concluded that when the high stability alginate is properly stored, it can produce accurate impressions for up to 5 days. However, they emphasized that the impressions obtained by these materials only had the purpose of making study stone cast models or manufacturing acrylic appliances. Rohanian et al.[9] also found satisfactory results for the alginates Hydrogum 5 and Alginoplast, stating that the impressions of these materials can be stored for up to 120 h and 72 h, respectively, without significant dimensional changes.

Differences in the results found in the literature may be related to the different methodologies employed (matrix types, conditions under which samples were stored, different trademarks, and so on). Todd et al.[10] found unsatisfactory results, observing that the tested high stability alginates (Kromopan and Triphasix) showed significant dimensional changes after 24 h and 100 h of storage. These data corroborate the results of the present study, in which the high stability alginate experienced statistically significant dimensional change after 24 h of storage. The matrix used by Todd et al.[10] was similar to that used in this study.

Regarding the maintenance of details, the analysis was made for the total continuity and sharpness of angles of three grooves molded in each sample (width of groove: $x = 50 \pm 5$ µm; $y = 20 \pm 5$ µm; $z = 75 \pm 5$ µm). According to the specification # 18 ANSI/ADA,[13] plaster models obtained from alginate should reproduce the groove of 75 µm in width. Thus, following the ADA recommendation, both alginates reproduced the groove of 75 µm in width, meeting this requirement satisfactorily.

Therefore, the first null hypothesis of this study was confirmed, with no statistically significant difference being observed between the alginates. The second hypothesis was rejected, showing that the dimensional stability and the maintenance of reproduction details were affected by the storage time for both alginates. Few studies have investigated the dimensional accuracy of high stability alginates[3,9,10,26,27] and, considering the controversial results found in the literature, alginate impressions should be stored for the shortest period of time. The dimensional stability of the molds of both alginates was affected by the storage time. However, both alginates reproduced the 75 µm groove at all storage periods. Regarding clinical application, the present results suggest that impressions made with both alginates would be most precise if poured within 15 minutes. Currently, the study of alternative impression materials, such as irreversible hydrocolloids, is increasing, aiming to overcome the issues associated with the water-based irreversible hydrocolloid impressions. Future studies testing the dimensional stability and the maintenance of reproduction details comparing different impression materials are encouraged.

CONCLUSION

The findings of this study showed that impressions made with these materials should be immediately poured to have satisfactory clinical results, since dimensional alterations were found after 24 hours, even on high stability alginates.

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ORIGINAL ARTICLE

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Dentofacial and skeletal pattern in African descendants from southeastern Brazil: clinical prospective study

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ABSTRACT

Objective: The aim of this study was to evaluate characteristics of African-Brazilians young adults with excellent dental occlusion, including bimaxillary protrusion; compare them to European-American Caucasian standards, and determine whether there is sexual dimorphism in the display of this phenotype. **Methods:** Lateral cephalometric radiographs were obtained from 43 African-Brazilians within military personnel (28 males and 15 females, average age 22.4 ± 3.4 years) with normal occlusion, selected from a group of 394 volunteers. Thirty-one angular and linear measurements were evaluated. Student's *t*-test for independent samples was used to compare results with those established by European-American standards, previously described in the literature. **Results:** Considering the dentoalveolar pattern, seven angular and six linear measurements showed statistically significant differences ($p < 0.001$) when compared to Caucasian cephalometric standards. African-Brazilians' subjects showed lower cranial base angle (SNAr = 119.87 ± 5.66°) and anterior cranial base length (SN-distance = 68.63 ± 4.50 mm) ($p < 0.001$). The maxilla (SNA = 88.51 ± 3.23°) and the mandible (SNB = 85.06 ± 3.24°) were protruded in relation to the SN line ($p < 0.001$). Sexual dimorphism was significant for L1.NB (degrees) ($p < 0.01$), and interincisal angle (U1.L1) ($p < 0.05$). **Conclusion:** African-Brazilian young adults presented differences regarding dental and craniofacial characteristics, when compared to European-American norms. It can be stated that Caucasian cephalometric norms should not be applied to African-Brazilian faces.

Keywords: Face. Cephalometry. Brazil. African continental ancestry group.

RESUMO

Objetivo: O objetivo do presente estudo foi avaliar características de jovens adultos afro-brasileiros com oclusão excelente, incluindo protrusão bimaxilar, e compará-los com os padrões caucasianos europeu-americanos, para determinar se há dimorfismo sexual na exibição desse fenótipo. **Métodos:** Radiografias cefalométricas laterais foram obtidas de 43 afro-brasileiros militares (28 homens e 15 mulheres, idade média de 22,4 ± 3,4 anos) com oclusão normal, selecionados de um grupo de 394 voluntários. Foram avaliadas 31 medidas angulares e lineares. O teste *t* de Student para amostras independentes foi utilizado para comparar os resultados com os estabelecidos pelos padrões caucasianos europeu-americanos, descrito previamente na literatura. **Resultados:** Considerando o padrão dentoalveolar, sete medidas angulares e seis lineares apresentaram diferenças estatisticamente significativas ($p < 0{,}001$) quando comparadas aos padrões cefalométricos caucasianos. Sujeitos afro-brasileiros apresentaram menor ângulo da base do crânio (SNAr = 119,87 ± 5,66°) e comprimento da base craniana anterior (distância SN = 68,63 ± 4,50 mm) ($p < 0{,}001$). A maxila (SNA = 88,51 ± 3,23°) e a mandíbula (SNB = 85,06 ± 3,24°) estavam protruídas em relação à linha SN ($p < 0{,}001$). O dimorfismo de sexo foi significativo para L1.NB (graus) ($p < 0{,}01$) e ângulo interincisal (U1.L1) ($p < 0{,}05$). **Conclusão:** Jovens adultos afro-brasileiros apresentaram diferenças em relação às características dentárias e craniofaciais, quando comparados às normas europeias-americanas. Pode-se afirmar que as normas cefalométricas caucasianas não devem ser aplicadas às faces de indivíduos afro-brasileiros.

Palavras-chave: Face. Cefalometria. Brasil. Grupo com ancestrais do continente africano.

INTRODUCTION

North American and European cephalometric standards are still widely used in orthodontic planning and extraction decision making, despite the ethnic and racial plurality found in contemporary society. However, cephalometric norms cannot be applied to all individuals due to certain racial characteristics and miscegenation, thus making it necessary to establish specific cephalometric patterns for different ethnic groups.[1,2]

Several studies have described dentoalveolar variations in Asian,[3-5] Arabic,[6-9] African,[10-15] African-American[16-20] and African-Brazilian[21,22] populations. Thereby, the cephalometric norms for some ethnic groups should be regarded carefully. For instance, the American black population derives from the miscegenation of different races found in the United States, with those from different parts of Africa.[23] Similarly, African descendants living today in Southeastern Brazil are very heterogeneous in morphology, because most of them descend from African Bantu slaves who mixed with Mediterranean European colonizers and Native American Indians. The Bantu people in turn, prevail in two vast regions of the African continent: Mid-Eastern Africa, including the Old Portuguese colonies of Angola and Mozambique, as well as the Congo region; and Western Africa ranging from the Southern coast up to the Guinea Golf.[24]

The 2010 census conducted in Brazil revealed that blacks and browns make up the equivalent of 50.7% of the population. However, the scientific literature is scarce in relation to the craniofacial morphology of Brazilian Afro-descendants,[22] and the few existing investigations describe only growing subjects. The intense demand for orthodontic treatment by young adults raises the need to evaluate cephalometric pattern concerning individual's profile of this ethnic group, since some characteristics diagnosed by cephalometric radiographs are highly associated with this population, such as bimaxillary protrusion.[21,22]

Bimaxillary protrusion can be described by the forward and proclined positioning of maxillary and mandibular incisors over the basal bone. This condition acts as an important motivating factor for orthodontic treatment, due to the negative esthetic impact of protruding lips and profile convexity.[1] The low prevalence of bimaxillary protrusion in Caucasians with normal occlusion differs highly from what has been reported in the literature for other ethnic and racial groups, such as relevant information about sexual dimorphism in African phenotype.

Based on the rising demand for orthodontic treatment by adults and the lack of studies for this specific Brazilian ethnic group, the aims of this study were: (1) to evaluate in 2D images the dental and craniofacial characteristics of African-Brazilian young adults with excellent dental occlusion, including bimaxillary protrusion, and compare them to European-American Caucasian standards; and (2) determine whether there is sexual dimorphism in the display of this phenotype.

MATERIAL AND METHODS

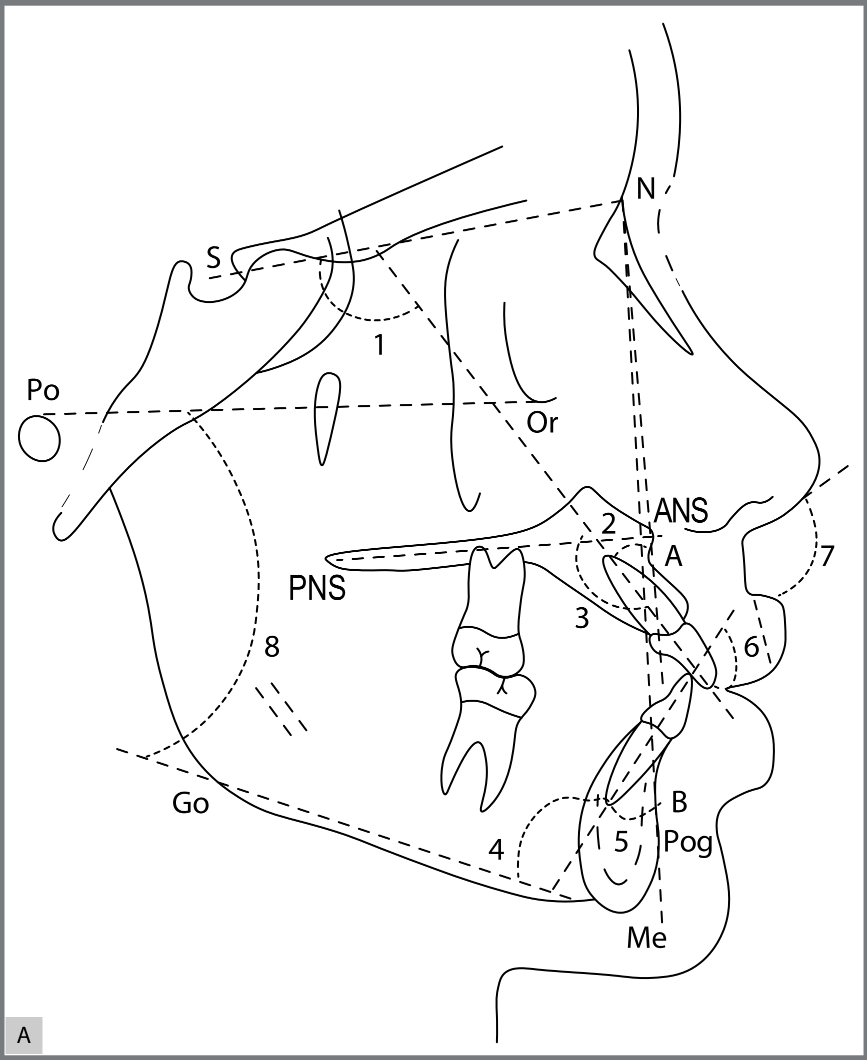
This prospective clinical study was approved by the Ethics in Research Committee of the Institute for General Health Studies at the Federal University of Rio de Janeiro (IESC – UFRJ, statement nº. 66/2011). All subjects gave written informed consent and were aware of the procedures adopted in the present research. The required sample size was determined according to the power analysis at $\alpha = 0.05$ significance level and 80% power (based on a 5.5° standard deviation and a 4.5° minimum clinically detectable U1.NA difference[24]). The sample size needed for the study was at least 39. A total of 43 volunteers (28 male and 15 female) were selected from 394 Brazilian active duty Navy personnel attending the Naval Central Dental Clinic (Rio de Janeiro – Brazil).

All subjects were born in southeastern Brazil and answered a questionnaire about their ancestors, in which they affirmed to having African ancestry up to the third generation. The average age in the group was 22.4 ± 3.4 years. Females presented an average age of 22.0 ± 4.3 years, and males, of 22.6 ± 3.1 years. All individuals were in good state of general health. The selection criteria included normal occlusion of first molars and canines (except for the presence of third molars); anterior crowding, slight rotations and small gaps up to 2 mm permitted, distributed over the dental arch; 20 to 30% overbite; 1 to 3 mm overjet; absence of crossbites and previous orthodontic or orthognathic treatments.

Orthodontic records including study casts, lateral cephalometric radiographs, facial and intraoral photographs were obtained for each subject. All lateral cephalometric radiographs were taken by the same operator, using the cephalostat (Ortophos Plus DS; Sirona Dental System, Bensheim, Germany) according to standard regulation of exposure time of 0.4s, X-ray tube voltage of 73 kV, and X-ray tube current of 15 mA, maintaining each individual with teeth placed in maximum intercuspation, lips at rest and Frankfort horizontal plane parallel to the ground, as in natural head position. Digitalized images obtained were 18 cm x 24 cm in size, and stored in TIFF format.

All cephalometric tracings were performed digitally by the same operator, using Dolphin Imaging® System 11.0 (Dolphin Imaging, Chatsworth, California, USA). Fifteen radiographs were randomly chosen and measured twice after an interval of two weeks, with the intention to test operator calibration for each value of interest, by means of intraclass coefficient correlation (ICC). Tracings were limited to 5 to 10 per day, to minimize fatigue-induced errors. Dolphin Imaging® System corrected X-ray distortions, so that angular and linear measurements were not altered. Cephalometric landmarks, reference lines and planes, angular and linear variables used in the study are presented in Figures 1 and 2. The nasolabial angle was included to investigate soft tissue convexity and the position of upper and lower lips, according to the esthetic plane proposed by Ricketts.[25]

Data normality of all variables was confirmed using Kolmogorov-Smirnov test. Descriptive analysis was performed, so that the measures of central tendency (mean and standard deviations) represented the most common characteristics found in the studied group. As the sample displayed normal distribution, Student's *t*-test for independent samples was used to assess differences found in African-Brazilian subjects as opposed to the European-American Caucasians norms defined in the literature,[25-29] and to evaluate sexual dimorphism in the study. Statistical analysis was carried out on SPSS software, version 16.0 (Chicago, Ill). A 5% level of significance was adopted.



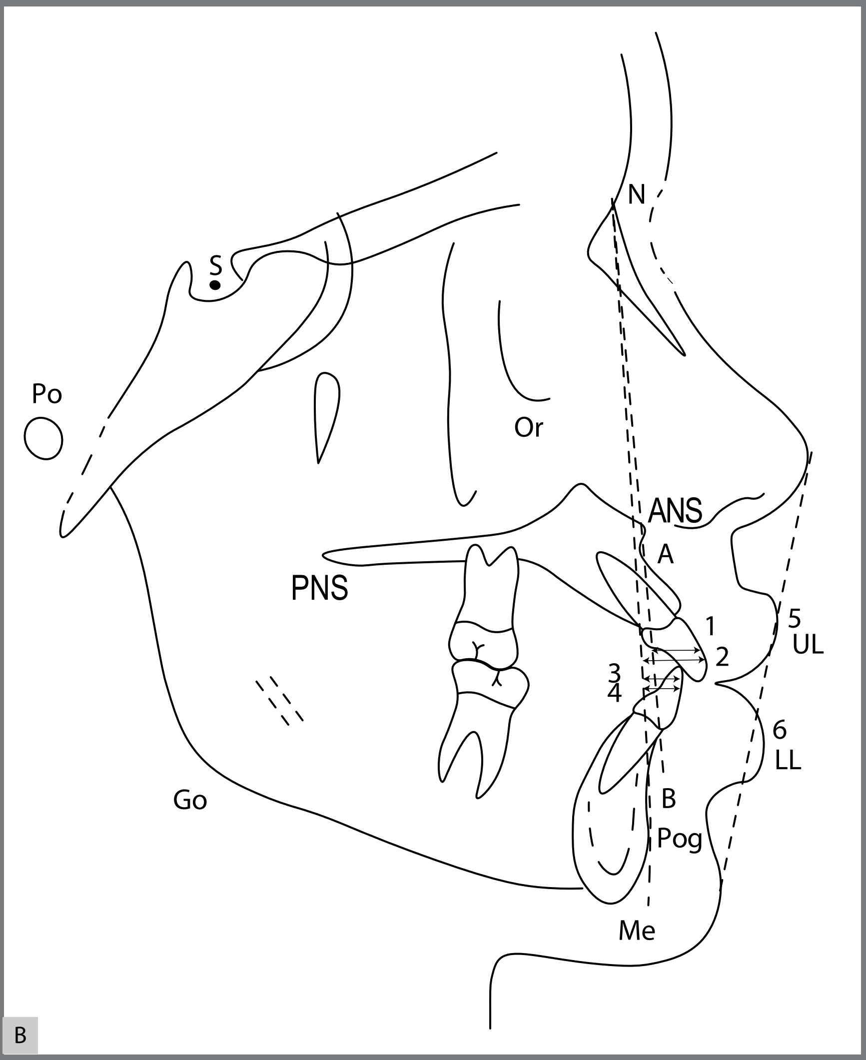


Figure 1: A) Angular measurements used for dental and soft tissue analysis. Reference points: S (Sella); N (Nasion); Po (Porion), Or (Orbitale); ANS (Anterior Nasal Spine); PNS (Posterior Nasal Spine); Pog (Pogonion); Go (Gonion); Me (Menton); A (Point A Subspinale); B (Point B Supramentale). Reference Lines: SN; NA; NB; Frankfort Horizontal Plane (Po-Or); Tweed´s Mandibular Plane (Go-Me); Palatal Plane (ANS-PNS); Upper incisor (U1); Lower incisor (L1); Ricketts´ Esthetic Plane (E). Angular measurements: 1) U1.SN; 2) U1.NA; 3) U1.PP; 4) IMPA; 5) L1.NB; 6) Interincisal Angle (U1.L1); 7) Nasolabial Angle; 8) FMA. **B)** Linear measurements used for dental and soft tissue analysis. Reference points: S (Sella); N (Nasion); Po (Porion), Or (Orbitale); ANS (Anterior Nasal Spine); PNS (Posterior Nasal Spine); Pog (Pogonion); Go (Gonion); Me (Menton); A (Point A Subspinale); B (Point B Supramentale). Reference lines: SN; NA; NB; Frankfort Horizontal Plane (Po-Or); Tweed´s Mandibular Plane (Go-Me); Palatal Plane (ANS-PNS); APog Line; Upper incisor (U1); Lower incisor (L1); Ricketts´ Esthetic Plane (E). Linear measurements: 1) U1-NA; 2) U1-APog; 3) L1-NB; 4) L1-APog; 5) UL-E; 6) LL-E.

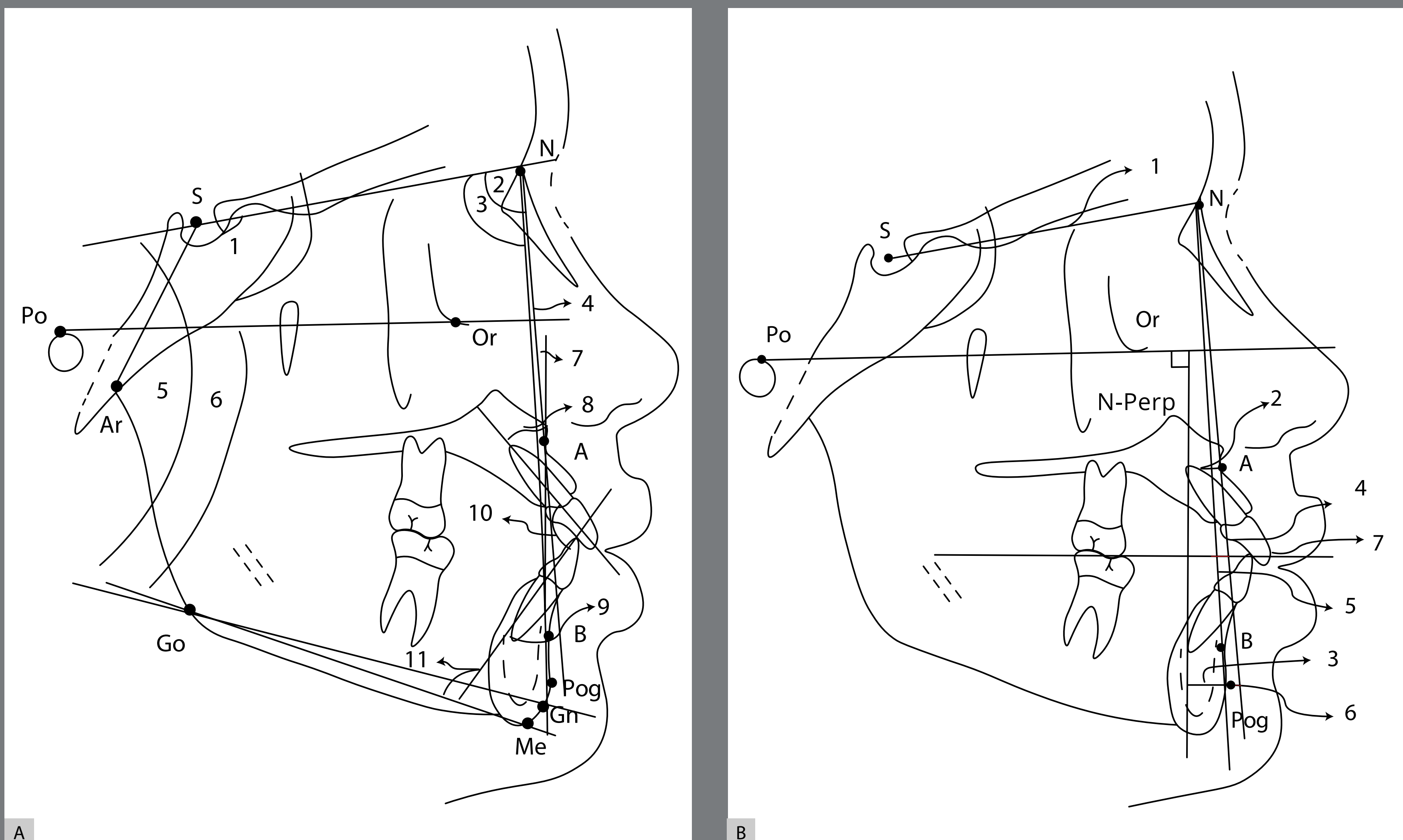


Figure 2: Angular and linear measurements for craniofacial analysis. Reference points: S (Sella); N (Nasion); Ar (Articular), A (Subspinale); B (Supramentale); Go (Gonion); Gn (Gnation); Pog (Pogonion); Or (Orbitale). Reference lines: SN; SAr; NA; NB; APog Line; Frankfort Horizontal Plane (Po-Or); Nperp Line(vertical reference line, i.e., extension of the line perpendicular to the Frankfort Horizontal Plane passing through point N); Occlusal Plane, Upper incisor (U1); Lower incisor (L1); Tweed's Mandibular Plane (Go-Me); Steiner's Mandibular Plane (Go-Gn); Long axis of Upper Incisor; Long axis of Lower Incisor. **A**) Angular measurements for craniofacial analysis: 1) SNAr; 2) SNA; 3) SNB; 4) ANB; 5) SNGoGn; 6) FMA; 7) Angle of Convexity (NAPog); 8) U1.NA; 9) L1.NB; 10) Interincisal Angle; 11) IMPA. **B**) Linear measurements for craniofacial analysis: 1) Cranial Base Length SN Distance; 2) A-Nperp Distance; 3) Pog-Nperp Distance; 4) U1-NA Distance; 5) L1-NB Distance; 6) Pog-NB Distance; 7) AO-BO distance (Wits Projection).

RESULTS

ICC analyses demonstrated excellent rates of reproducibility, with values > 0.9 for all variables.

Considering the dentoalveolar pattern, African-Brazilians presented statistically significant differences compared to Caucasian cephalometric standards ($p < 0.001$). The maxillary and mandibular incisors were significantly more proclined and protruded in African-Brazilians than in European-Americans, as was observed for linear and angular variables in Table 1. Thus, the interincisal angle was more acute (average = 117 ± 7.2º) compared to Steiner´s norm (U1.L1 = 131º). Bimaxillary protrusion was evidenced in African-Brazilians with excellent occlusion (Table 1). Regarding soft tissue profile, the proclination and protrusion of underlying dentoalveolar structures contributed to a significant decrease of the nasolabial angle (89.04 ± 9.33º) and to the projection of upper and lower lips beyond Rickett's esthetic plane (Table 1).

Table 1: Descriptive data analysis and comparisons for angular (degrees) and linear (mm) variables related to dentofacial pattern of African-Brazilians adults, compared to the European-American cephalometric norms defined by Riedel[26] (1952), Tweed[27] (1954), Downs[28] (1956), Ricketts[25] (1960), and Steiner[29] (1960).

Variable	African-Brazilians (adults) (n=43)	European-American Norms	
	Mean ± SD	Mean	t
U1.SN (degrees)	114.45 ± 5.38	104	12.73***
U1.NA (degrees)	25.92 ± 4.51	22	5.70***
U1.PP (degrees)	115.84 ± 5.31	109	8.44***
IMPA (degrees)	99.31 ± 5.82	90	10.49***
L1.NB (degrees)	32.91 ± 5.56	25	9.32***
U1.L1 (degrees)	117.71 ± 7.2	131	-12.08***
U1-NA (mm)	8.20 ± 1.98	4	13.86***
U1-APog (mm)	9.92 ± 2.50	2.7	18.87***
L1-NB (mm)	9.19 ± 2.41	4	14.09***
L1-APog (mm)	7.15 ± 2.37	1	16.98***
FMA (degrees)	25.58 ± 4.36	25	0.873
Nasolabial angle (degrees)	89.04 ± 9.33	102	-9.09***
UL-E (mm)	1.26 ± 2.71	-7	19.94***
LL-E (mm)	4.23 ± 2.75	-2	14.80***

Values are expressed in degrees or mm, mean ± standard deviation (SD). Student's *t*-test for independent samples between groups. ***$p < 0.001$.

African-Brazilians' subjects showed lower cranial base angle (SNAr = 119.87 ± 5.66º) and anterior cranial base length (SN-distance = 68.63 ± 4.50 mm) ($p < 0.001$). The maxilla (SNA = 88.51 ± 3.23º) and the mandible (SNB = 85.06 ± 3.24º) were protruded in relation to the SN line ($p < 0.001$). Regarding the Ricketts' Nperp line, the protrusion of the maxilla was less evidenced (A-Nperp = 1.19 ± 2.79 mm) ($p < 0.01$), with no significantly difference for the mandible (Pog-Nperp = -3.33 ± 5.32 mm) when compared to the European-American standard (Table 2).

Table 2: Descriptive data analysis and comparisons for angular (degrees) and linear (mm) variables related to craniofacial pattern of African-Brazilians' subjects, compared to the European-American cephalometric standards.

Variable	African-Brazilians (adults) (n=43)	European-American Norms	
	Mean ± SD	Mean	t
SNAr (degrees)	119.87 ± 5.66	124	-4.7 ***
SN-distance (mm)	68.63 ± 4.50	77.3	-12.62***
SNA (degrees)	88.51 ± 3.23	82	13.18***
A-Nperp (mm)	1.19 ± 2.79	0	2,80**
SNB (degrees)	85.06 ± 3.24	80	10.23***
Pog-Nperp (mm)	-3.33 ± 5.32	-4	0.81NS
Pog-NB (mm)	0.45 ± 1.57	4	-14.73***
ANB (degrees)	3.46 ± 1.70	2	5.62***
Angle of Convexity (degrees)	6.12 ± 4.08	0	9.83***
Wits Projection (mm)	0.10 ± 2.27	-1	3.19**
SN-GoGn (degrees)	26.47 ± 4.72	32	-7,65***
FMA (degrees)	25.58 ± 4.51	25	0.87 NS
U1.NA (degrees)	25.92 ± 4.51	22	5.70***
U1-NA (mm)	8.20 ± 1.98	4	13.86***
L1.NB (degrees)	32.91 ± 5.56	25	9.13***
L1-NB (mm)	9.19 ± 2.41	4	14.09***
IMPA (degrees)	99.31 ± 5.82	90	10.49***
U1.L1 (degrees)	117.71 ± 7.21	131	-12.08***

Values are expressed in degrees or mm, mean ± standard deviation (SD). Student´s *t*-test for independent samples between groups. $p \geq 0.05$ non-significant (NS). * significant at $p < 0.05$; ** significant at $p < 0.01$; *** significant at $p < 0.001$.

Sexual dimorphism was significant for L1.NB (degrees) ($p < 0.01$), and interincisal angle (U1.L1) ($p < 0.05$). The larger proclination of mandibular incisors in women (L1.NB = 35.91 ± 6.02º) contributed to an even more acute interincisal angle, giving females a more characteristic aspect of bimaxillary protrusion in relation to males (Table 3). The anterior cranial base was significantly shorter in females (SN-distance = 64.94 ± 2.60 mm) ($p < 0.001$). Females showed a greater protrusion of the skeletal bases, when compared to the Nperp line for the maxilla (A-Nperp = 2.82 ± 2.38 *mm*) ($p < 0.01$) and mandible (Pog-Nperp = -0.64 ± 3.17 mm) ($p < 0.05$) (Table 4).

Table 3: Descriptive data analysis and comparisons for angular (degrees) and linear (mm) variables related to dentofacial pattern for both genders of African-Brazilian young adults.

Variable	Male (n=28)	Female (n=15)	t	P
	Mean ± SD	Mean ± SD		
U1.SN (degrees)	114.12 ± 5.07	111.04 ± 6.05	-0.529	NS
U1.NA (degrees)	26.06 ± 3.96	25.66 ± 5.54	-0.279	NS
U1.PP (degrees)	115.30 ± 4.57	116.86 ± 6.53	-0.919	NS
IMPA (degrees)	98.16 ± 5.36	101.47 ± 6.21	-1.82	NS
L1.NB (degrees)	31.30 ± 4.66	35.91 ± 6.02	-2.78	**
U1.L1 (degrees)	119.41 ± 6.54	114.52 ± 7.52	2.21	*
U1-NA (mm)	8.25 ± 2.06	8.10 ± 1.88	0.239	NS
U1-APog (mm)	9.81 ± 2.65	10.12 ± 2.28	-0.377	NS
L1-NB (mm)	9.06 ± 2.10	9.42 ± 2.98	-0.460	NS
L1-APog (mm)	7.00 ± 2.28	7.45 ± 2.60	-0.591	NS
FMA (degrees)	25.97 ± 4.61	24.84 ± 3.90	0.811	NS
Nasolabial angle (degrees)	87.40 ± 9.64	92.10 ± 8.17	-1.60	NS
UL-E (mm)	1.13 ± 2.81	1.49 ± 2.60	-0.553	NS
LL-E (mm)	4.06 ± 2.69	4.55 ± 2.94	0.407	NS

Values are expressed in degrees or mm, mean ± standard deviation (SD). Student´s t-test for independent samples between groups. NS, not significant. ** P < 0.01; * P < 0.05.

Table 4: Descriptive data analysis and comparisons for angular (degrees) and linear (mm) variables regarding craniofacial pattern for both genders of African-Brazilian young adults.

Variable	Male (n=28)	Female (n=15)	P
	Mean ± SD	Mean ± SD	
SNAr angle (degrees)	119.13 ± 6.25	121.24 ± 4.21	0.252 NS
SN-distance (mm)	70.61 ± 4.04	64.94 ± 2.60	0.000***
SNA (degrees)	88.05 ± 3.36	89.37 ± 2.89	0.207 NS
A-Nperp (mm)	0.32 ± 2.63	2.82 ± 2.38	0.004**
SNB (degrees)	84.84 ± 3.59	85.46 ± 2.53	0.554NS
Pog-Nperp (mm)	-4.78 ± 5.71	-0.64 ± 3.17	0.013*
Pog-NB (mm)	0.63 ± 1.74	0.11 ± 1.18	0.310 NS
ANB (degrees)	3.22 ± 1.52	3.91 ± 7.34	0.208 NS
Angle of Convexity (degrees)	5.47 ± 3.83	7.34 ± 4.39	0.157 NS
Wits Projection (mm)	0.23 ± 2.46	-0.12 ± 1.94	0.625 NS
SN-GoGn (degrees)	26.27 ± 4.86	26.83 ± 4.60	0.719 NS
FMA (degrees)	25.97 ± 4.61	24.84 ± 3.90	0.422 NS
U1.NA (degrees)	26.06 ± 3.96	25.66 ± 5.54	0.781 NS
U1-NA (mm)	8.25 ± 2.06	8.10 ± 1.88	0.812 NS
L1.NB (degrees)	31.30 ± 4.66	35.91 ± 6.02	0.008**
L1-NB (mm)	9.06 ± 2.10	9.42 ± 2.98	0.648 NS
IMPA (degrees)	98.16 ± 5.36	101.47 ± 6.2	0.075 NS
U1.L1 (degrees)	119.41 ± 6.54	114.52 ± 7.52	0.032*

Values are expressed in degrees or mm, mean ± standard deviation (SD). Student´s t-test for independent samples between groups. P ≥0.05 - non-significant (NS). * significant at P <0.05; ** significant at P <0.01; *** significant at P <0.001.

DISCUSSION

There is vast literature[2-18,20-22] of scientific articles proposing cephalometric norms for Caucasian and non-Caucasian ethnic groups. To our knowledge, this may be considered the first cephalometric study to include bimaxillary prevalence in young adult African descendants with excellent occlusion in southeastern Brazil. Other research previously established craniofacial cephalometric norms for adolescent African-Brazilians.[21,22]

The inclusion criteria chosen in the present study for this group of African-Brazilians selected from active duty military personnel included: black ancestry up to the third generation, lack of previous orthodontic treatment, southeastern origin, and age ranging from 18 to 30 years. The predominance of males (n=28) over females (n=15) reflect the prevalence rate found in the Brazilian Navy, where subjects were selected. Such restrictive inclusion criteria when applied to populations with high miscegenation tend to limit significantly sample sizes. Nevertheless, there are recent literature reports using groups of similar sizes.[13,21,22]

African-Brazilians with excellent occlusion showed lower cranial base angle (SNAr) and shorter cranial base (SN distance), when compared to the Caucasian standard (Table 2). The results for the cranial base length are in agreement with previous investigations,[4,5,8] which also revealed that the melanodermas' cranial base is significantly smaller in relation to the leucodermas. This feature confers a posterior position to the Nasion point (N), influencing all measures related to the Sela (S) point or the SN line. The lower angulation of the middle cranial fossa, however, contradicts the findings of Enlow[30] (1982), which associates a high obtuse SNAr angle with the greater forward and downward displacement of the posterior cranial base, making the middle cranial fossa less angulated and flatter, causing the mandibular branch to rotate back and down. This feature could contribute to shift the mandible to a retrognathic position, thus being the predominant pattern in Class I blacks. The present study found lower values for the cranial base deflection angle (SNAr = 119.87 ± 5.66º) for the Brazilian Afro-descendants and it would be associated with the horizontal facial growth pattern and greater mandibular prognathism. These findings indicated the morphological heterogeneity of Brazilian melanoderma and reinforce the need for specific cephalometric norms for ethnic groups from different regions.

Regarding the maxilla and mandible, the African-Brazilians presented maxillary and mandibular bases significantly more protruded than the Caucasian standard (Table 2). Similar results were found in previous studies that evaluated other melanoderma populations.[12,13,15] High values for SNA and SNB are expected when the cranial base is significantly decreased.[5,6] The maxillary protrusion was confirmed with the A-Nperp distance, however, in a less expressive way, when it was compared to the SNA angle. On the other hand, the mandibular prognathism was not significant when considered Pog-Nperp variable.

The present results showed highly significant differences between African-Brazilians and the European-American standards on all variables (linear and angular) ($p < 0.001$) related to the dentoalveolar pattern (Table 1). When compared to Caucasians, African-Brazilians have significantly more proclined and protruded maxillary and mandibular incisors over the respective basal bone, and consequently more acute interincisal angles. These results support the findings of previous investigations[12,13,15,17,18,22] on African-descent populations, which found that bimaxillary protrusion resulted from more labial positioning of maxillary and mandibular incisors. However, other studies found excessive protrusion and proclination only of lower incisors.[10,20]

Sexual dimorphism was not observed in most of the analyzed variables, except for angular measurements L1.NB and U1.L1, which support the findings of previous studies[9,11,13] that established the high proclination of lower incisors as the main contributor to more acute interincisal angles in females, including in other ethnic groups (Table 3). This difference was statistically significant between genders in the present study and suggests that, among African-Brazilians, women have a greater tendency to present more pronounced bimaxillary protrusion than men.

Soft tissue profile analysis revealed that Brazilians of African descent have a significantly diminished nasolabial angle, and a larger bilabial projection into Ricketts' Esthetic Plane when compared to European-American standards (Table 1). This confirms the larger projection of soft tissue as a result of dentoalveolar protrusion found on southeastern African-Brazilians with excellent occlusion, as opposed to African populations previously described in the literature.[12,17,18,20,22] These characteristics provided a bilabial protrusion and subsequent soft tissue profile convexity to the group considered in the present research.

In the present study, there was no statistical difference ($p > 0.001$) comparing African-Brazilians and Caucasians, with regard to divergence of the Frankfort Mandibular Plane (FMA). The mean value found for this sample (25.68 ± 4.36º) is within the norm proposed by Tweed (FMA = 25º), which indicates that the pronounced incisor projection is not related to discrepancies in anterior facial height or clockwise mandibular rotations. It can be suggested the association to the more anterior positioning of the maxilla with respect to the cranial base. There are some differences between the vertical growth pattern presented in this study, and what was found in the literature regarding African or African-American groups. Many studies found more obtuse values for Frankfort Mandibular Plane angle (FMA) in African[11,12,15] and African-American[16,17] subjects when compared to Caucasians. However, there are records of hypodivergence, horizontal facial growth pattern and low values of Frankfort Mandibular Plane angle (FMA) in African[13] and African-Brazilian[22] populations. This emphasizes the importance of determining specific cephalometric standards for each ethnic group according to its geographic origin.

The limitation found in this study was the possible magnification difference of the devices used to obtain the radiographic images between this research and the studies used as European standard. However, these same standard studies are used in the orthodontist's routine. Besides that, it would be interesting to compare this African-Brazilian group to another African standards and with a control group of white southeastern Brazilians.

CONCLUSIONS

African-Brazilian young adults presented differences regarding dental and craniofacial characteristics when compared to European-American norms.

European-American cephalometric norms do not apply to these individuals and therefore should not be used as references to orthodontic treatment planning for this specific ethnic group, in which a bimaxillary protrusion is more acceptable than for the Caucasian population.

African-Brazilian women revealed larger lower incisor proclination and smaller interincisal angles compared to men.

AUTHORS CONTRIBUTIONS

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Tomographic analysis of midpalatal suture prior to rapid maxillary expansion

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ABSTRACT

Introduction: In Orthodontics and Facial Orthopedics, the timing of treatment onset may be critical and individual analysis should be applied to promote a favorable treatment planning. In this study, individual analysis of midpalatal suture (MS) and palatal measurements were performed in teenagers and young adult patients treated with rapid maxillary expansion (RME).

Description: Twenty-six patients submitted to RME with a tooth-supported appliance (Hyrax) were evaluated. The inclusion criteria were: minimum age of 14 years, presenting all posterior teeth, diagnosed with transverse maxillary discrepancy, and with a clinical indication for maxillary expansion. The pretreatment CBCT scans of these patients were assessed to obtain the stages of MS maturation (MSM); density ratio (MSD); and palatal length, thickness (anterior, intermediate and posterior) and sagittal area.

Results: The maturation stages present were C, D or E; the density ranged from 0.6 to 1, and lower density ($MSD < 0.75$) and higher density ($MSD \geq 0.75$) groups were determined. Individuals with higher MSD presented smaller sagittal area, compared to the lower density group. Individuals in D and E MSM stages presented smaller sagittal area and intermediate thickness, compared to stage C.

Conclusions: Smaller palatal sagittal area was observed in the high MSD groups and in the stages D and E of MSM.

Keywords: Palatal expansion technique. Imaging, three-dimensional. Cone-beam computed tomography.

RESUMO

Introdução: Em Ortodontia e Ortopedia Facial, o momento de início do tratamento pode ser crítico, e uma análise individual deve ser aplicada para promover um planejamento de tratamento favorável. No presente estudo, foram realizadas a avaliação individualizada da sutura palatina mediana (SPM) e medições no palato de adolescentes e adultos jovens tratados com expansão rápida da maxila (ERM).

Descrição: Foram avaliados vinte e seis pacientes submetidos à ERM com aparelho dentossuportado (Hyrax). Os critérios de inclusão foram: idade mínima de 14 anos, apresentando todos os dentes posteriores, diagnosticado com discrepância transversa da maxila e com uma indicação clínica para expansão maxilar. A tomografia computadorizada de feixe cônico (TCFC) pré-tratamento desses pacientes foi avaliada para obter os estágios de maturação da SPM (MSPM), densidade da SPM (DSPM), comprimento do palato, espessura (anterior, intermediária e posterior) e área sagital.

Resultados: Os estágios de maturação presentes foram C, D ou E; a densidade variou de 0,6 a 1, e foram determinados grupos de baixa (DSPM < 0,75) e alta densidade (DSPM ≥ 0,75). Indivíduos com maior DSPM apresentaram menor área sagital, em comparação com o grupo de densidade mais baixa. Indivíduos nos estágios D e E de MSPM apresentaram menor área sagital e espessura intermediária, comparados aos indivíduos no estágio C.

Conclusão: Uma menor área sagital palatina foi observada nos grupos de alta DSPM e nos estágios D e E de MSPM.

Palavras-chave: Técnica de expansão palatal. Imagem tridimensional. Tomografia computadorizada de feixe cônico.

INTRODUCTION

The ideal moment for orthodontic treatment varies according to each patient's malocclusion. Transverse discrepancies should be treated as soon as possible,[11] since the timing of treatment onset may be critical when treatment is implemented too late.[2]

In rapid maxillary expansion (RME), the skeletal effect is expected to be greater than the dental one; therefore, the maxillary arch width increase must be achieved by opening the midpalatal suture (MS), and not by the inclination of posterior teeth.[3,4] However, the resistance of the suture to opening increases as suture fusion advances, which makes the RME controversial in young adults.[4,5]

The ossification of the MS occurs from the posterior to the anterior region;[6] and is not directly related to chronological age.[7,8] There is a consensus that RME in patients up to 14 years of age is predictable, but individual variations in MS fusion process must be analyzed based on the definition of its maturation stage (MSM)[7,9] and density (MSD).[10] Suture images can be obtained from cone beam computed tomography (CBCT), and that approach has been increasingly used in orthodontics.[11]

A recent study[12] suggested that patients older than 15 years of age have a positive prognosis for RME when the MS is at an intermediate stage of maturation, although the efficacy of the MSM analysis is not conclusive to predict the magnitude of expected changes.[13]

Therefore, the purpose of the present study was to assess whether palatal baseline measurements differ in teenagers and young adult patients submitted to RME, according to their MS density ratio and maturation stage. The null hypothesis was that there is no difference.

MATERIAL AND METHODS

The protocol of this research was approved by the Research Ethics Committee of the Federal University of Rio de Janeiro (UFRJ, protocol #68388017.5.0000.5257).

In a previous pilot study, the area of the palate was evaluated in the sagittal section of the images of ten patients randomly chosen. The mean and standard deviation of the areas found were calculated. A sample size calculation was performed, considering a test power of 80%, $\alpha = 0.05$ and a difference to be detected of 45 mm^2, and a total of thirteen patients were required in each group.

Inclusion criteria were: patients with a minimum age of 14 years, presenting all posterior teeth, diagnosed with transverse maxillary discrepancy, and who had a clinical indication for maxillary expansion. Patients were recruited for RME with a tooth-supported appliance (Hyrax), and obtained MS opening after the active phase. Two orthodontists treated the study patients in a private clinic. The Hyrax was activated twice a day. Patients were followed up weekly until clinical observation of molar transverse relation overcorrection. The clinical favorable accomplishment of RME was confirmed by the presence of the interincisal diastema (Fig 1).[3] The device was maintained for retention, and patients were subsequently treated with fixed orthodontic appliances.

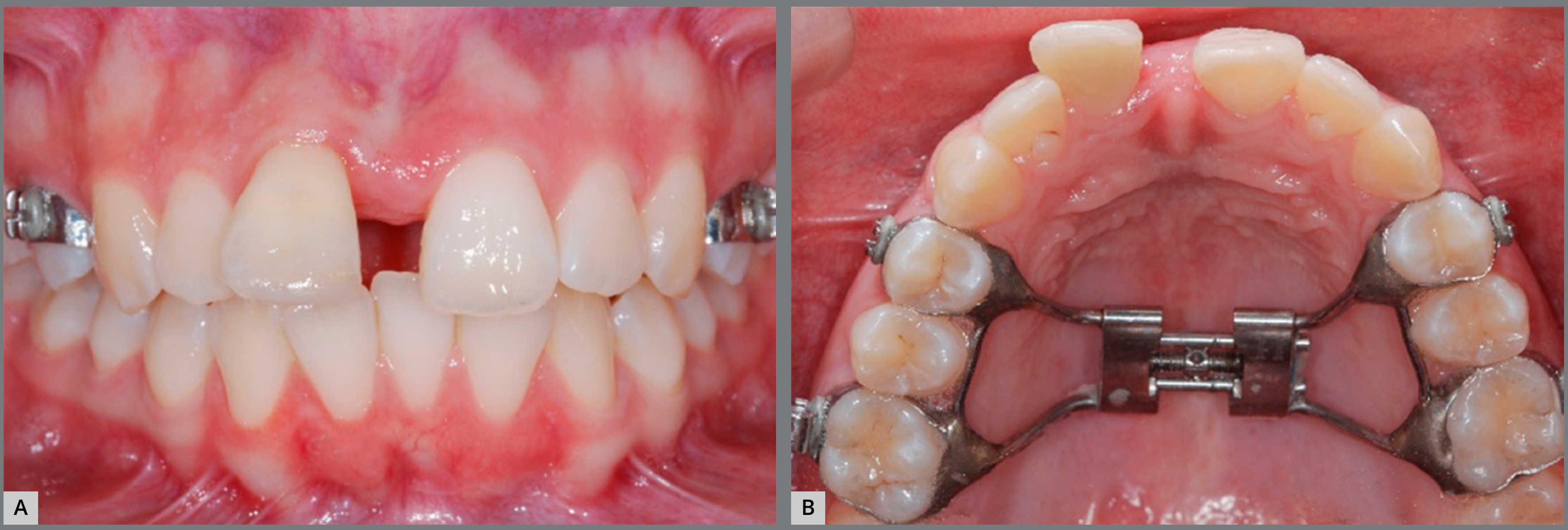

Figure 1: Interincisor diastema after RME with Hyrax. **A**) Frontal view; **B**) Occlusal view.

CBCT scans were obtained with an i-CAT tomography scanner (Imaging Sciences International, Hatfield, PA, USA) before the RME. On the images, the MS was evaluated with respect to the density ratio (MSD), maturation stage (MSM), and measurements of palatal length, thickness, and sagittal area. Data from the CBCT with extended field of view were exported in DICOM format to Invivo Dental 5.1 (Anatomage, San Jose, CA, USA) and Dolphin 3D imaging (Dolphin Imaging Systems, Chatsworth, CA, USA) softwares.

The evaluation of MSD was performed in the InVivo software, based on the methodology described by Grunheid, Larson and Larson.[10] The images were oriented; then, the density values of the regions of interest were obtained (Fig 2). For the determination of the posterior border of the central rectangle in MS, the largest diameter of the crown of the first molars was used as reference and, in cases of asymmetry, tooth #16 was used as reference (Fig 3). The region of the suture and the palatine process were determined in the central axial slice of the hard palate. The inferior axial slice of the hard palate was used to set the soft palate rectangle by moving the axial line in the sagittal slice to the lower limit of the hard palate. Then the rectangle was positioned in the center of the soft palate in the axial slice (Fig 4). The mean values of the density in each region were used to calculate MSD according to the equation below:[10]

$$MSD = \frac{\text{Density}_{\text{suture}} - \text{Density}_{\text{soft palate}}}{\text{Density}_{\text{palatal process}} - \text{Density}_{\text{soft palate}}}$$

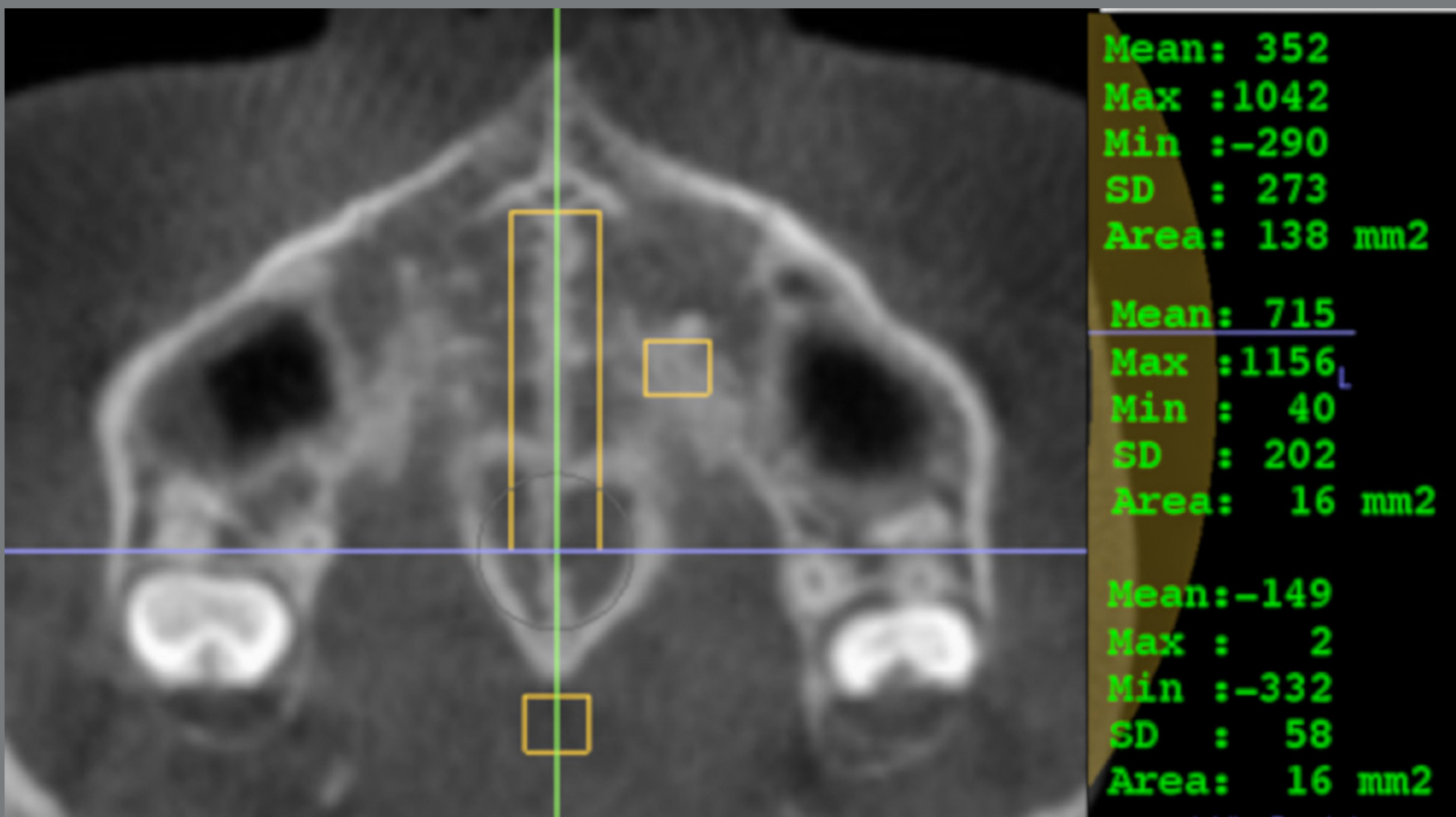

Figure 2: Regions used to determine MSD. The gray density of the palatal process and the soft palate was determined in a 4x4-mm area; the gray density of the suture was determined in a 6 mm-wide rectangle.

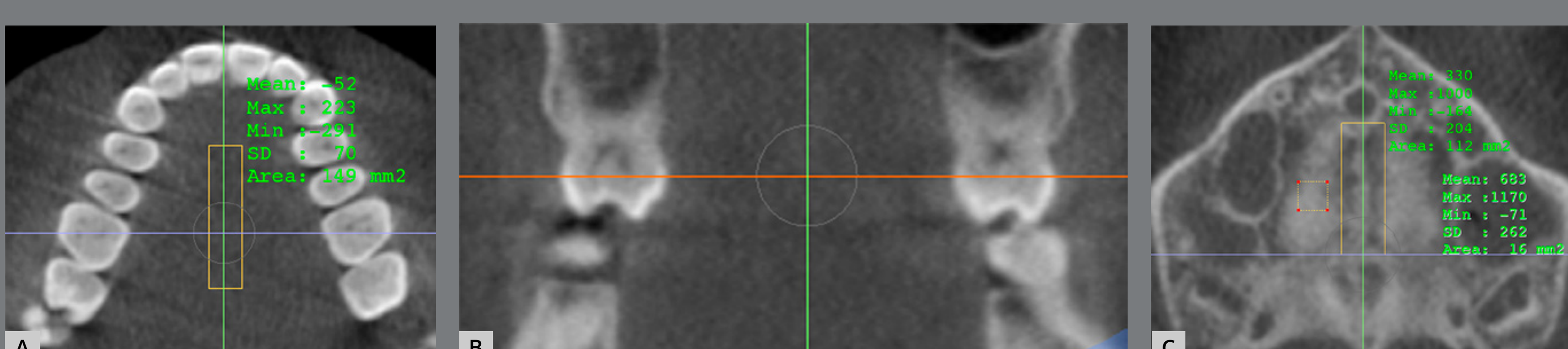

Figure 3: Determining the posterior limit of the rectangle of the suture. **A, B)** The largest diameter of the crown of tooth #16 in axial (purple line) and coronal (orange line) slices; **C)** The posterior border of the central rectangle in MS (purple line).

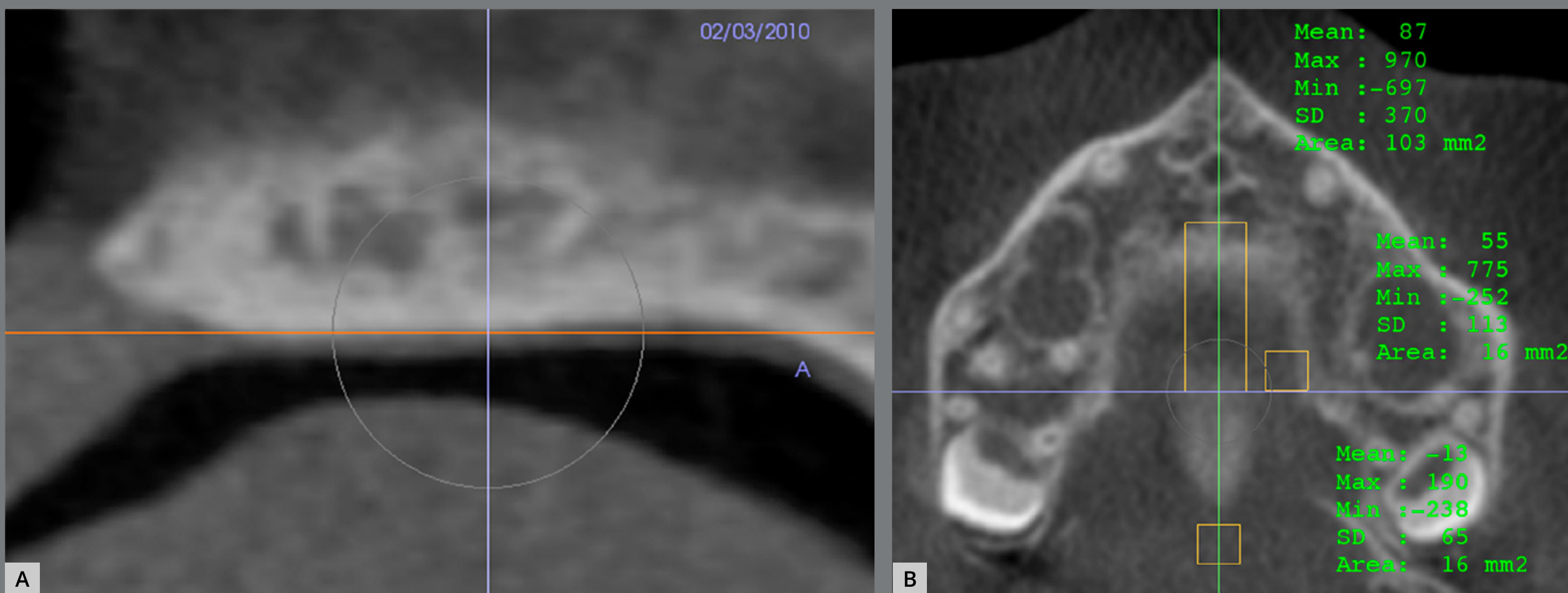

Figure 4: Density in the soft palate. **A)** Axial slice (orange line) positioned in the inferior limit of palate; **B)** 4 x 4-mm square in the center of soft palate.

The MSD ratio can range from 0 to 1, with lower values indicating less calcification, and higher values indicating greater calcification.

After this assessment, patients were divided in groups of MSM stages (C, D and E) and in groups of lower density (MSD < 0.75) and higher density (MSD ≥ 0.75).

Evaluation of the MSM stage was performed in the axial slices of the pre-treatment scans using InVivo. Head positioning and slice acquisition were performed according to the steps described by Angelieri et al.[7] These images were then organized in Microsoft Office – Power Point (2007; Microsoft, Redmond, Washington), with a black background, numbered, and with no identifying information such as name or age. Two observers, who were experienced in the evaluation of tomographic images and MSM analysis, classified each patient's suture into stages A, B, C, D, or E.[7]

The assessment of the length, thickness, and sagittal area of the palate was performed on the sagittal slice corresponding to the midsagittal plane of the scans, using Dolphin software. The images were oriented according to the palatal plane based on the orientation described in the methods above.[7,10] Natural head position in all three planes of space (axial, sagittal and coronal) was obtained and, in the sagittal view, the patient's head was positioned so that the anteroposterior long axis of the palate was parallel to the horizontal plane. The point posterior to the incisive foramen (PF) and the posterior nasal spine (PNS) were selected in the axial slice and checked in the other slices (Fig 5). The measurements were performed in the sagittal slice. Palatal length was determined by the horizontal distance between PF and PNS. The sagittal area was determined; and the thickness measurements were performed with the limits of the edges of the palate area (Fig 6). The anterior thickness intersected the PF point, the intermediate intercepted half the length of the palate, and the posterior one was located 5 mm anterior to the PNS.

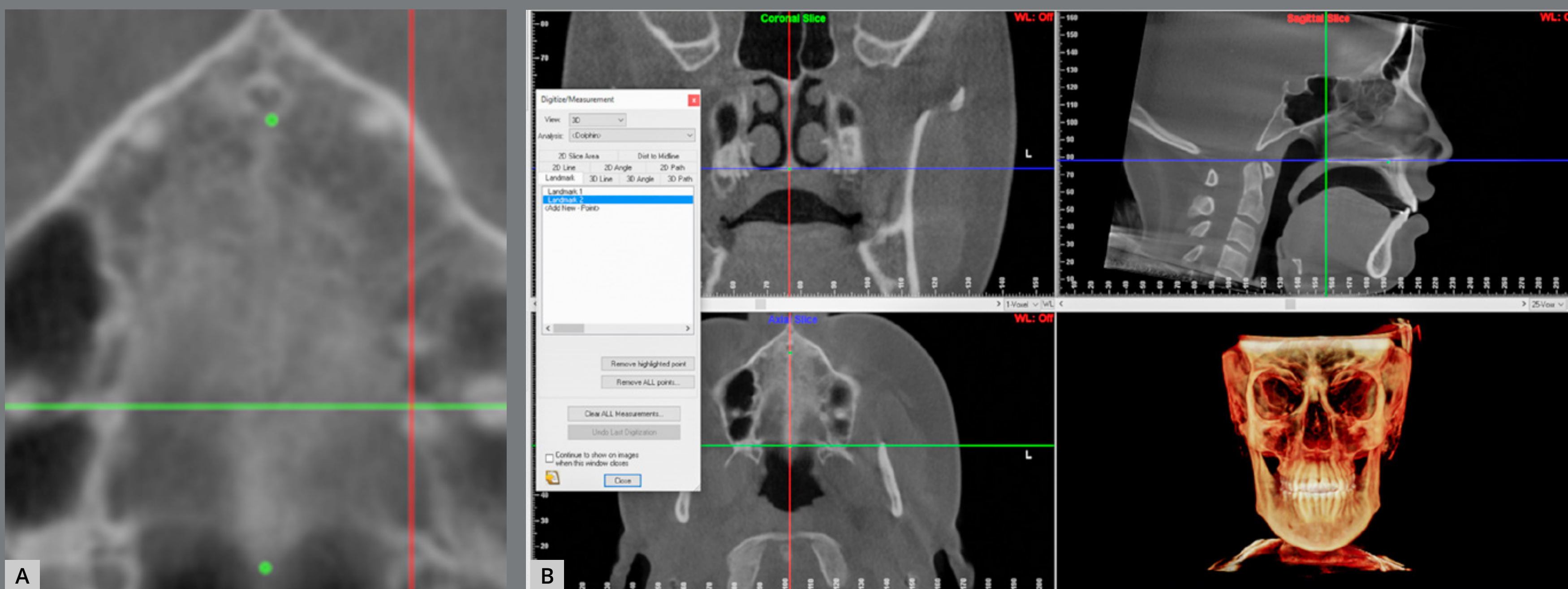

Figure 5: Points PNS and PF: **A)** selected in axial slice; **B)** confirmed in a sequence of slices.

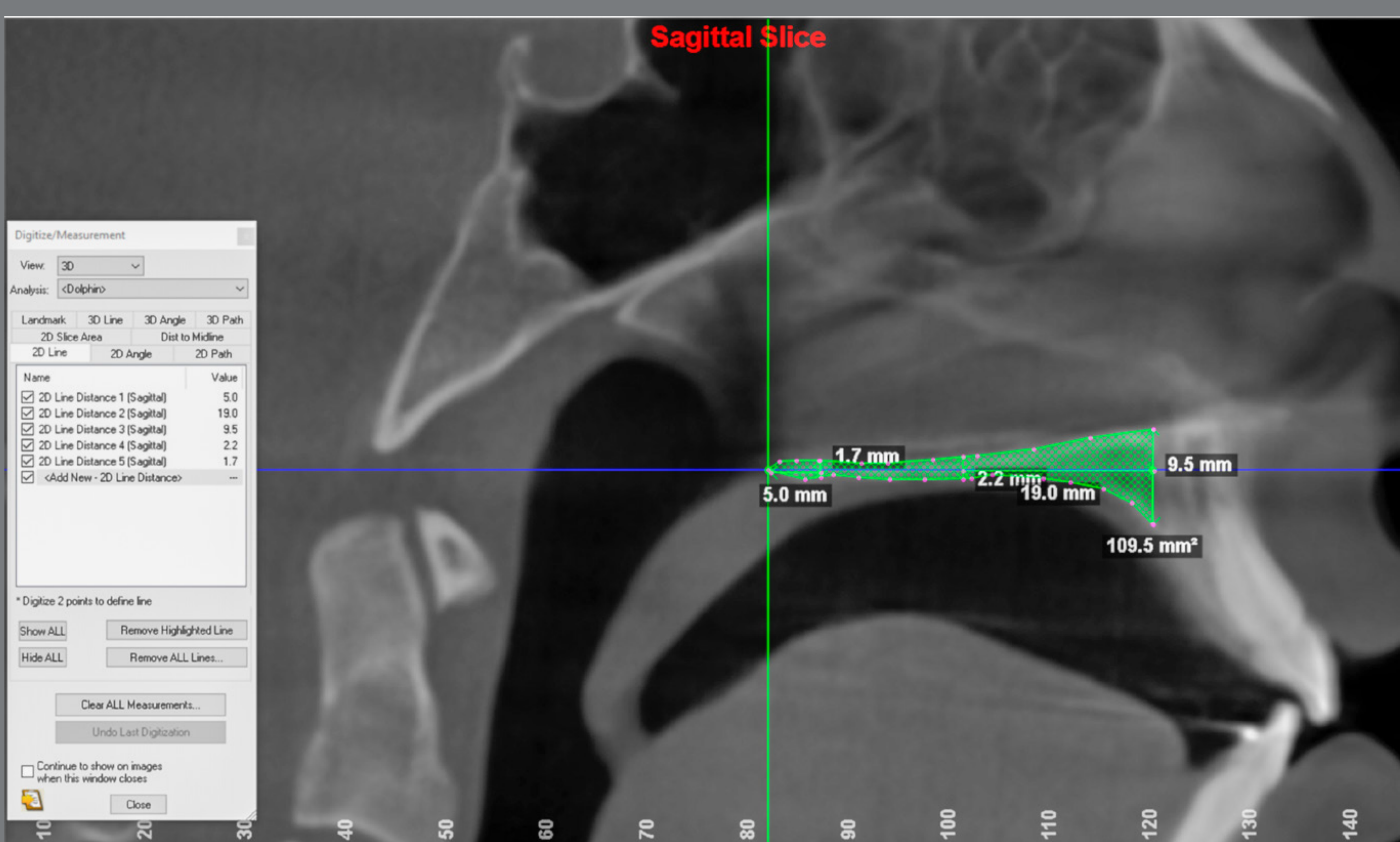

Figure 6: Palate measurements: length (19.0 mm), thickness (9.5 mm anterior; 2.2 mm intermediate; 1.7 mm posterior) and area (109.5 mm²).

A single operator performed the linear and area measurements of the palate, and the density measurements. After repeating all measurements after a two-week interval, the calibration of the operator was tested with the intraclass correlation coefficient (ICC). Categorical variables were described quantitatively and by percentage of individuals in each category (stages of maturation and sex). Descriptive statistics of continuous variables (age and density) were provided. Normality of the data was tested with the Shapiro-Wilk test. The chi-square and Fischer's exact test were used to compare differences in MSM and sex distribution; for comparison of age and MSD, the ANOVA with Tukey post-test was used between MSM groups, and the independent *t* test, between density groups.

RESULTS

Twenty-six patients were included in the sample (6 males and 20 females). Patients' age ranged from 14 to 28 years (mean of 16.42 years), and only the C, D, and E stages of MSM were represented. With respect to MSD, the patients were divided into two groups of 13 patients each, and characterized according to low or high density. The operator was calibrated (ICC ranged from 0.836 to 0.985). The linear and area measurements obtained from the sample were normally distributed.

When divided into two groups according to density, a significant difference was observed in relation to MSM stages ($p = 0.003$) and MSD ($p < 0.001$) (Table 1).

Regarding the different stages of MSM (Table 2), MSD and patients' age were significantly different ($p < 0.05$). MSD increased progressively from stages C to E, with fusion of the suture. Age decreased with progressing stages of MSM.

Table 1: Sample characteristics, with patients divided into two groups, according to the midpalatal density ratio (MSM stages distribution; gender distribution; age, and density mean and standard deviation, SD) and *p*-value (significance) of chi-square test for differences in distribution, and independent *t* test for differences in mean.

MSM stage	Lower density (n=13)		Higher density (n=13)		Significance
	n	%	n	%	
C	4	30.8	1	7.7	0.003*
D	9	69.2	4	30.8	
E	0	0	8	61.5	
Sex					
Male	5	38.5	1	7.7	0.063
Female	8	61.5	12	92.3	
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	
Age	17.38 (2.53)	14-23	15.46 (3.86)	14-28	0.147
Density ratio	0.60 (0.07)	0.47-0.72	0.82 (0.06)	0.75-1.0	<0.001**

* $p < 0.01$; ** $p < 0.001$.

Table 2: Sample characteristics, with patients divided in MSM stages (gender distribution; age and density mean and standard deviation, SD) and *p*-value (significance) of Fisher's exact test for differences in distribution, and ANOVA for differences in mean.

	Stage C (n=5)		Stage D (n=13)		Stage E (n=8)		Significance
	n	%	n	%	n	%	
Male	2	40	4	30.8	0	0	0.162
Female	3	60	9	69.2	8	100	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	
Age	19.4 (5.07)	16-28	16.38 (2.87)	14-23	14.62 (1.06)	14-17	0.036*
Density	0.62 (0.12)	0.50-0.84	0.67 (0.10)	0.47-0.83	0.83 (0.08)	0.75-1.0	0.002**

*$p < 0.05$; **$p < 0.01$.

The length of the palate was not significantly different between the MSM and MSD groups ($p > 0.05$) (Tables 3 and 4). With respect to thickness, there was a statistically significant difference ($p < 0.05$) in the intermediate and posterior regions of the palate at the different stages, with the more advanced stages (D and E) tending to be thinner, which may indicate that the disjunction occurs in stages D and E when the patient has a smaller palate thickness (Table 3). The area presented statistically significant difference for the different MSM ($p = 0.01$) and MSD groups ($p < 0.05$) (Tables 3 and 4). Since length was not significant and the areas observed in stages D and E were smaller, thickness of the palate may have an important influence (except in the anterior region).

Table 3: Mean and standard deviation (SD) of palate measurements for each midpalatal suture maturation group (according to the stages), and *p*-value (significance) of ANOVA and Tukey's *post-hoc* test applied for intergroup differences.

	Stage C (n=5)		Stage D (n=13)		Stage E (n=8)		Significance
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	
Length (mm)	34.82 (1.53)	32.20-36.00	35.72 (2.14)	31.50-39.90	34.33 (2.21)	31.10-37.10	0.328
Thickness (mm)							
anterior	9.84 (2.01)	7.90-13.20	9.73 (2.21)	5.00-12.70	8.43 (2.54)	4.60-13.00	0.406
intermediate	6.02 (2.23)^{A}	3.70-9.60	3.40 (1.07)^{B}	1.60-5.30	3.32 (0.90)^{B}	2.10-4.80	0.002**
posterior	4.60 (1.91)^{A}	3.10-7.90	2.68 (0.67)^{B}	1.70-4.50	3.18 (1.22)^{AB}	1.90-5.60	0.016*
Area (mm²)	196.30 (54.66)^{A}	147.10-284.10	140.23 (34.42)^{B}	94.10-217.50	124.42 (33.11)^{B}	82.70-187.70	0.01*

A,B different superscript letters means statistically significant difference in the same line; $*p< 0.05$; $**p < 0.01$.

Table 4: Mean and standard deviation (SD) of palate measurements for each midpalatal suture density group and p-value (significance) of independent *t* test applied for intergroup differences.

	Lower density (n=13)		Higher density (n=13)		Significance
	Mean (SD)	Range	Mean (SD)	Range	
Length (mm)	35.57 (2.18)	31.50-39.90	34.66 (1.97)	31.10-37.10	0.277
Thickness (mm)					
anterior	10.19 (1.84)	7.40-13.20	8.52 (2.43)	4.60-13.00	0.061
intermediate	4.49 (1.81)	2.50-9.60	3.26 (1.23)	1.60-6.20	0.056
posterior	3.41 (1.60)	1.70-7.90	3.00 (0.99)	1.90-5.60	0.435
Area (mm²)	166.72 (45.38)	118.50-284.10	125.57 (35.28)	82.70-201.30	0.016*

$*p < 0.05$.

DISCUSSION

RME is the most frequently chosen treatment in cases of maxillary atresia, with well-established benefits in growing patients.[1] Late skeletal growth of the patient is proportional with less strength to promote opening of the MS, compared to individuals with earlier growth.[3,14] Some methods have been proposed to individually assess patients and predict response to RME, based on analysis of maturation stages[9] and density ratio of MS.[10] However, information from a recently published systematic review indicates that evidence is still weak.[15]

The developmental stages of the MS have been defined histologically and divided into infantile, juvenile, and adolescent periods; in the third stage, MS separation is not possible without fracture occurring in the areas of interdigitation.[17] Angelieri et al.[7] consider the sutures in stages D and E to have fused partially or completely, and surgically-assisted rapid palatal expansion (SARPE) could then be considered.[9,12] Tomographic studies of MSD have provided information about resistance to RME,[18] and changes in MS before and after RME.[19,20] The results indicate that a lower suture density is directly related to a clinical favorable accomplishment of the expansion.[10,18,20]

In the present sample, it was verified that participants' mean age was significantly different among MSM stages, similarly to a previous study.[21] Additionally, in a published study[22] with 16 to 20-year-old participants, MSM stages C, D and E were the most often observed, similar to the present sample. Angelieri et al.[23] reported that chronological age could also be considered a viable alternative to predict suture maturation. In the present study, the mean age decreased with progressing stages of MSM, indicating that RME may probably be better accomplished in older patients if they are still in earlier stages of fusion. With respect to the two MSD groups defined in this study (low and high density), no significant difference was found for age, which is similar to previous studies.[10,18]

The sample in this study was predominantly female, and no significant difference was found regarding patient sex in different MSM or MSD groups, although the composition of the high-density and the last maturation stage groups were more than 90% and 100% female, respectively. The same was observed in other studies, where 77.2% of the patients in the more advanced MSM stages were female,[12] 100% of the patients in stage E were female,[7] or the percentage of female, separated by age (16-20 years), in stage E was higher than for male.[22]

The MSD was significantly different between MSM stages, increasing from stage C to E. This indicates that the more advanced maturation stages present a higher-density suture. When the suture is not calcified, it is similar to the gray levels at the density of the soft palate. As progression of suture closure advances, some bony spicules begin to appear, and calcified and non-calcified areas are visible. As a consequence, the density increases, which means that the gray levels in the suture are approaching that of the palatine process (cortical bone), until there is fusion of the suture.[10]

A significant difference between average MSM was observed when the patients were divided in groups of high and low MSD. In the low-density group, all individuals were in stages C and D; while in the high-density group, more than 60% of the patients were in stage E. Patients older than 13 years in stages A, B, or C of MSM may have favorable prognosis for RME,[9,12] despite that in stage C the skeletal response is lower than in the previous stages. Nevertheless, other authors[10] reported the correlation between MSM and clinical skeletal measures after RME as negative and not significant, and they considered that density better predicted the response to RME.

The thickness of the palate might interfere in the response to RME, and thinner palates probably have less resistance to the forces of the treatment.[12] In the present study, palate thickness was smaller in individuals who were in the final stages of MSM and in the high density group. These findings suggest that RME may present better prognosis in individuals in the final stages of MSM if the palate is thinner. The significant results found in the palate area using the sagittal slice for measurement were probably due to thickness differences, which corroborates the idea that thickness must be considered in the diagnosis, in addition to the maturation stages and/or density of MS. These variables (MSM, MSD and palatal measurements) can help the orthodontist decide about trying RME or indicating SARPE. Therefore, MSM stages A, B or C, and/or with low suture density values would indicate RME; and thin palates could indicate trying RME even in older patients in MSM stages D or E, and/or with high density values. SARPE would be recommended in patients in MSM stages D or E with high density values and thick palates. However, these findings should be confirmed in RCTs.

Patients' division in groups of MSM stages was more informative than division in groups of density when the length, thickness and the area of the palate were evaluated, at least in the present sample, even though there were fewer patients in each stage. Differences in age were observed, which shows that the MSM stages allow better defined classification of the characteristics of palate and range of age, whereas differences in groups of MSD were not so marked. Nonetheless, density might be a predictor of RME outcomes; however, if groups are divided by density, characteristics of palate and the age of patients may not be so well defined, since there may be significant individual changes in the MSD.

The present findings and other recently published articles[9,12] about individual analysis of MSM showed that the CBCT can be used in cases of maxillary atresia with RME questionable prognosis. The evaluation of MSM stages, density, and thickness of palate provides valuable information in patients older than 14 years of age. The radiation dose must be as low as reasonably achievable (ALARA principle); therefore, CBCT with reduced field of view should be requested, which can reduce the radiation dose to the patient and present important information to treatment planning.[10,24,25]

It is important to mention that, in addition to midpalatal suture, other structures — such as internasal, maxillonasal, frontomaxillary, frontonasal, zygomaticomaxillary, zygomaticotemporal, and zygomaticofrontal sutures and spheno-occipital synchondrosis — can be affected by RME, and may also be used in pre-expansion analysis, in order to determine the best treatment for each patient.[26-28]

The clinical relevance of this study is that, although midpalatal suture opening during orthodontic treatment with rapid maxillary expansion is frequent and may reach 12 to 52 percent of the total screw expansion,[29] failures may occur and, although SARPE has proven long-term stability,[30] it is also a rather invasive procedure.

One of the limitations of the present study was its retrospective nature. Ideally, the study should be conducted as a randomized clinical trial with patients treated by the same orthodontist. The absence of an occlusal radiograph or CBCT after the RME is another limitation of present study, because these exams could have provided information about the proportion of skeletal and dental results. Further studies are necessary to corroborate the present findings.

CONCLUSIONS

In 14-year old or older patients submitted to rapid maxillary expansion with a clinical favorable accomplishment, smaller sagittal area was observed in patients with high midpalatal suture density or suture maturation in stages showing partial or complete fusion. A tomographic individual analysis of midpalatal suture characteristics is recommended in older adolescents and young adults, to consider the possibility of conservative and less invasive treatment.

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The correlation between external apical root resorption and electric pulp test responses: a prospective clinical trial

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ABSTRACT

Objective: The current study investigated the correlation between pulpal sensitivity to the electric pulp tester (EPT) and external apical root resorption (EARR) in four types of maxillary anterior teeth of fixed orthodontic treatment patients.

Methods: In this prospective cohort study, 232 anterior teeth of 58 patients (mean age 18.96 ± 6.13 years) treated with fixed orthodontic treatment were examined. The EPT readings were recorded at twelve time points immediately before archwire insertion. Root resorption of four maxillary incisors were measured by means of parallel periapical radiographs at three time intervals (six months interval from the start) through design-to-purpose software to optimize data collection. A multiple linear regression model and Pearson correlation coefficient were used to assess the association of EPT values and observed EARR ($p < 0.05$).

Results: The highest level of EPT measurement was recorded at initial visit, and then there was a decreasing trend in EPT level during treatment for the next six and twelve months. There was another increasing trend after six months till the finishing time of the treatment. There was a significant correlation between changes in root length and time of recording the root length ($p < 0.001$). There was significant positive correlation between changes in EPT level and amount of observed root resorption ($p < 0.001$).

Conclusion: The relative decrease in electric pulp test level could be a diagnostic sign of root resorption during orthodontic treatment. Further studies with longer follow up are needed to confirm the current results.

Keywords: Root resorption. External apical root resorption. Electric pulp test. Orthodontic treatment.

RESUMO

Objetivo: O presente estudo investigou a correlação entre a sensibilidade pulpar ao teste pulpar elétrico (TPE) e a reabsorção radicular apical externa (RRAE) nos quatro dentes anteriores superiores de pacientes em tratamento ortodôntico com aparelho fixo. **Métodos:** Nesse estudo de coorte prospectivo, foram avaliados 232 dentes anteriores de 58 pacientes (idade média 18,96 ± 6,13 anos) tratados com aparelho ortodôntico fixo. As leituras do TPE foram registradas em doze tempos de avaliação, imediatamente antes da inserção dos arcos. As reabsorções radiculares dos quatro incisivos superiores foram aferidas por meio da média das radiografias periapicais, em três intervalos de tempo (em intervalos de seis meses desde o início) por um *software* desenvolvido para essa finalidade, com o intuito de otimizar a coleta de dados. Para aferir a associação entre os valores de TPE e as RRAE observadas ($p < 0,05$), foram utilizados o modelo de regressão linear múltiplo e o coeficiente de correlação de Pearson. **Resultados:** O nível mais alto das medidas do TPE foi registrado na primeira visita e, daí em diante, houve uma tendência de diminuição no nível do TPE durante o tratamento, nos seis a doze meses seguintes. Houve, também, outra tendência de aumento após os seis meses até o término do tratamento, além de uma correlação significativa entre as mudanças no comprimento radicular e o tempo de registro do comprimento radicular ($p < 0,001$), bem como uma correlação positiva significativa entre as mudanças no nível do TPE e a quantidade de reabsorção radicular observada ($p < 0,001$). **Conclusão:** Uma diminuição relativa no nível de sensibilidade ao teste pulpar elétrico pode ser um sinal diagnóstico de reabsorção radicular durante o tratamento ortodôntico. Estudos futuros com acompanhamentos mais longos são necessários para confirmar os presentes resultados.

Palavras-chave: Reabsorção radicular. Reabsorção radicular apical externa. Teste pulpar elétrico. Tratamento ortodôntico.

INTRODUCTION

External apical root resorption (EARR) occurring in permanent teeth during comprehensive orthodontic therapy is a common iatrogenic phenomenon.[1] Histologically, orthodontically induced external apical root resorption has been reported to occur with an incidence greater than 90%. However, the radiographic incidence is lower, at approximately 48-66%.[2] The underlying causes of this unwanted process can be divided into two broad categories, biological and mechanical aspects.[2] Mechanical factors include orthodontic treatment-related risk factors, such as treatment duration, magnitude of applied force, direction of tooth movement, amount of apical displacement, and method of force application.[3] The maxillary incisors are the teeth most affected by root resorption, followed by the mandibular incisors and first molars. EARR occurs in different degrees of severity. Severe EARR is defined as a shortening greater than 4 mm or one-third of the root length, and is observed in 1-5% of teeth.[3]

3D imaging (CBCT) has shown to be radiographically valid and reliable in the assessment and diagnosis of EARR. However, considering the potential radiation risks of 3D imaging, the most common diagnostic strategies for root resorption remains 2D conventional images, as panoramic and periapical radiographs, and lateral cephalometries.[4] Panoramic and lateral cephalometries have been proposed to be more applicable for measurement of EARR, considering their significant advantages of less radiation exposure, visualization of the complete dentition, less time-consuming for the operator, and more patient-friendly, compared to very recent micro-CT three-dimensional methods.[5] However, they are still considered to be less accurate than periapical films, and overestimate the EARR by 20% the amount of root loss.[6,7] Furthermore, periapical films are prone to magnification errors. According to the recent study by Pereira et al,[8] this magnification error may be overcome by using the percentage of root/tooth variation, instead of direct measurement of root resorption. Recent advances in the digital image processing and artificial intelligence techniques have made it possible for the computer-assisted superimpositions to be done more accurately, and have increased their clinical applicability. If any root resorption is diagnosed, an inactive phase of 4 to 6 months before the resumption of orthodontic treatment is currently advocated.[5] Unfortunately, early detection of this condition could not be accomplished before six months from the beginning of resorption.[9]

To date, many studies have evaluated the effect of orthodontic forces on the dentin-pulp complex.[10,11] Different pulp tests have been used in the diagnosis of pulp status.[12] Electrical pulp test is a simple, noninvasive test that can be used as a sensitivity test for detection of pulp status.[13] Several studies investigated the correlation between the health of pulpal tissue and the presence of external apical root resorption, with or without orthodontic treatment. Available literature on predisposing higher chance of external apical root resorption in teeth with history of trauma demonstrated the possibility of cause and effect relationship between pulpal tissue and EARR. Therefore, there may be a relationship between electric pulp test (EPT) response of pulp condition and early diagnosis of root resorption. The purpose of the present study was to determine the correlation between orthodontically-induced external apical root resorption and electrical pulp test response of anterior teeth during fixed orthodontic treatment.

MATERIAL AND METHODS

SAMPLES AND SAMPLE SIZE CALCULATION

In this prospective non-controlled cohort study, 58 patients (42% male; age range 12-35 years; mean age 18.96 ± 6.13 years) who were referred to the orthodontic department of School of Dentistry, Shahid Beheshti University of Medical Sciences, were selected using random-cluster sampling method. Sample size was determined to be equal to 50 patients (200 anterior teeth sample size) considering $\alpha = 0.05$, $\beta = 0.20$ (power equal to 0.80) and $r = 0.2$ (low effect size), using sample size calculation software v. 3.0.43. Considering the possibility of dropouts to be 20% during the study, we enrolled 58 patients with 232 anterior teeth.

Inclusion and exclusion criteria

Eligible patients were defined as a minimum of 12 years of age at treatment onset, and treated with multibonded Roth appliances with 0.022 × 0.028-in brackets (3M, Unitek, Monrovia, CA, USA), using the following archwires sequence: 0.016-in round NiTi, 0.016-in round stainless steel, and 0.017 x 0.025-in stainless steel (American Orthodontics, Sheboygan, WI, USA).

The exclusion criteria were the presence of congenital, systemic or concomitantly diagnosed serious medical conditions, allergy, asthma, familial dysostosis and also history of dental trauma before or during the study, history of lingered pain to thermal stimuli, open apex, any medication, history of previous root resorption, extraction treatment regimen (crowding greater than 7mm in any arch) and also presence of parafunctional habit. Those whose radiographs lacked visibility of maxillary incisors, those with significantly distorted radiographs, crowding of teeth (greater than 7mm in any arch), unclear roots and those with unilaterally and bilaterally lateral missing teeth in the maxilla were also excluded. Those patients who missed to attend their regular monthly follow up or diagnosed with other treatment plans like removable appliances or orthognathic surgery were also excluded from the study. Healthy periodontium (probing depths not exceeding 3 mm, no bone loss as determined by radiographs) and dentition (no carious lesions, no endodontically treated maxillary incisors and closed apex) were necessary to enroll in this study.

All the related demographic data of the patients were recorded. Written informed consent was obtained from the patients and parents for the entire process of the study, including EPT evaluations. The study protocol was based on the ethical principles governing medical research and human subjects in Helsinki Declaration (2013 version, http://www.wma.net/en/30publications/10policies) and also approved by the Research Ethics Committee of Research Institute of Dental Sciences, Shahid Beheshti University of Medical Sciences (ID #3509).

Examination of periapical radiographs

The original periapical radiographs of all three groups were obtained with the same digital X-ray unit (KODAK 2100 Intraoral X-Ray, at the same distance and using the same exposure settings: 60 kvp, at 7 mA, 0.2 s). All radiographs were exported and saved in JPEG format using the Digora® software, v. 2.8. The digital radiographs were then visualized and analyzed using Photoshop CS (Adobe Systems Inc., San Jose, CA, USA). A magnification of up to 150% was applied when necessary. All the periapical radiographs were taken in natural head positions, and the examiners used the scanned version of the radiographs.

Root resorption assessment

All parallel periapical radiographs were taken with the same device in six months' time intervals (at the treatment onset and every six months till the first year). To assess the amount of root resorption in the maxillary incisors for each subject, all radiographs were scored by an examiner trained for point registration and blinded to EPT values. In order to measure the distances, a proprietary tool was developed on MATLAB's image processing toolbox (MATLAB 7.14 2012a, Mathworks Inc, MA, USA). Using this tool, the operator marked three points including root apex, mesial and distal crown edges at the level of cementoenamel junction (CEJ) on the target tooth in both pretreatment and post-treatment X-rays. A perpendicular line was drawn from the apex to the middle of a line passing from mesial to distal points. The incisal midpoint was defined by the intersection of this perpendicular line on incisal edge of each tooth (Fig 1). The root resorption was then calculated automatically by the software, based on the formulation presented by Pereira et al.[8]

Figure 1: Evaluation of EARR: **A)** Point selection on an incisor, at the treatment onset; **B)** Point selection on the same tooth, at the end of fixed orthodontic treatment.

To standardize the parallel periapical radiographs, a correction factor was calculated based on the assumption that the crown length had to remain unchanged. Therefore, the ratio C_1/C_2 (pre-treatment crown length [C_1]/post-treatment crown length [C_2]) could determine the inconsistency between crown lengths of the two X-rays, and was used to compensate for the enlargement factor. Apical root resorption was then calculated as follows:

$$CF = C_1/C_2, \quad (1)$$

$$CR_2 = R_2 \times CF, \quad (2)$$

$$\text{Root resorption} = 1 - (CR_2/R_1), \quad (3)$$

Where CF is the correction factor, C_1 and R_1 are the crown length and root length in pretreatment X-rays, while R_2 and CR_2 are root length and corrected root length in post-treatment X-rays, respectively. The point marking process was done on an enlarged version of the X-ray, to help reduce the error. Furthermore, the operator repeated the markings five times on each pair of X-rays, recorded the software output after each marking, and used the averaged value as the final root resorption.

Electric Pulp Test (EPT)

Electrical stimulation was provided by the digital electrical pulp tester (Parkell, Farmingdale, NY, USA; 0-80) with toothpaste (Oral B laboratories, Aylesbury, Bucks, England) used as the conduction medium. Examination procedures were performed by the same operator and same EPT unit at each time point. The test of electrical stimuli was applied to the experimental maxillary central and lateral incisors.

To prevent any temperature change and false responses, patients were asked to not eat or drink ten minutes before each visit. After removal of orthodontic archwires, every tooth was isolated with cotton rolls and dried thoroughly before EPT evaluation. The testing site was confined to sound enamel on the midpoint incisal edge of each tooth. This is necessary in order to avoid the orthodontic brackets, and to minimize the risk of false-positive responses elicited by inadvertent stimulation of the periodontal nerve fibers, or stimulation of adjacent teeth. The probe did not touch any orthodontic bands or brackets. Testing of each tooth started upon contact of the smallest electrode tip with voltage 1 on the tooth surface, and terminates when the subjects raised their hands to show feeling of the first sensation (heat or tingling). The EPT has an analog display, providing a score from 01 to 64, correspondent to the stimuli applied. To minimize the procedural errors, a double determination method was used. During testing, current flow was increased slowly from the initial zero current state, by adjusting the variable voltage control. Testing was repeated after a three-minute interval, to reduce subjective fatigue and to minimize the possibility of nerve accommodation.

The numerical values on the EPT display were recorded at twelve treatment points. The initial EPT levels were recorded exactly before starting the treatment. The EPT scores were also recorded each month immediately before insertion of the new archwire. Teeth that fail to respond to electric testing were recorded as a reading of 0 EPT units. The following clinical and radiologic criteria were used to define pulp necrosis: loss of pulpal sensitivity, gray color changes in the crown, and periapical radiolucency. Loss of pulpal sensitivity and at least one other clinical or radiologic sign were considered necessary before the diagnosis was made.

Statistical analysis

All data were statistically analyzed by SPSS v. 18.0 software (SPSS Inc., USA). To avoid inter-observer error, all the measurements were done by the same operator. In this prospective cohort study, descriptive statistics (including the mean and standard deviations for the EPT response) in experimental group were measured in twelve different time intervals. The observed root resorption were measured by means of periapical radiographs at three time intervals. After all radiographs were assessed, a random subset of ten radiographs was re-examined after fourteen days, to estimate the methodological error by means of percentage of absolute intra-observer agreement (the agreement was 0.81). The EPT values were expressed as mean ± SD. The generalized estimating equation (GEE) with unstructured coefficient and linear equation were used to determine the associations between apical root resorption (EARR) and EPT values status, presented as continuous variables.

RESULTS

DESCRIPTIVE DATA

Root length alterations

The radiographs of 58 patients (42% male; age range 12 to 35 years; mean age 18.96 ± 6.13 years) participants were evaluated. Two of the samples were excluded and replaced because of unclear periapical radiographs. Mean and standard deviation of the root length measurement is demonstrated in Table 1. Pairwise comparisons of root length alterations were done within different time points, including initial treatment with sixth month, initial treatment time with twelfth month, and also sixth month with twelfth month measures. The amount of root length alterations in all three comparisons demonstrated statistically significant differences ($p < 0.001$).

Table 1: Mean and standard deviation of root length measurements (mm) at three different time points.

Type of teeth	Time point (months)	Mean	Standard deviation
Central incisor	0	14.58	2.60
	6	13.95	2.56
	12	13.61	2.60
	Total	14.05	2.61
Lateral incisor	0	14.50	2.44
	6	13.88	2.38
	12	13.47	2.37
	Total	13.95	2.43
Total	0	14.54	2.51
	6	13.92	2.47
	12	13.54	2.48
	Total	14.00	2.52

Root length alterations in both central and lateral incisors also followed the similar pattern. Both teeth demonstrated the maximum root length at baseline and the minimum root length after twelve months. According to Figure 2, the maximum rate of decreasing root length was on the first six months and was similar in both central and lateral incisors (Fig 2). However, the rate of root resorption was higher in laterals in the second six months of the study (time interval 6-12 months). Furthermore, there was a significant correlation between length of the treatment time and root resorption ($p < 0.001$). Based on the measurements, there was about 0.1-mm reduction in root length in each month. Additionally, the type of the tooth (central or lateral) did not have significant effect on the amount of root resorption ($p = 0.583$).

EPT levels

EPT changes from T_0 to T_{12} are demonstrated in Table 2 and Figure 3. The recorded EPT levels were significantly reduced at the first six months, compared to baseline ($p = 0.007$). Comparing the twelfth month with baseline, EPT level was also significantly reduced ($p < 0.001$). However, the reduction in the second six months was not significant comparing to the first six months (Fig 3).

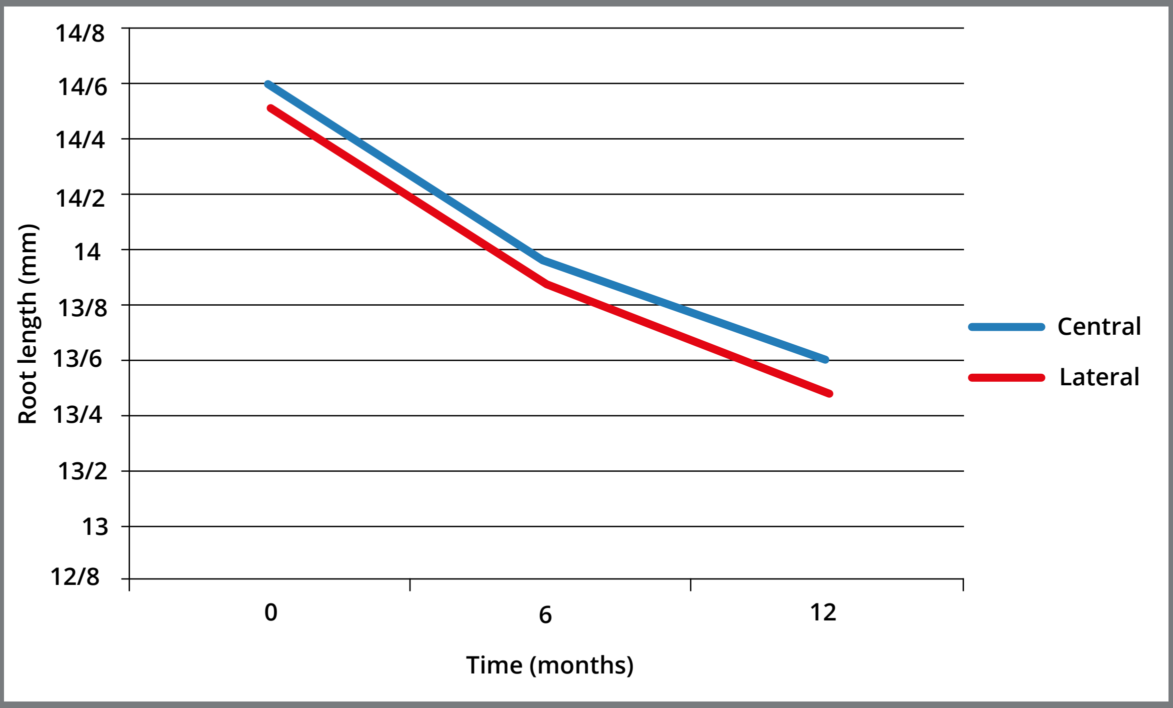

Figure 2: Root length alterations of central and lateral incisors over time.

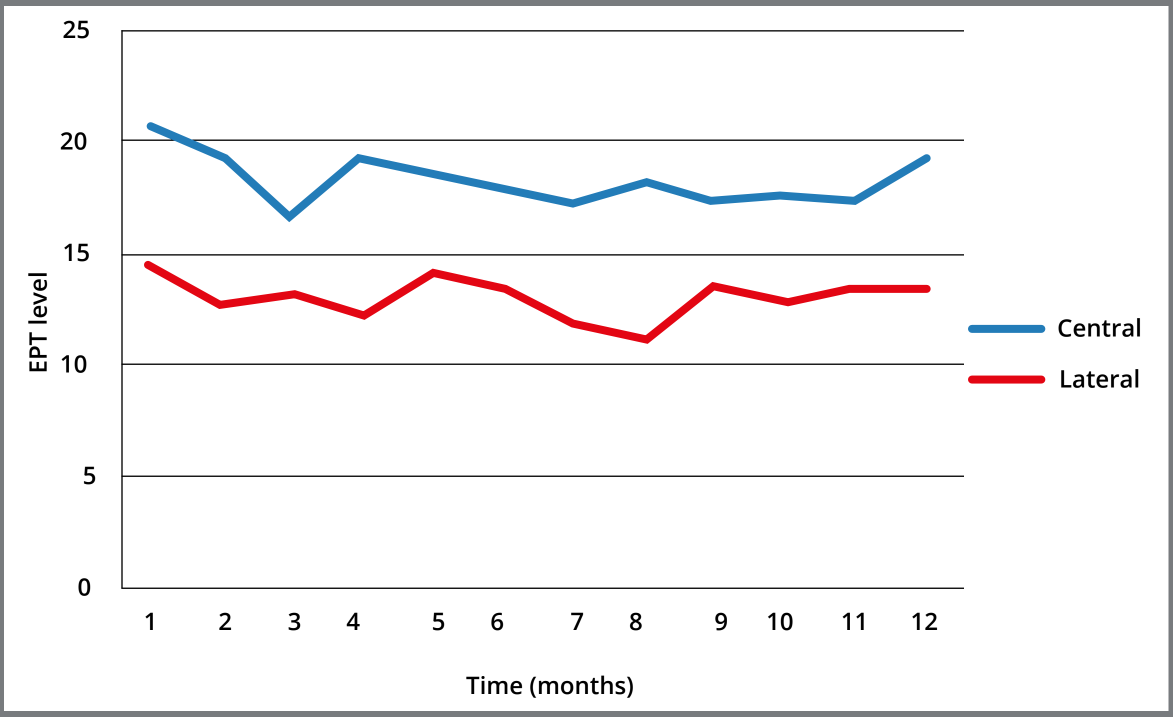

Figure 3: EPT level alterations of central and lateral incisors over time.

Table 2: Mean and standard deviation of EPT measures at twelve different time points.

Type of teeth	Time point (months)	Mean	Standard Deviation
Central	1	14.50	9.97
	2	12.83	9.03
	3	13.35	7.84
	4	12.24	8.16
	5	14.17	11.17
	6	13.54	10.90
	7	11.75	6.77
	8	11.24	6.41
	9	13.51	9.68
	10	12.88	8.83
	11	13.50	8.91
	12	13.45	8.65
	Total	13.08	8.98
Lateral	1	20.68	12.35
	2	19.38	13.23
	3	16.64	9.08
	4	19.42	10.49
	5	18.85	12.56
	6	18.14	11.70
	7	17.12	9.84
	8	18.20	10.92
	9	17.36	10.11
	10	17.65	10.26
	11	17.42	11.24
	12	19.24	10.54
	Total	18.37	11.12
Total	1	17.55	11.61
	6	15.71	11.49
	12	16.22	10.01

The recorded EPT level alterations for central and lateral incisors followed similar pattern. For both type of teeth, the highest levels were recorded in the first visit, and the levels diminished during treatment. Very close to the twelfth month follow up, there was an increasing tendency in the recorded levels. Although the general pattern was the same for both, all the recorded values were significantly smaller in lateral incisors ($p < 0.001$).

Correlation of age with root resorption, and age with EPT response

Age did not demonstrate significant correlation with the amount of observed root resorption ($p = 0.497$). Therefore, the selected age range in this study (mean age 18.96 ± 6.13 years) has no statistically significant effect on root length alterations in time. The correlation of EPT values with age demonstrated a significant statistically reverse correlation ($p > 0.001$). Regarding the findings, with each unit increase in age (one year), the EPT level response decreased about 0.86 unit (Table 3).

Table 3: Correlation between EPT response and tooth length changes.

Variable	Correlation coefficient *B*	Standard error	*p* value
Fixed value of model	14.517	0.5036	0.001
Treatment time	-0.094	0.0084	0.001
EPT	0.016	0.0041	0.001
Type of tooth	-0.028	0.1746	0.872
Age and root resorption	0.022	0.03	0.497
Age and EPT	-0.861	0.1407	0.001

Correlation of EPT response, treatment duration and type of tooth with root resorption

The generalized estimating equation (GEE) with unstructured coefficient and linear equation were used to determine the associations between apical root resorption and EPT values. EPT demonstrated statistically significant correlation with the amount of observed root resorption ($p < 0.001$). The correlation coefficient was 0.016 in regression model (standard error of 0.0041), explaining that with each unit reduction in EPT level, 0.02-mm reduction would be expected in root length (Table 3).

DISCUSSION

External apical root resorption (EARR) is a common adverse outcome of orthodontic tooth movement. This unwanted phenomenon is seen mostly in teeth that underwent heavy orthodontic forces for long period of time. EARR is also seen in teeth with weak periodontal support.[14] Various factors including biological and mechanical elements are responsible for the initiation of EARR and its progress during orthodontic tooth movement.[15,16] The most common teeth to undergo EARR are the maxillary incisors and maxillary and mandibular canines, with the average amount of 0.2 to 2.93 mm. The possible controversy regarding the average amount of EARR between studies is mostly due to difference in sample size, individual patient characteristics, type of the tooth considered for the study, type of orthodontic tooth movement, and the measurement method. Different measurement techniques include lateral cephalometry, panoramic view, bisect and parallel periapical radiographs. Parallel periapical radiographs were used in this study at three time points, including before starting treatment, six months, and twelve months after treatment onset. The advantage of using parallel periapical radiographs is the possibility of using fixed and reproducible landmarks, dramatically reducing the subjectivity of the analysis of the level and degree of resorption. The error level of periapical radiographs is four times less than cephalometry radiographs.[17]

Evaluation of the root length in three different time intervals demonstrated that there was a significant reduction in the root length at both time points, compared to baseline ($p < 0.001$). The root length also was significantly reduced between the sixth and twelfth months of study ($p < 0.001$). As orthodontic tooth movement creates inflammatory responses in bone and periodontium, the release of some inflammatory cytokines, including prostaglandins and leukoterins, will occur and increase the possibility of root resorption.[18] These cytokines increase the vascularity of the regions under orthodontic force. Therefore, pre-osteoclasts and pre-cementoclasts may be created and migrate to the area through the RANK-RANKL pathway. Although osteoclasts and cementoblasts are very similar, cementoclasts are smaller in size and have less number of neuclous.[18] Previous study of Levander et al[19] evaluated the risk of root resorption of maxillary incisors during orthodontic tooth movement. Root resorption of 390 upper incisor teeth was evaluated at four time points, including baseline, six months, nine months after treatment onset, and after debonding, using periapical parallel radiographs. The result of the mentioned study demonstrated high risk of root resorption in 6-9 months after initiating orthodontic treatment.[19] The authors did not report any severe orthodontic root resorption after finishing orthodontic treatment. Another study done by Ravanmehr et al[20] evaluated the amount of external apical root resorption in time periods of baseline, six, and twelve months. The result of the study was in accordance with the present study, demonstrating significant reduction in root length at six and twelve months following orthodontic treatment.

The current study evaluated root length alterations based on the type of teeth (central/lateral). The result of this assessment demonstrated similar pattern of root length reduction in both tooth types. Additionally, the tooth type did not show a significant effect on the amount of observed root resorption ($p = 0.583$).

This result is in contrast with the result reported by Beck et al,[21] that found an increased root resorption in lateral incisors. However, in Beck's study, panoramic radiographs were used instead of periapical radiographs. Krieger et al[22] also did not report any significant difference between the amount of root resorption and tooth type, using panoramic radiographs. The difference in tooth root morphology was not evaluated in any of these studies.

The maximum rate of the root length changes was reported in the first six months period of fixed orthodontic treatment. However, there was no statistically significant difference between central and lateral teeth. The overall rate of root length alteration was reduced in the second six months period, although lateral incisors demonstrated higher rate of root length alteration in this time period (6-12 months). This study reported the overall rate of 0.1-mm root length reduction per month in these teeth. These reports could be clinically significant in orthodontic patients, and help the clinicians to control or reduce the implemented force to prevent further root resorption in such cases.

The effect of orthodontic force on dental pulp is evaluated in various studies in the literature.[23] There is no general consensus regarding the effect of orthodontic forces on dental pulp, and these contradictory results could be due to differences in sample size and type of tested tooth.[13,24] Additionally, evaluation of dental pulp necrosis requires a histopathologic evaluation that is not clinically possible for most cases. Another method is using an electric pulp test (EPT), which is a non-invasive, easy and cost-effective method to evaluate nerve response to orthodontic tooth movement.[24] This method was used to evaluate the status of pulps in this study. The descriptive results on the changes of EPT values demonstrated a significant reduction in EPT values from baseline to sixth and twelfth months. However, the EPT values did not show any significant change between six to twelve months periods of time. In another study, Hall et al [25] evaluated the alteration in EPT values from the baseline, immediately after starting, and at four and eight weeks after treatment. EPT values and temperature testing (cold/hot) were used to evaluate the effect of orthodontic forces.[25] Based on the reported results, the EPT values were reduced in time, which was in accordance with the result of the current study. In the reported study, the ratio of no response to EPT compared to temperature responses was higher.[25] Han et al[10] evaluated the effect of orthodontic forces on EPT responses before, immediately after bonding, and also eight weeks after starting the orthodontic force. They reported an immediate increase in EPT levels response following orthodontic force.[10] This result is in contrast to the present study, in which reduced EPT level responses were observed. This difference could be due to reduced sample size and shorter periods of follow up. However, the sensitivity of teeth to thermal and EPT was reduced after eight weeks, which is in accordance with the result of previous studies and also the current study.[26]

For Han et al,[10] the maximum level of reported EPT levels were at the eighth week. However, the maximum level of EPT was immediately before bonding in the present study. This difference could be attributed to different follow up intervals and the type of tested teeth. Modaresi et al[13] evaluated the effect of orthodontic forces on tooth responses to electric pulp test during 1-month time interval. They reported a significant increase in EPT response threshold immediately after orthodontic loading in maxillary incisors. The EPT responses level decreased after one month of starting orthodontic tooth movement. Two studies also evaluated the effect of orthodontic force on EPT response in nine months, and their finding was the gradual decrease in EPT level in time[10,27] which is in accordance with the result of the current study. However, the follow up time interval was less than the currently tested.

The mechanism underlying these changes includes the alteration in vascularity following orthodontic tooth movement and consequently the presence of transient hypoxia in dental pulp tissue.[28] This hypoxia could affect $A\delta$ and $A\beta$ nerve fibers and therefore the pulp response to EPT would change.[13] Alteration in EPT levels demonstrated similar patterns in both central and lateral teeth. The lowest levels of EPT responses were recorded at the third and eighth months for laterals and centrals incisors, respectively. Regarding previous studies, it seems that the response of different teeth to EPT depends on the type of the teeth. As lateral incisors are subjected to longer and heavier forces during orthodontic treatment, they demonstrated the maximum effect of orthodontic forces. Lateral incisors also are reported to have the maximum amount of root resorption during orthodontic treatment.[29] Different hypotheses include canine guidance theory, high frequency of crown size and shape malformation, and consequently higher manipulation with orthodontists, high frequency of root shape anomalies like dilacerated and pointed roots, and also smaller root surface area had been mentioned in the literature for this observation.[30] This study was the first clinical study evaluating the association between EPT responses and root resorption in maxillary incisors. According to the results of the study, for each unit reduction in EPT, a response of 0.02-mm reduction in root length is expected. The clinical application of this study is that without any evidence-based risk factor of root resorption, clinicians could use EPT records as diagnostic tool, to prevent severe root resorption before being evident in panoramic radiographs.

Further studies with larger sample size and follow up until conclusion of orthodontic treatment are needed to confirm the current results. As EPT only provides information on the status of pulpal nerves, and does not directly determine the vitality (vascularity) of pulp, it is also suggested to repeat the study with vascular measurement techniques, instead of nerve response measurement, which could be a more valid measure to be attributed to root resorption sequel in teeth undergoing orthodontic tooth movement.[28] Additionally, considering that the EPT evaluation is non-invasive cost effective pulp evaluation, subgroup analysis also is recommended in future studies in case of having large pool of samples based on the presence of various risk factors of root resorption, degree of perceived pain, different morphology of root, different teeth, different treatment regimens (extraction *versus* non extraction). Finally, having access to CBCT radiographs, with significant reduced exposure dosage, would change the ideal measurement tool of EARR in orthodontics.

CONCLUSION

1. Root resorption was observed in all three-time intervals, and demonstrated a constant increase during twelve-months follow up.

2. The highest level of EPT response was at the first visit and then reduced over time, with slight increase in last months.

3. There was no significant association between type of tooth and observed root resorption, however the association between EPT level change and root resorption was significant.

4. The association between root resorption and EPT levels demonstrated that for each unit reduction in EPT level, a 0.02-mm root resorption was observed.

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Final approval of the article:
FY, MBa, KD, AS, SS, SKN, MBe, AE.

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BBO'S SELECTED ARTICLE

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Skeletal posterior crossbite in patient with mandibular asymmetry: an alternative solution

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ABSTRACT

Introduction: Skeletal posterior crossbite (SPCB) has a multifactorial etiology, as it may be caused by parafunctional habits, atypical position of the tongue, tooth losses and maxillary or mandibular transverse skeletal asymmetries. Skeletal involvement may lead to facial changes and an unfavorable aesthetic appearance. The treatment of SPCB diagnosed in an adult patient should be correctly approached after the identification of its etiologic factor. Surgically-assisted rapid maxillary expansion (SARME), one of the techniques used to correct SPCB in skeletally mature individuals, is an efficient and stable procedure for the correction of transverse discrepancies that may be performed in the office or in a hospital.

Objective: This study discusses the results of asymmetrical SARME used to correct unilateral SPCB associated with transverse mandibular asymmetry.

Conclusion: The treatment alternative used in the reported case was quite effective. At the end of the treatment, the patient presented adequate occlusion and facial aesthetics.

Keywords: Facial asymmetry. Palatal expansion technique. Orthognathic surgery. Corrective Orthodontics.

RESUMO

Introdução: A mordida cruzada posterior esquelética (MCPE) apresenta etiologia multifatorial, podendo ser causada por hábitos parafuncionais, posição atípica da língua, perdas dentárias e assimetrias esqueléticas transversais da maxila ou da mandíbula. Alterações faciais podem estar presentes quando há envolvimento esquelético, levando a estética desfavorável. O tratamento da MCPE, quando diagnosticada no paciente adulto, requer abordagem correta, com identificação do fator etiológico. Entre as técnicas utilizadas para correção da MCPE em pacientes esqueleticamente maduros, cita-se, em especial, a Expansão Rápida de Maxila Assistida Cirurgicamente (ERMAC). Essa modalidade tem se mostrado bastante eficiente na correção dos problemas transversais, apresenta estabilidade e pode ser realizada em ambiente ambulatorial ou hospitalar.

Objetivo: O objetivo do presente trabalho será discutir os resultados da ERMAC assimétrica para correção da MCPE unilateral associada a assimetria transversal da mandíbula.

Conclusão: A alternativa de tratamento utilizada no caso relatado mostrou-se bastante eficiente. Ao fim do tratamento, o paciente apresentou adequada oclusão e boa estética facial.

Palavras-chave: Assimetria facial. Técnica de expansão palatina. Cirurgia ortognática e Ortodontia corretiva.

INTRODUCTION

Adults have been increasingly seeking orthodontic treatment. Some patients have skeletal and facial asymmetries in addition to occlusal problems, which may worsen their condition or complicate their treatment. The human face is not perfectly symmetrical, but facial asymmetries are so small in most cases that they are hardly noticed in social life.[1] However, differences between sides of the face in patients with skeletal asymmetries of the maxillary bones may be visible and, therefore, disturbing and uncomfortable. Facial asymmetries smaller than 3 to 4 mm usually go unnoticed by the layperson. Orthodontists, in contrast, may see asymmetries as small as 2 mm.[2] Mandibular shift and asymmetries are more visible[1] and are usually associated with congenital malformation or deformity of the craniofacial skeletal structures, with asymmetrical growth or with mandibular posture compensation.[1] These factors may be the origin of unilateral skeletal posterior crossbite (SPCB). This type of malocclusion rarely has a spontaneous resolution, and requires a specific diagnosis to detect the skeletal and dental components involved. Intervention time is also a decisive factor in the treatment of SPCB[3,4]. In children and young adolescents, conventional rapid maxillary expansion (RME) using expanders is an efficient method to correct SPCB.[5,6,7] However, when used for older adolescents and adults, dentoalveolar effects are predominant, with little or no skeletal expansion.[7] This may lead to root resorption of the teeth used for anchorage, excessive dental tipping, dehiscence, fenestration and expansion failure.[8,9] For these patients, other treatment options, such as miniscrew-assisted rapid palatal expansion (MARPE) and surgically-assisted rapid maxillary expansion (SARME) should be considered.[10,11] Treatments using either of these techniques have positive and stable results.[10-15] SARME consists of a bilateral Le Fort osteotomy and separation of the midline at the incisor region.[13,14] It may be performed in the office, under local anesthesia, or in the hospital, when it requires general anesthesia.[15] The technique may be adapted to correct individual needs and include, for example, pterygomaxillary disjunction to ensure greater posterior expansion and unilateral osteotomy to decrease the areas of resistance and promote asymmetrical expansion.[15-19] When SPCB is unilateral and a result of mandibular asymmetry, sagittal split ramus osteotomy (SSRO) is an option. However, this complex and invasive technique has high risks and may trigger undesirable side effects.[20] In cases of unilateral SPCB, expansion is not enough to completely correct malocclusion. Most cases will also need further orthodontic treatment to correct the anteroposterior and vertical position of teeth and achieve normal occlusion.[4,21]

Thus, the present study discusses the results of asymmetrical SARME used to correct unilateral SPCB associated with transverse mandibular asymmetry, and presents the case of an adult woman with Class II, division 2, left subdivision malocclusion and unilateral SPCB.

CASE REPORT

DIAGNOSIS AND DESCRIPTION

A 45-year-old woman presented with a complaint that she described as: *"I'm biting with my teeth in an inverted position in the posterior region".* Her general health was good and she did not report any significant medical problem. She had good gingival health, but defective restorations.

She had a slightly concave profile and well-proportioned facial thirds. Her face was slightly asymmetric, as the left side of the mandible seemed to be larger than the right side. Lip seal was passive, her smile was asymmetric, and her left buccal corridor was larger than the right one (Fig 1).

She had Class II malocclusion, division 2, subdivision left because of loss of tooth #25 and consequent mesial movement of teeth #26 and #27, together with a reduced axial inclination of her maxillary incisors. Examinations revealed overbite, an edge-to-edge relationship and maxillary lateral incisors with a reduced mesiodistal diameter.

Figure 1: Initial facial and intraoral photographs.

The mandibular midline was slightly deviated to the right of the facial midline, and the maxillary, to the left. Left unilateral SPCB and slightly expanded maxillary teeth in the left side were not enough to avoid the crossbite. Occlusal wear facets were found mainly in the anterior teeth, because of malocclusion (Fig 1). Analyses using plaster models revealed asymmetries in the maxillary and mandibular arches (Fig 2 and Table 1).

A panoramic radiograph revealed that teeth #25, #18, #28, #48, #38 were missing and that the crown of tooth #26 was inclined mesially. There was generalized horizontal bone loss, but no active periodontal disease (Fig 3). Tooth #36 had an unsatisfactory endodontic treatment, with a partially obturated canal. The cephalometric radiograph (Fig 4) revealed that the maxilla and the mandible were well positioned in relation to the anterior cranial base. The patient had a balanced mesofacial growth pattern. Her maxillary incisors were slightly retruded and had a decreased axial inclination. Her mandibular incisors were slightly protruded, and their axial inclination was satisfactory. Her bone profile was straight, and her soft tissue profile was concave (Table 2).

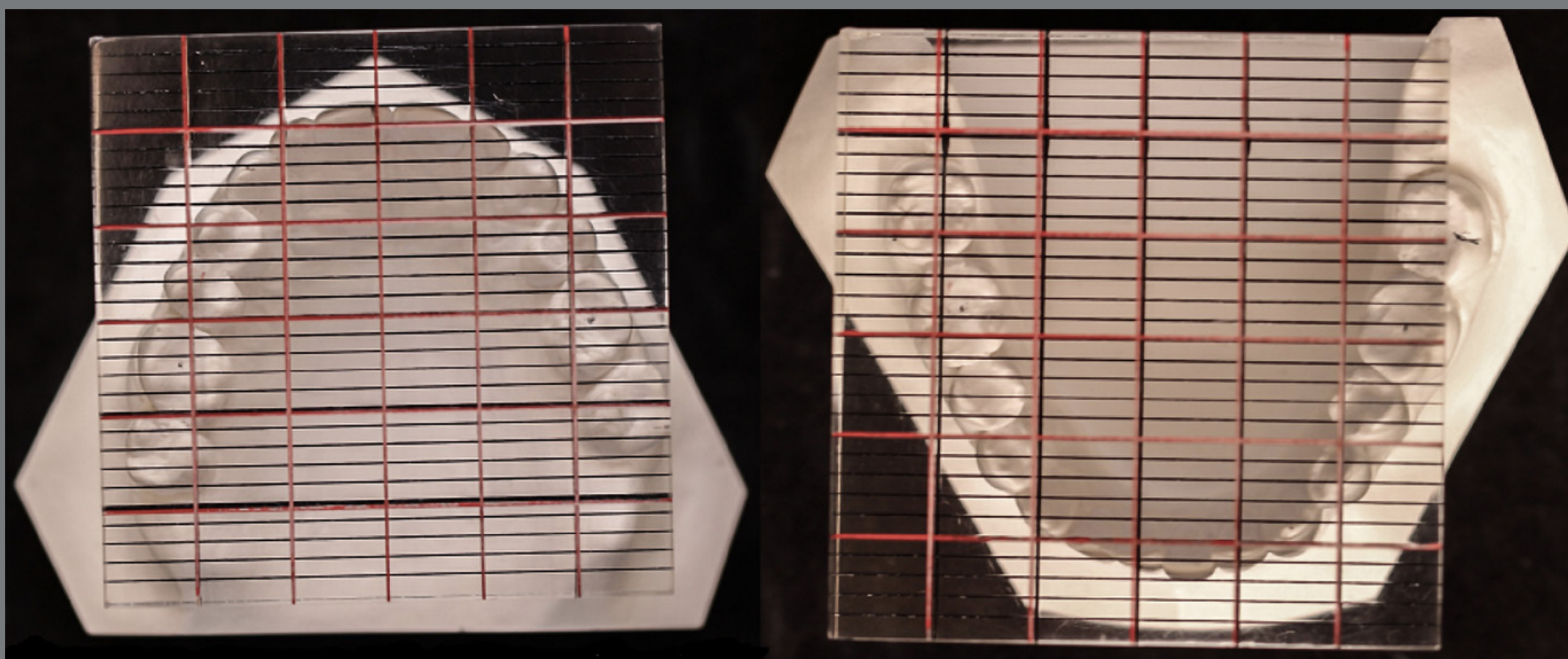

Figure 2: Analysis of dental arch symmetry, using a measuring plate (Schmuth).

Figure 3: Baseline panoramic radiograph.

Table 1: Analysis of dental arch symmetry.

Anteroposterior	Teeth	Arches	
		Maxillary	Mandibular
	Canines	#13: 1 mm mesial to #23	#33: 1 mm mesial to #43
	Molars	#26: 3 mm mesial to #16	#36: 1 mm mesial to #46
Transverse	**Teeth**	**Arches**	
		Maxillary	**Mandibular**
	Canines	#23: 2 mm expanded to #13	#33: 6 mm expanded to #43
	Molars	#26: symmetric to #16	#36: 8 mm buccal to #46

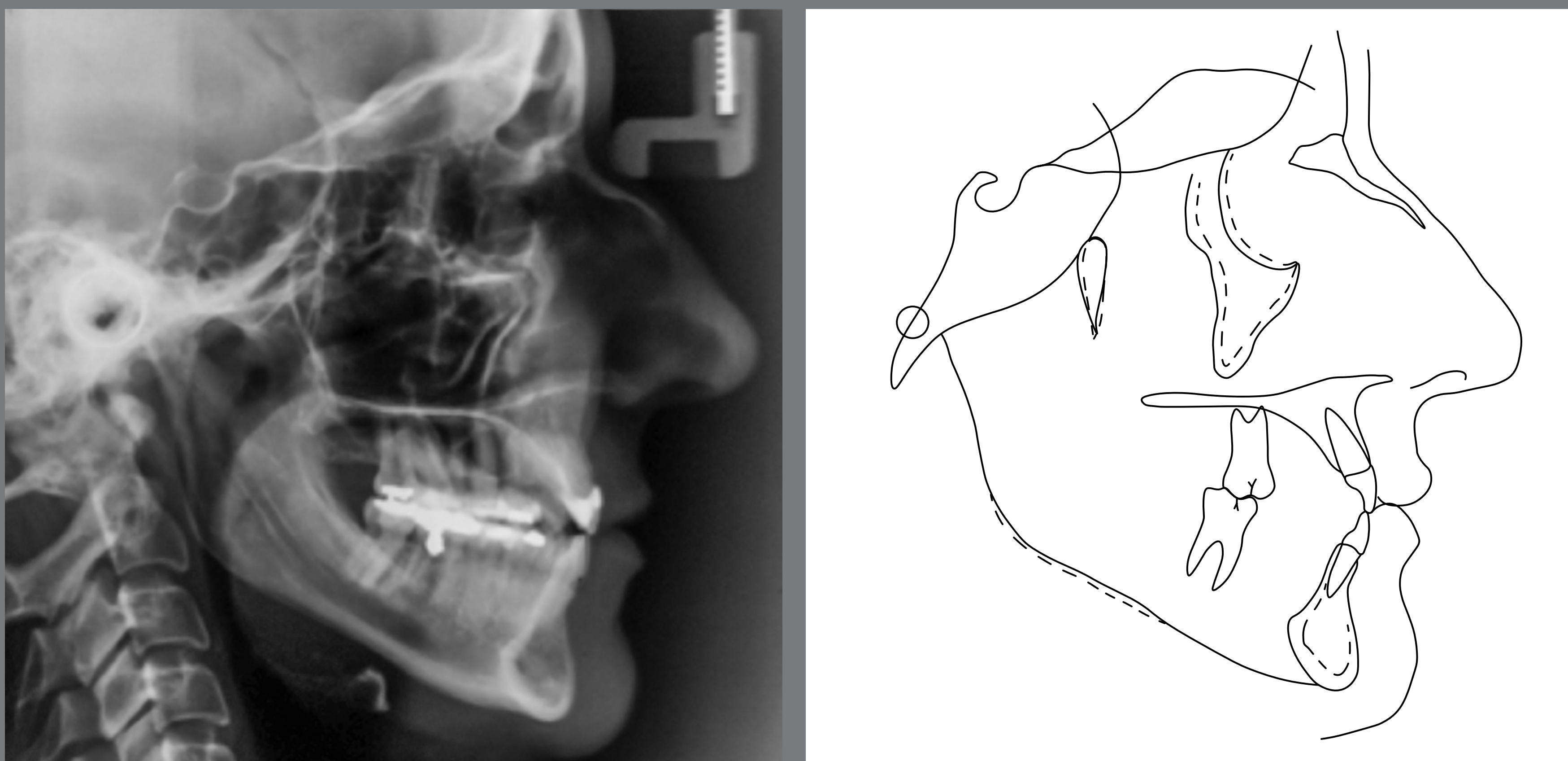

Figure 4: Baseline cephalometric radiograph and cephalometric tracing.

TREATMENT OBJECTIVES

The main treatment objectives were: 1) preserve dental aesthetics; 2) correct unilateral SPCB; 3) correct overbite and overjet; and 4) achieve functional occlusion, adequate disclusion and bilateral, simultaneous occlusal contacts.

TREATMENT OPTIONS

Three treatment options were considered:

1) Left SSRO for constriction and consequent correction of mandibular asymmetry and unilateral SPCB.

2) Extraction of tooth #35, anchorage loss in teeth #36 and #37, and constriction of the left mandibular dental arch.
3) Surgical expansion of the left side of the maxilla, to accentuate the discrete asymmetry, as well as to correct unilateral SPCB and achieve asymmetric arch coordination.

All treatment options would be associated with corrective orthodontic treatment, to restore normal occlusion at the end of the treatment.

Option 1 was undoubtedly the most adequate, because it would act directly on the resolution of bone asymmetry in the mandible, and would correct facial asymmetry. However, the patient refused this option, because she did not want to undergo an invasive and traumatic surgery. She also said she was happy with her dental aesthetics and that asymmetry did not affect her self-esteem. She also refused option 2 because of the need to extract one more tooth (#35), as she already had five missing teeth. Therefore, she chose option 3. The patient received the information that her mandible and face would remain asymmetric, and that the maxillary arch would be more expanded in the left side because of the correction of the unilateral SPCB.

SURGICAL ORTHODONTIC TREATMENT AND ORTHODONTIC MECHANICS

Maxillary arch

After the placement of bands on teeth #14, #24, #16 and #26, impressions of the maxillary arch were taken, and the bands were transferred. A Hyrax palatal expander was fabricated, and the patient was referred to surgery. The procedure consisted of a Le Fort I maxillary segment osteotomy on the left side, from the pyriform aperture to the zygomatic buttress, and midline splitting in the anterior maxilla (Fig. 5A, B, C). An osteotome was used for midline splitting, and the expander screw was activated 8/4 of a turn, to a total of 2 mm. After that, the screw was turned back 4/4 of a turn, to a total of 1 mm, which resulted in a 1-mm diastema between maxillary central incisors. Seven days after surgery, the patient received instructions to activate the screw 2/4 of a turn in the morning and 2/4 in the evening. Weekly return visits were scheduled. Expansion was discontinued when unilateral SPCB was overcorrected, that is, when the palatal cusps of maxillary molars and premolars occluded with the buccal cusps of mandibular molars (Fig. 5D, E, F). During that same visit, the screw was locked in position using self-curing acrylic resin. Occlusal radiographs were taken before the procedure, when the screw was locked in position and before the expander was removed.

Figure 5: Unilateral Le Fort I osteotomy and unilateral expansion immediately after activations.

The expander was used for retention for six months and then removed. After that, the orthodontic appliance was placed in the maxillary arch. For leveling and alignment, 0.014-in to 0.020-in stainless steel archwires were used to preserve left dental arch asymmetry, as the left side was expanded. Space mesial and distal to teeth #12 and #22 was preserved for later aesthetic reconstruction. Intermaxillary elastics were used to correct the maxillary midline and anchorage loss. A 0.019 x 0.025-in stainless steel archwire was used to complete the treatment and adjust intercuspation. The asymmetry in the maxillary arch was preserved, and torque and bends were used to stabilize the transversal relationship. A panoramic radiograph was requested at the time the last archwire was used, to evaluate root parallelism and to plan future retention.

Mandibular arch

After the brackets and tubes were bonded in the mandibular dental arch, the interproximal reduction of teeth #33, #32, #31, #41, #42 and #43 was used for the correction of anterior crowding and the deviation of the mandibular midline to the left. Leveling and alignment were performed using 0.014-in to 0.020-in stainless steel archwires, and the baseline asymmetry of the mandibular arch was preserved. A 0.019 x 0.025-in stainless steel archwire was coordinated with the maxillary archwire for treatment completion. Completion bends were included to improve intercuspation.

Occlusion function and arch stability were followed up for 60 days before the appliance was removed. After debonding, a wraparound retainer was prescribed for continuous use for two years, together with a thin 3x3 lingual arch. The patient was seen at each 30 days in the beginning, and after 3, 6, 9 and 12 months.

RESULTS

The initial objectives of the orthodontic treatment were achieved. Extraoral photographs at the end of the treatment show a harmonious facial profile and smile, at the same time that a slight mandibular asymmetry was preserved in the left side (Fig. 6). Angle Class II, division 2, subdivision left relationship was preserved, and unilateral SPCB was corrected, which restored normal occlusion in the left side. Maxillary and mandibular midlines were coincident with the facial midline, and overbite and overjet were within normal parameters. The slight anteroinferior crowding was corrected. Maxillary lateral incisors received aesthetic restorations to correct their mesiodistal diameter (Fig 6).

Figure 6: Final facial and intraoral photographs.

Figure 7: Final panoramic radiograph.

At the end of the treatment, root parallelism was satisfactory (Fig 7). There were no significant cephalometric changes (Figs 8, 9 and Tab. 2). Her facial profile was preserved: the maxillary incisors were proclined and extruded.

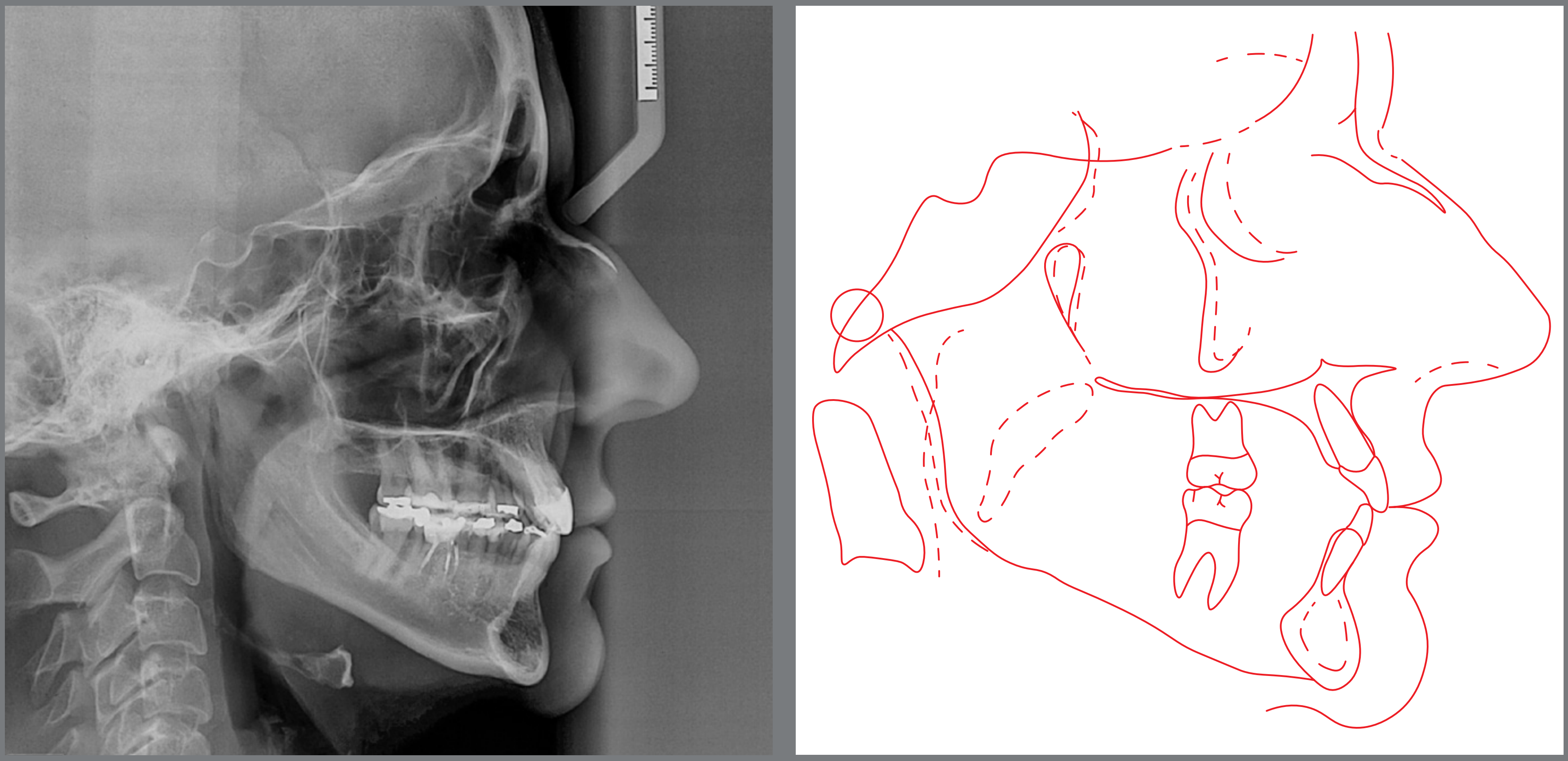

Figure 8: Final cephalometric radiograph and cephalometric tracing.

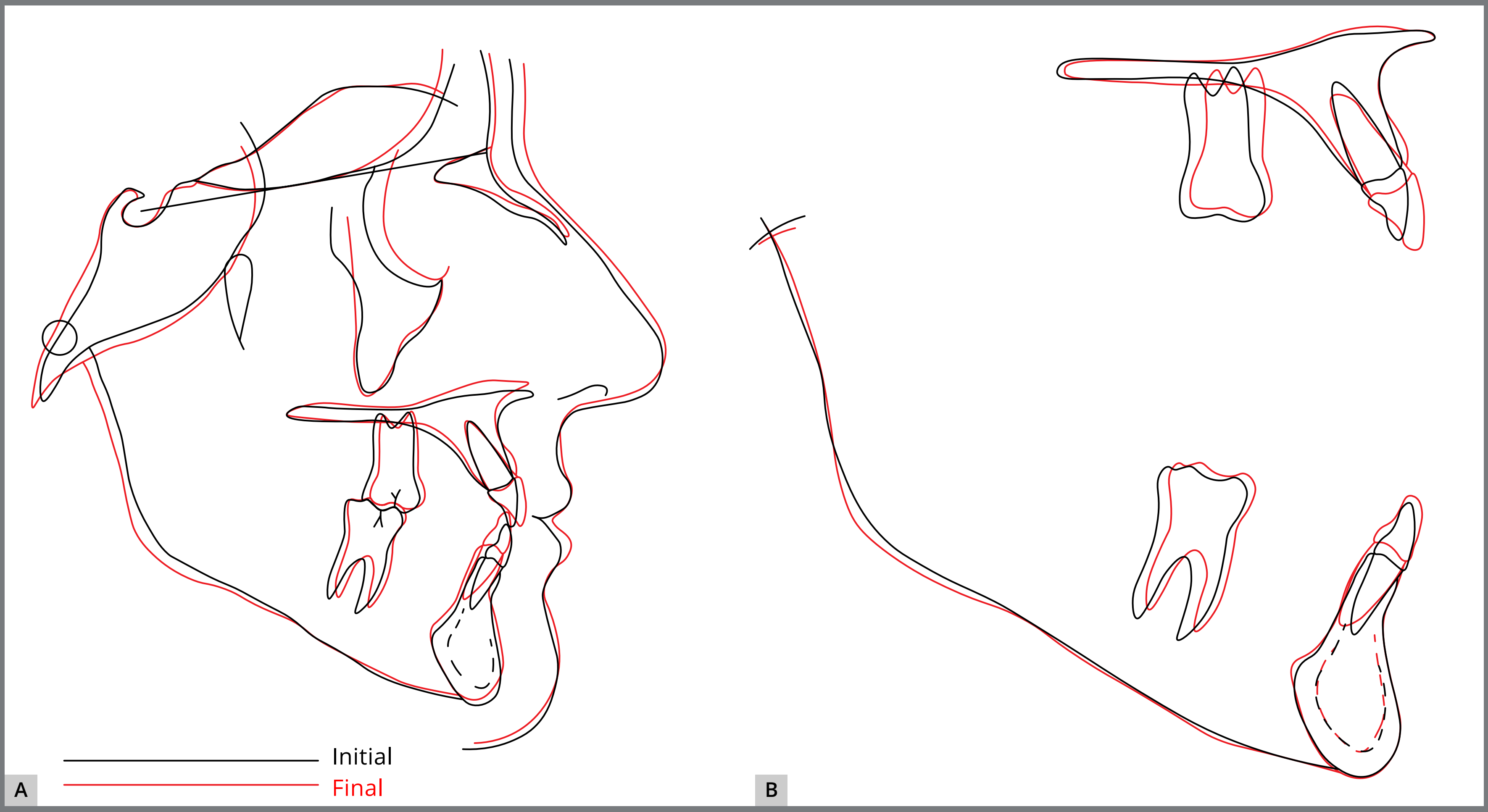

Figure 9: Total (**A**) and partial (**B**) baseline (black) and final (red) cephalometric tracing superimpositions.

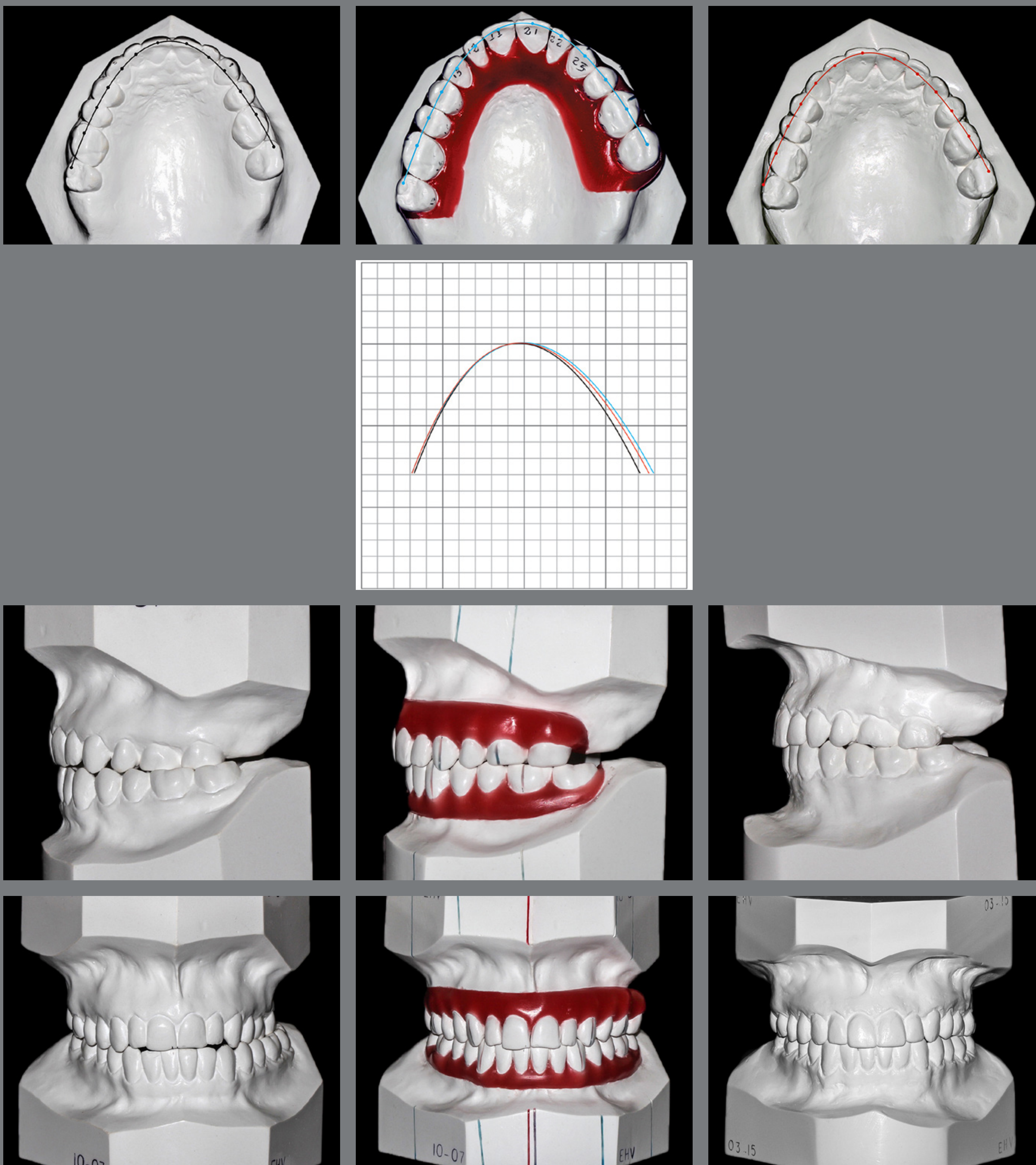

Figure 10: Photographs comparing baseline working casts, orthodontic setup, and final casts; and simulated arch superimpositions on millimeter paper.

Table 2: Baseline and final cephalometric landmarks.

	MEASURES		Normal	A	B	Difference A/B
Skeletal pattern	SNA	(Steiner)	82°	81°	80°	-1
	SNB	(Steiner)	80°	79°	79°	0
	ANB	(Steiner)	2°	2°	1°	-1
	Wits	(Jacobson)	♀ 0 ±2mm ♂ 1 ±2mm	1.5mm	1mm	-0.5
	Angle of convexity	(Downs)	0°	2°	-2°	-4
	Y-Axis	(Downs)	59°	62°	60°	-2
	Facial Angle	(Downs)	87°	84°	85°	1
	SN.GoGn	(Steiner)	32°	35°	31°	-4
	FMA	(Tweed)	25°	30°	29°	-1
Dental pattern	IMPA	(Tweed)	90°	91°	94°	3
	$\underline{1}$.NA (degrees)	(Steiner)	22°	19°	28°	9
	$\underline{1}$-NA (mm)	(Steiner)	4 mm	3.5mm	6mm	2.5
	$\overline{1}$.NB (degrees)	(Steiner)	25°	24°	25°	1
	$\overline{1}$-NB (mm)	(Steiner)	4mm	4.5mm	5mm	0.5
	$\frac{1}{1}$ - Interincisal angle	(Downs)	130°	135°	125°	-10
	1 - APg	(Ricketts)	1mm	2mm	2.5mm	0.5
Profile	Upper Lip – Line S	(Steiner)	0mm	-3mm	-4.5mm	-1.5
	Lower Lip – Line S	(Steiner)	0mm	-4mm	-3mm	1

DISCUSSION

SPCB in adults and adolescents whose skeletal maturation is advanced is a challenge, and a corrective surgery is often necessary. The dentoalveolar and skeletal characteristics involved in the several different clinical situations possible should be identified before a decision is made about which approach to use.[4,22-24] SPCB correction in skeletally mature patients using conventional RME or dental expansion may lead to unsatisfactory results, with damage to supporting tissues and instability. Therefore, other expansion procedures should be used.[9,10,12,15] Among those most often used, SARME and MARPE have had good results.[10,11] MARPE was not used in the treatment of this clinical case despite its advantages. It is less invasive and less expensive, its expander is easier to place, and it may be used for the parallel separation of the midpalatal suture. However, it was not an accessible option at the beginning of the treatment. In addition, clinical experience indicates that the use of MARPE is substantially effective in young adults aged 18 to 25 years; however, it has a certain rate of failure for older individuals, such as the patient in this clinical report.

To restore symmetry, many orthodontists prefer to correct the asymmetry at its place of origin because of a cause and effect relationship. If they had to work with this case, they would restore symmetry in the mandible, which was the specific place of origin. To do that, they would perform SSRO in a hospital under general anesthesia. SSRO has some surgical risk, because the dentoalveolar segment is separated from the basal bone of the mandible and repositioned lingually. This procedure requires an extensive surgical intervention and has significant risks, such as segment necrosis, loss of pulp vitality and temporary or permanent paresthesia in the area of the mental nerve. When compared with the surgical risks of conventional orthognathic surgery, SSRO morbidity is higher. Therefore, this surgical approach is not often used.[21-24] SSRO may result in a greater constriction in the canine region than in the molar region,[20] which would be unfavorable in this case, because constriction was more necessary in the region of tooth #36, with an 8-mm expansion, in relation to tooth #46. The patient refused this option because of the complexity of the surgical procedure in the mandible. Therefore, after considering the specific characteristics of the case and preparing the orthodontic setup, we chose to accentuate left maxillary asymmetry using SARME to correct SPCB. The procedure was performed in the office, and there was no need of hospitalization or general anesthesia. It should be stressed that SARME also poses risks to patients; however, these risks are less significant than those posed by SSRO, as discussed above. Glassman et al.[16] found that no unilateral osteotomies in their study were performed to camouflage another asymmetry, which indicates that the clinical case described in this report received a different treatment for unilateral SPCB.

In cases of unilateral SPCB, the expansion can be uni or unilateral. In case of bilateral expansion, osteotomy should include all the maxilla. In contrast, when the condition affects only one side, surgery is performed only in that side. The case reported here illustrates this SARME modality, as the osteotomy was performed only in the left side and promoted the asymmetric expansion of the maxilla. This procedure also opened the diastema between the central incisors, which increased the space available in the maxillary dental arch. As the osteotomy was not performed on the side without a crossbite, there was no significant expansion in this segment.[16,17]

Before the orthodontic treatment in this clinical report, the patient had a Class II, division 2, subdivision left relationship because of loss of tooth #25 and the consequent mesial movement of #26. At the end of the treatment, the Angle Class II molar relationship was preserved in the left side, and there was a correct Class I occlusion of the canines in both sides. This is in agreement with the consensus that this molar anteroposterior relationship is stable and functional.[25-28] During corrective orthodontic treatment, one of the objectives was the improvement of left side intercuspation, to make it functional. To promote an adequate occlusal contact with the mandibular arch, molars in Class II relationship should not be offset.

Another treatment option presented to the patient included the extraction of tooth #35 and the mesial movement of teeth #36 and #37, which would be moved to a narrower area of the mandibular arch, correcting SPCB and resulting in a Class I molar relationship. The anteroposterior relationship of canines and molars in both sides was already satisfactory at the beginning of the treatment and should be preserved. Although plausible, this treatment option may lead to problems, such as a probable uprighting of mandibular incisors, which would worsen her facial profile and substantially increase her slight sagittal mandibular dental asymmetry. Moreover, mandibular bone asymmetry, which had a skeletal origin, would persist even though her unilateral SPCB was corrected.

After the correction of unilateral SPCB, orthodontic treatment became easier, because the patient has a minor tooth-size/arch-length discrepancy (-2 mm), a normal curve of Spee, and well-positioned mandibular incisors (1.NA=24º). Treatment plan included the interproximal reduction of mandibular incisors to treat crowding and correct the mandibular midline. Intermaxillary elastics and torque control were used to adjust occlusion and intercuspation, as well as to achieve the proclination of maxillary incisors. These orthodontic mechanics ensured the correction of overbite and overjet, as well as the improvement of her facial profile.

Facial asymmetries, usually visible when larger than 4 mm, are not well accepted by patients. Asymmetries are among the most difficult problems to treat and are often corrected only by means of surgical procedures.[1,2] However, the patient in this case had a slight facial asymmetry noted only by the people closest to her and by specialized professionals. The treatment option selected for this case did not aim at the correction of that asymmetry, as the patient was comfortable with this condition.

The results simulated in the orthodontic setup were very close to the actual clinical results, which confirms the great value of this physical or virtual diagnostic modality in complex cases (Fig 10). This case also illustrates that, although asymmetry is a very important aesthetic and functional problem, the correct and thorough coordination of dental arches is essential to achieve a good treatment completion.

CONCLUSION

Asymmetries are usually corrected at the site where they originate. This report described a clinical case in which asymmetry was approached differently, as the symmetric basal bone was surgically expanded asymmetrically, thus correcting unilateral SPCB. At the end of the treatment, correct occlusion and satisfactory facial aesthetics were achieved by means of a combination of surgical and orthodontic treatments.

AUTHORS CONTRIBUTIONS

Fábio Lourenço Romano (FLR)

Marcelo Antônio Mestriner (MAM)

Conception or design of the study:

FLR, MAM.

Data acquisition, analysis or interpretation:

FLR, MAM.

Writing the article:

FLR, MAM.

Critical revision of the article:

FLR, MAM.

Final approval of the article:

FLR, MAM.

Overall responsibility:

FLR, MAM.

Patients displayed in this article previously approved the use of their facial and intraoral photographs.

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SPECIAL ARTICLE

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The smile arc: review and synthesis

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ABSTRACT

Introduction: The smile arc is an esthetic parameter that has been better investigated by Orthodontics after the "new esthetic paradigm". Its diagnostic evaluation and inclusion in the objectives of orthodontic planning has become fundamental for professionals seeking for more beautiful and youthful natural esthetic outcomes.

Objectives: To review concepts related to the smile arc, analyze the determinants of its appearance, understanding how the possible variations can affect the esthetic perception of smile.

Keywords: Esthetics. Upper incisal line. Smile arc. Orthodontic planning.

RESUMO

Introdução: O arco do sorriso é um parâmetro estético que passou a ser mais bem estudado pela Ortodontia a partir do "novo paradigma estético". A sua avaliação diagnóstica e inclusão nos objetivos dos planejamentos ortodônticos tornou-se fundamental para profissionais que buscam resultados estéticos mais belos e joviais.

Objetivos: Revisar conceitos relacionados com o arco do sorriso, analisar as determinantes da sua aparência, e compreender como suas possíveis variações podem repercutir na percepção estética do sorriso.

Palavras-chave: Estética. Linha incisal superior. Arco do sorriso. Planejamento ortodôntico.

INTRODUCTION

The smile is the most pleasant expression on the face, translating the beauty, youth and personality of people. From this understanding, raises one of the objectives of orthodontic treatment: the ability to restore smiles adapted to the face, age and lifestyle of patients, enhancing their positive esthetic characteristics and increasing the self-esteem and self-confidence when smiling.[1,2,3]

The components that define the maximum esthetic potential have been extensively discussed in the orthodontic literature, many originated from concepts of complete dentures. One of the most important, the "Smile arc" (also known as "Smile curve"), was defined as the relationship between the curvature of the incisal edges of maxillary anterior teeth (upper incisal line) and the curvature formed by the lower lip when smiling (Fig 1).[4,5] This issue has been extensively studied by restorative specialties,[6-9] and has gained the attention of orthodontists, based on the "new esthetic paradigm",[10,11] which has been guiding treatments since the 1990s.

In August 2001, David Sarver published one of the most read papers of AJODO: *"The importance of incisor positioning in the esthetic smile: The smile arc."*[5] His contribution was mainly based on the findings of some studies that confirmed the lower attractiveness of flatter upper incisal lines, and in studies reporting that

Figure 1: The ideal Smile Arc occurs when the upper incisal line has a similar curvature as that formed by the lower lip when smiling.[4,5]

this flattening was more common in orthodontically treated patients, compared to individuals with "normal" untreated occlusion.[3,12,13,14]

This publication by Saver[5] became popular by recognizing the importance and impact of this esthetic parameter on the orthodontic outcomes, in both short and long terms, besides evaluating the resources and mechanical decisions that harm, maintain or optimize its design and appearance. Then, clinical orthodontists began to dedicate more attention to this aspect, since it had been scarcely observed, understood and addressed for a long time.

Several other scientific publications also provided well-known and important contributions on this topic.[15-18] Following are the most known:

» The smile arc was considered as "consonant and pleasant" when it looks younger and presents the curvature of the upper incisal line similar to the curvature formed by the lower lip when smiling (presented in the literature as the esthetically most well accepted) (Fig 2A); "flat", when presents a flattened upper incisal line in relation to the curvature of the lower lip (Fig 2B); and "inverse", when presents a more aged appearance, in which the upper incisal line forms an opposite curvature to that formed by the lower lip, during social or voluntary smile (Fig 2C). According to Dong et al.[7], 60% of patients present smile types "consonant and pleasant"; 34% present arches type "flat" and 5%, "inverted" (Fig 2C).

Figure 2: Types of smile arcs: **A)** pleasant and youthful; **B)** straight or flat, and **C)** reverse or inverted.

» It is known that females present a more marked upper incisal line than males, and in both the curvatures formed by the upper incisal line and lower lip when smiling tend to be flatter with the increase in age.

» It has been observed that, during the aging process, the lips assume a lower position, contributing to the reduction of exposure of the maxillary anterior teeth and increased exposure of mandibular anterior teeth.

» Orthodontics acknowledges its limitations when facing problems related to the morphology and behavior of the lips when smiling. The lower lip does not always form a concave curvature to serve as parameter for the convexity of the upper incisal design.[2,16] Since the smile arc is formed by the consonance of two curved lines, the isolated establishment of a beautiful curvature of the upper incisal line is insufficient to define its formation and aspect. However, this is the only site of action whose change is within the scope of Orthodontics.

Considering previous publications and using some clinical perception on the issue, this paper aims to organize and summarize the subject, facilitating the diagnosis and understanding of factors that can determine the achievement of different esthetic perceptions in relation to the smile arc.

The determining factors for its formation and aspect can be listed into three main groups, described in Figure 3.

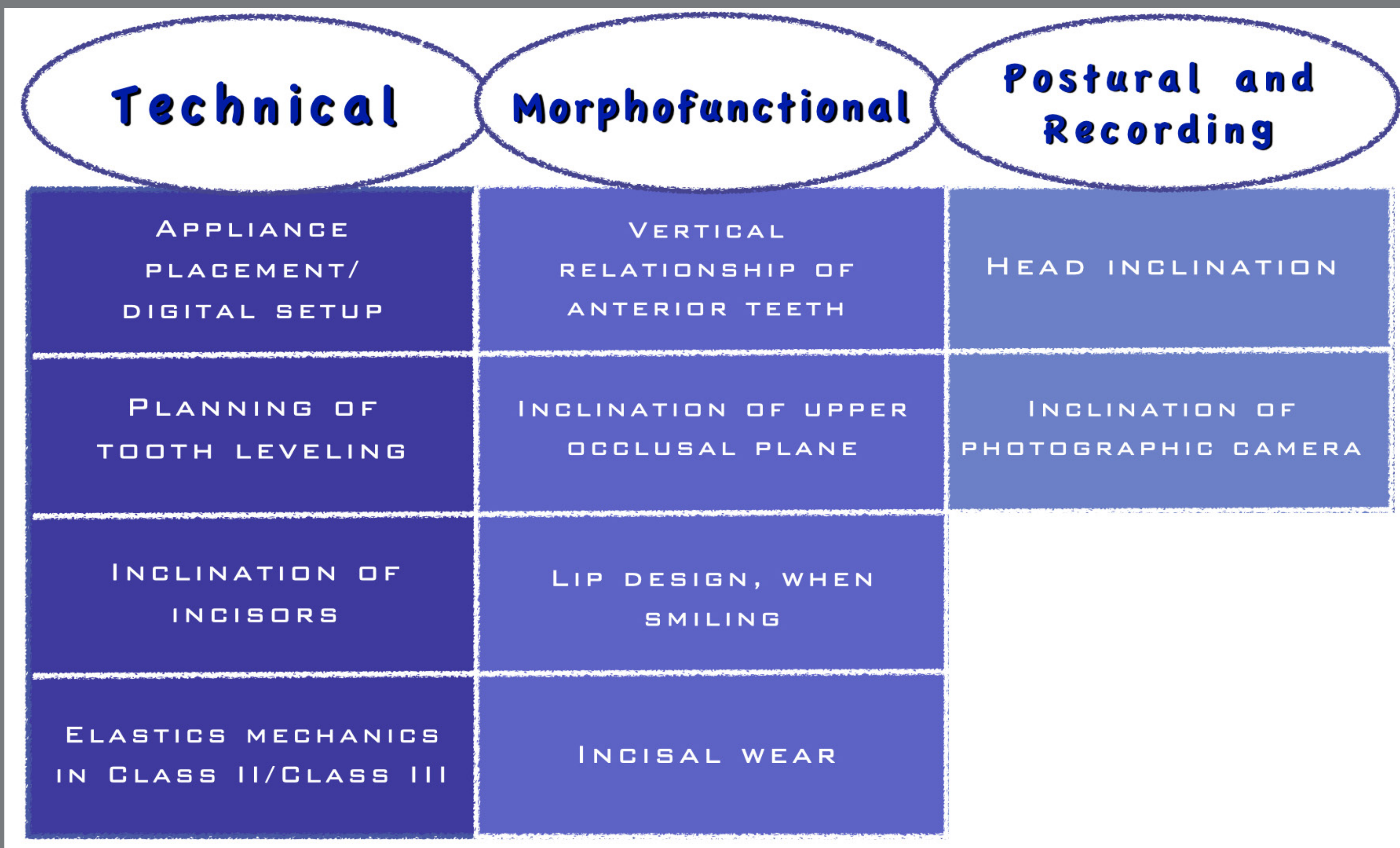

Figure 3: Determinants of the formation and aspect of the Smile Arc can have a technical nature, morphofunctional origin and those related to posture and photographic recording issues.

1 - TECHNICAL DETERMINANTS

The aspects related to planning and accomplishment of orthodontic or orthodontic-surgical treatment.

» *Appliance placement/Digital setup:* Figuring as the initial step of active treatment, this should be performed aiming at achieving an individualized incisal design, according to the patient's gender and age.[15,19-22] In the recent past, with planning focused almost exclusively on occlusion, the concern with the role of canines in laterality movements defined a more occlusal positioning of their cusp tips, when compared to the incisal edges of upper central incisors (Fig 4A). Currently, the appliances position the edges of maxillary central incisors leveled with the canine cusp tips (Fig 4B), since the achievement of correct disocclusion in laterality can be compensated by the more occlusal positioning of mandibular canines. The edges of lateral incisors should be nearly 1mm below the maxillary central incisors, creating an upper anterior incisal design shaped as a “deep dish” [2,16] (Fig 5). Concerning factors related to gender and age, female smiles accept an incisal design exhibiting greater height discrepancy between maxillary central and lateral incisors (from 1.0 to 1.5mm), while older patients require less marked incisal designs, with smaller height discrepancies between the upper incisal edges. Figure 6A shows a situation in which the upper incisal line was flattened due to an inadequate appliance placement, and Figure 6B shows its correction after retreatment using a more favorable placement. Also, the perception of canine tips in frontal view is influenced by the distortion of perspective, the known parallax effect (what is more distant seems smaller) and by the occlusal plane inclination, as shown later.[2] In digital planning, it is possible to use tools to guide the upper incisal design, such as the “Smile Curves” template.[15]

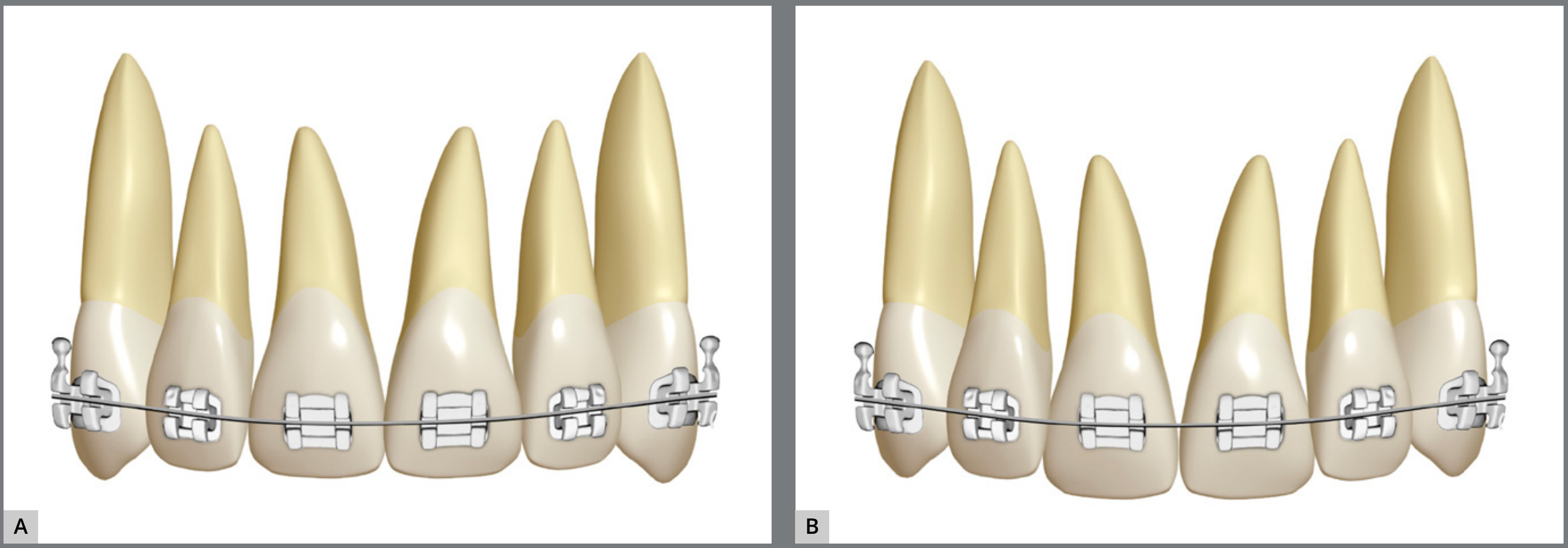

Figure 4: A) Placement of upper appliance with attention focused on achieving the canine guidance: the heights of brackets tend to flatten the smile arc. **B)** Appliance placement based on the contemporary esthetic paradigm: decreased dominance of cusp tips of maxillary canines and formation of a smooth convex upper incisal line (shaped as a "deep dish"), which allows the formation of an esthetically pleasant smile arc .

Figure 5: Upper incisal line shaped as a "deep dish".

Figure 6: A-C) Intraoral and extraoral photographs of the upper incisal line flattened by orthodontic treatment, forming a straight and not so youthful smile arc for a 15-year-old girl. **B)** Improvement of the upper incisal design, after a new appliance placement, promoting greater curvature of the upper incisal line and forming a more pleasant, feminine and youthful smile arc.

» ***Planning of arch leveling:*** the correction of vertical problems present in the anterior region of dental arches, as increased overbite and open bite, requires planning based on the ideal exposure of maxillary incisors, in lip rest position.[1,5,6,10,12,13,20] Currently, an excellent tool for planning of orthodontic leveling is the "Functional Aesthetic Occlusal Plane" published by Câmara and Martins[20] in 2016.The "FAOP" allows to identify the needs and limits of vertical movement of anterior teeth, favoring the maintenance or achieving the ideal exposure of maxillary incisors in lip rest position. In the past decades, flat and inverted smile arcs, caused by the correction and control of overbite by anterior maxillary teeth intrusion performed with "steps" or marked curves of Spee in the dental arches, were responsible for very undesirable esthetic results regarding the beauty and youthfulness of smile (Fig 7). Therefore, in the search for patients with pleasant and youthful smile arcs, planning the leveling of dental arches becomes absolutely essential.

Figure 7: Intraoral and extraoral photographs of the inverted upper incisal line after overbite correction by a sharp curve of Spee in the upper arch **(A-C)**. **D, E)** Retreatment of the case, with good control of overbite, reestablishment of the curvature of the upper incisal line and formation of a more pleasant and youthful smile arc.

» ***Inclination of maxillary incisors:*** It is known that, when projecting the maxillary anterior teeth, the anterior overbite is reduced, the upper incisal line is flattened and the light reflection on the buccal surfaces of maxillary incisors is changed.[2,5,7,17] The esthetic losses in these cases are notorious and range from the perception of incisors with smaller vertical dimensions and altered proportions to a smile with a less youthful aspect (Fig 8A to E). Conversely, when the position of these teeth is planned more orthogonally in relation to the environment light beam, the perception of the actual size and proportions of maxillary incisors is allowed, as well as a more marked curvature of this incisal line (Fig 8F to J). These considerations become particularly important concerning treatments performed by previous dental expansions, either to solve lack of space, to compensate for a marked overbite or Class III malocclusion.

Figure 8: A-E) Patient treated by projection of incisors, presenting dentoalveolar biprotrusion, anterior open bite, flat upper incisal line, and change of light reflection on the buccal surfaces of maxillary incisors. **F-J)** Retreatment performed by tooth extractions and retraction of anterior teeth: improved light reflection from the smile and achievement of an upper incisal line shaped as a “deep dish”. The correct appliance placement and tooth movement performed enabled the formation of a more esthetically acceptable smile arc.

» ***Utilization of Class II and III elastics.*** It is known that the use of this mechanical resource can promote changes in the inclination of the occlusal plane. When prescribed in Class II direction, they tend to rotate the upper occlusal plane in clockwise direction, which can influence the increase in overbite and increase the perception of convexity of the upper incisal line. Conversely, elastics in Class III direction can promote counterclockwise rotation of the lower occlusal plane, tending to increase the overbite by the extrusion of mandibular anterior teeth (Figs 9A and B). This side effect requires the accomplishment of compensatory maxillary anterior teeth intrusion that are very unfavorable to the smile esthetics and speech (by reducing the exposure and increasing the buccal inclination of maxillary incisors, besides flattening the upper incisal line).

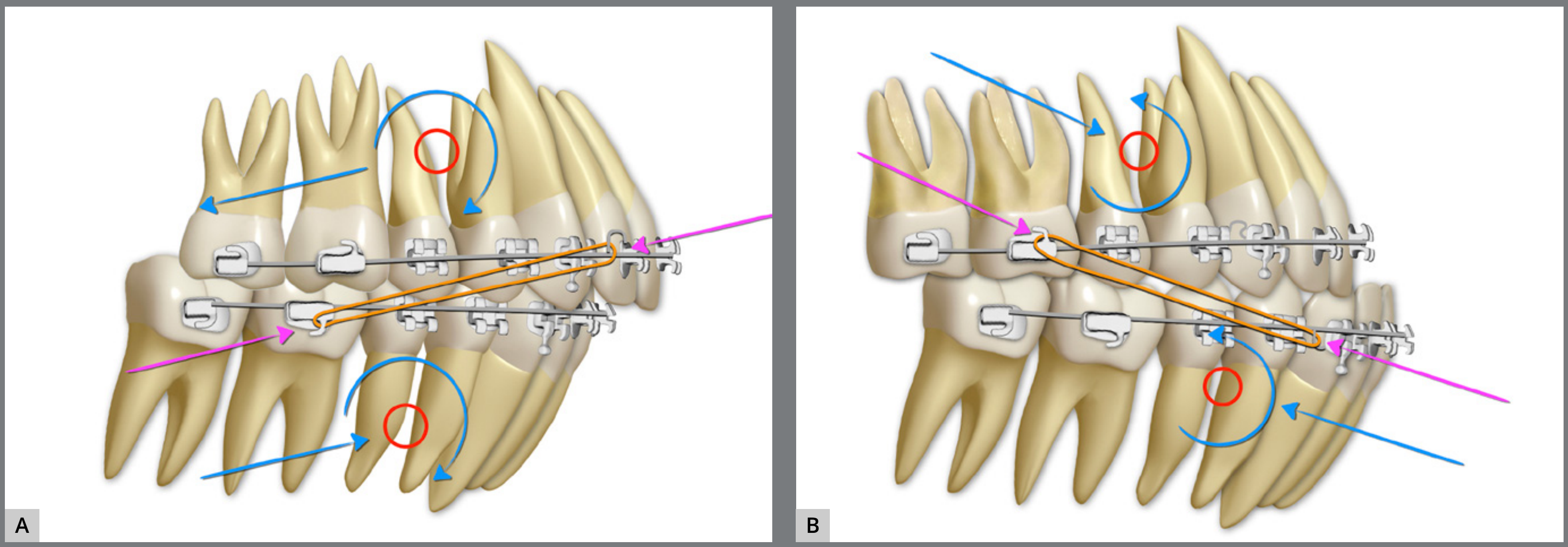

Figure 9: Elastic mechanics applied in Class II (**A**) and Class III (**B**) directions, and their possible side effects in the inclination of upper and lower occlusal planes.

2 – MORPHOFUNCTIONAL DETERMINANTS

Aspects related to the anatomic and functional pattern of individuals, originated from their dentoskeletal, muscular and soft tissue characteristics.

- ***Inclination of upper occlusal plane in the sagittal plane***: it is known that individuals with brachycephalic facial archetypes present occlusal and mandibular planes more inclined in counterclockwise direction in relation to the Frankfort horizontal plane (FHP), and more parallel to each other, due to a predominantly horizontal facial growth vector. Clinically, it is observed that these patients tend to have flatter upper incisal lines (or even reverse, if the maxillary bone bases present counterclockwise rotation) (Fig 10A).[2] Though not yet scientifically evidenced, this seems to be a relevant clinical perception. The opposite may also be expected: patients with dolicocephalic facial archetypes, presenting occlusal and mandibular planes more inclined in clockwise direction in relation to the FHP, tend to have greater possibilities for the achievement and visualization of more convex and marked upper incisal lines (Fig 10B).

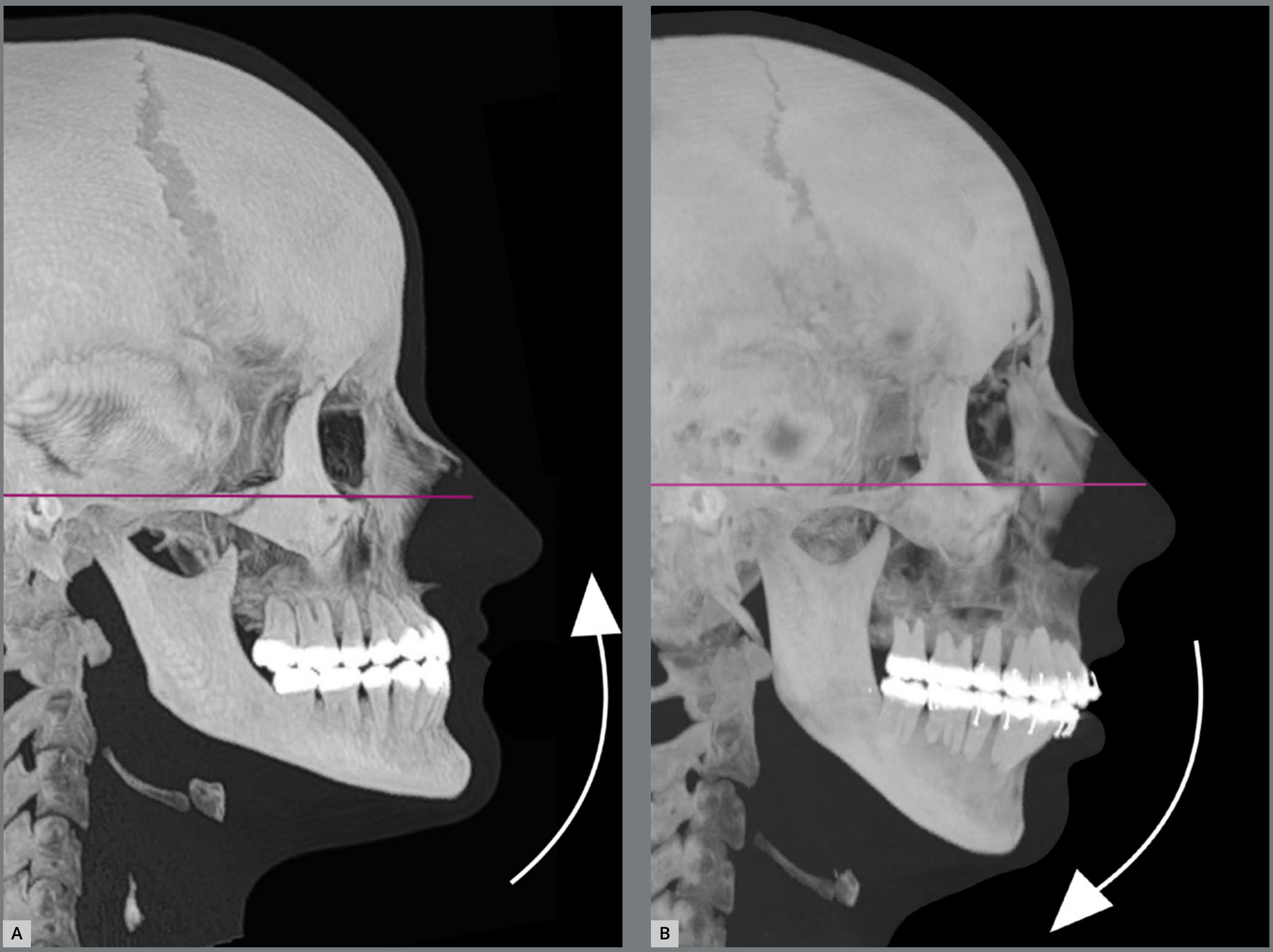

Figure 10: Relationship between facial archetypes and the smile arc. **A)** Short faces, in which there is greater tendency to counterclockwise rotation of the maxillomandibular complex, usually present occlusal plane with upward inclination, little exposure of maxillary anterior teeth when smiling and in lip rest position, more buccally inclined maxillary incisors, and a flatter or even inverted incisal line. **B)** Long faces, in which there is a greater tendency to clockwise rotation of the maxillomandibular complex, have opposite characteristics to those previously described and greater possibilities to achieve more pleasant smile arcs.

- ***Vertical relationship of anterior teeth:*** this topic includes some malocclusions that present changes in overjet and overbite, as dentoalveolar open bite, edge-to-edge incisor relationship, and increased overbite. Open bites of dentoalveolar origin (usually caused by abnormal pressure habits) have an inverted upper incisal curvature, besides minimal or no exposure of maxillary anterior teeth in lip rest position and during speech. In mild and moderate cases, the achievement of a convex upper incisal line occurs in a relatively simple and predictable manner, by the extrusion and/or retraction of maxillary anterior teeth (Figs 11 A to D).

Figure 11: A, B) Young patient, with anterior open bite, concave upper incisal line and inverted smile arc. **C, D)** Upper leveling performed by the combination of posterior intrusive and anterior extrusive movements, achieving a better upper anterior incisal design. Retreatment of this case provided a pleasant smile arc, compatible with the patient's age and personal preference.

Conversely, individuals with minimal overbite or edge-to-edge anterior relationship require improvement of overjet and overbite. If the situation occurs due to presence of tooth-size discrepancy, with excess of lower dental tissue, the problem can be corrected by proximal stripping (obviously, if allowed by the dental anatomical and periodontal conditions), followed by retraction of mandibular incisors and extrusion of maxillary incisors (the clinical case described in Figures 12 to 14 illustrates this situation). If the case involves a compensated Class III malocclusion, the formation of a convex upper incisal line and a pleasant smile arc is more difficult.

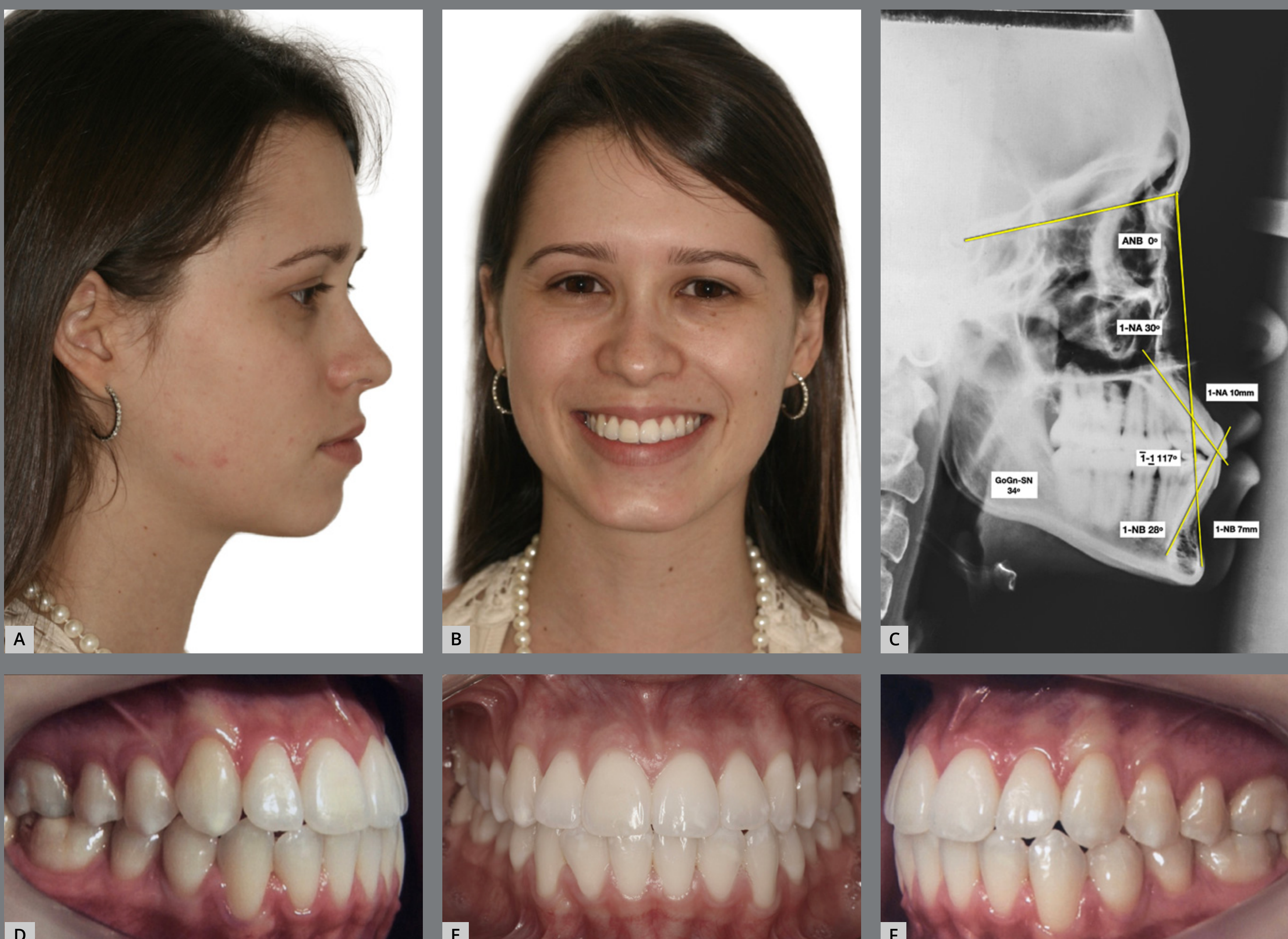

Figure 12: A, B) Facial photographs of patient with a slightly convex profile, lower lip protrusion and buccal inclinations of maxillary incisors. **C)** Initial lateral cephalogram and some Steiner cephalometric measurements, describing a skeletal Class III pattern and dentoalveolar bimaxillary protrusion. **D-F)** Intraoral photographs showing mild Angle Class III malocclusion, compensated by the projection of maxillary incisors, presenting acceptable posterior intercuspation, minimum values of overbite and overjet, flattening of the upper incisal line, and tooth-size discrepancy with 2-mm excess of mandibular anterior teeth width.

Figure 13: Final intraoral photographs of orthodontic retreatment, showing good overjet and overbite, and good coordination of dental arches. The desired tooth movement was allowed by proximal stripping performed in the maxillary and mandibular anterior regions, aiming at correcting the Bolton discrepancy, and improving the maxillary anterior dental proportions (increased dominance of the maxillary central incisors). Also observe the greater convexity of the upper incisal line.

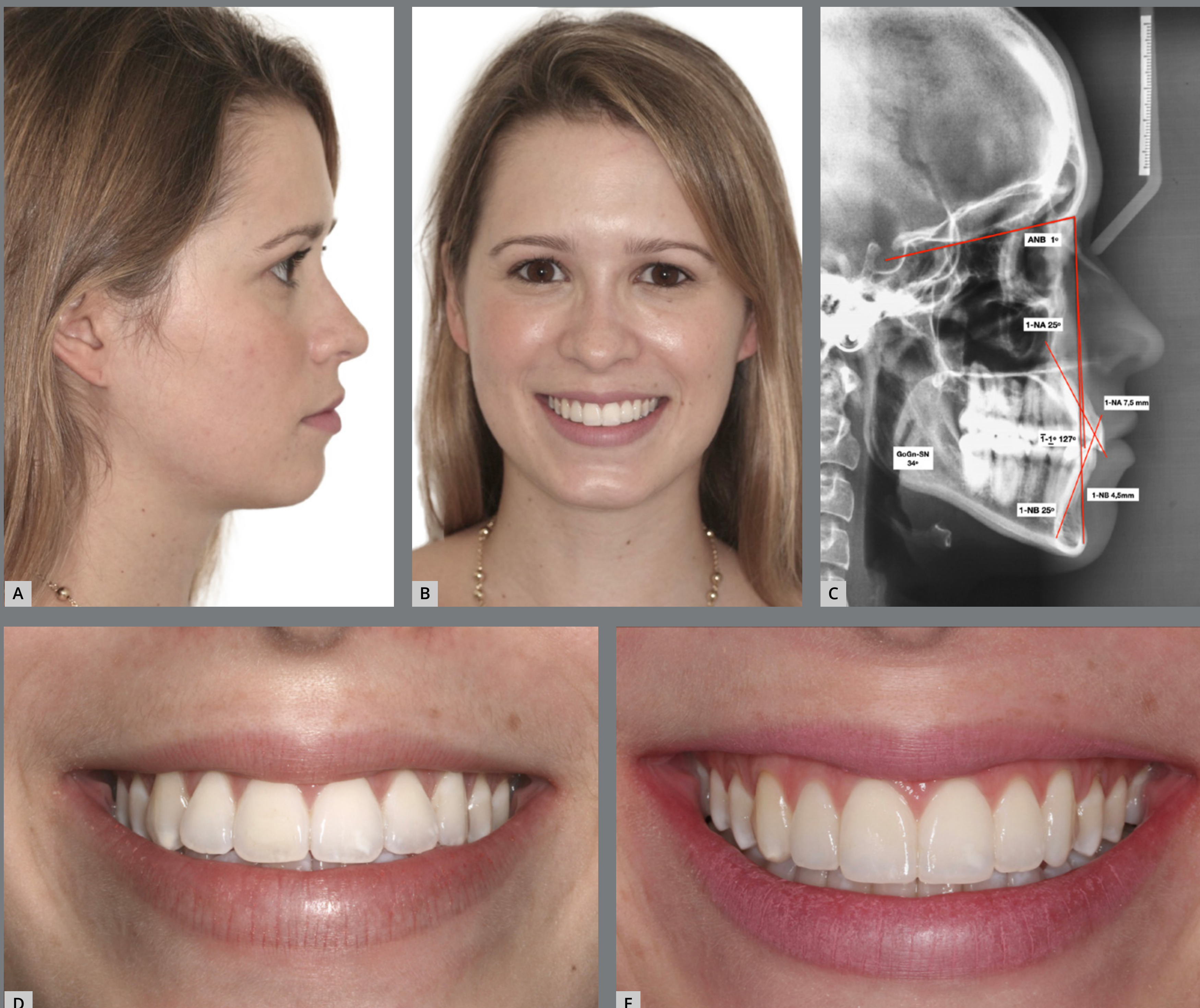

Figure 14: A, **B)** Final facial photographs, showing the reduction of lower lip protrusion and the improvement of maxillary teeth inclination. **C)** Final lateral cephalogram and some Steiner cephalometric measurements, showing the reduction of dentoalveolar bimaxillary protrusion. Close-up photographs of the initial (**D**) and final (**E**) smile, showing the esthetic improvement obtained after disinclination and extrusion of maxillary incisors, increase of gingival exposure and upper incisal line curvature, with consequent achievement of a more beautiful and youthful smile arc.

The increased overbite may be observed in all types of malocclusions, and its presence is associated with some overjet, either positive (Class II or due to the presence of tooth-size discrepancy) or negative (Class III). Two important aspects should be understood:

1. The strategies for correction are determined by the exposure of maxillary incisors in dynamic analysis (lip position at rest and during speech).[1,2,5,9,10,11,13,17,20] If it is necessary to maintain or improve this important esthetic aspect, maxillary anterior teeth intrusion should not be performed. Also, for example, the use of "steps" in continuous or utility archwires is considered a very unfavorable mechanical strategy for overbite correction, when it is desired to maintain or achieve pleasant and youthful upper incisal lines.[3,12,13,14]

Analyzing the "time" factor, the expected reduction of maxillary teeth exposure and the tendency to flattening of the upper incisal line — resulting from dentofacial aging — should always be remembered. Excessive appearance of maxillary incisors during speech and in lip rest position, as well as excessively marked incisal curvatures, in older individuals, may not be welcome. Patients become esthetically more natural when their dentofacial characteristics are as expected for each stage of their lives.[3,4,5,6,10,13,18]

2. Clinically, it seems that cases of overbite more favorable to maintaining or achieving a beautiful smile arc are those that can be corrected by mandibular anterior teeth intrusion and/or mandibular posterior teeth extrusion (Fig 15).

When marked overbite is associated with a brachycephalic skeletal pattern, in a patient with short face and horizontal occlusal and mandibular planes or even with counterclockwise rotation, there is an esthetic problem with difficult orthodontic solution. Usually, the improvement of maxillary teeth exposure and the possibility to achieve a convex and pleasant upper incisal line requires an orthodontic-surgical approach, with downward replacement of the maxilla and clockwise rotation of the aforementioned planes.

Figure 15: Intraoral and smile photographs, initial (**A-D**) and final (**E-H**), showing a case of marked overbite and upper dentoalveolar protrusion. The improvement in upper incisal line curvature was obtained by extrusion and displacement of maxillary incisors. For that purpose, it was necessary to perform an excellent leveling of the mandibular arch.

» ***Incisal wear:*** the wear of edges of maxillary anterior teeth can be diagnosed at different ages, even though they are more common in adult patients. They can be physiological and considered as "marks" of the functional activity of teeth, or they may indicate substantial loss of coronal tissue, most often caused by perimolysis and/or eccentric bruxism.[23]

Besides changing the size of teeth and their esthetic proportions, the wear changes the design of incisal lines and consequently the perception of the smile arc (Fig 16A to F). In some situations, they are followed by compensatory extrusion of incisors and changes in gingival contour and in the "pink esthetics" (Fig 16B). These patients should be treated, ideally and conservatively, by a transdisciplinary approach in which orthodontics works in partnership with restorative specialties.[23-27]

Figure 16: Initial (**A, B; D, E**) and final (**C, F**) intraoral and smile photographs of two young patients with anterior "edge-to-edge" relationship, incisal wear, changes in volume and dental proportions and gingival contour of the maxillary anterior region, inverted curvature of the upper incisal line and reverse smile arc. Both patients were orthodontically treated to obtain adequate levels of overjet and overbite and restoration of worn teeth.

» ***Lip design, when smiling:*** Since the smile arc is an esthetic parameter that depends on symmetry and consonance between two curved lines with the same orientation — the upper incisal curvature and the line formed by the lower lip when smiling —, it is possible to understand the orthodontic limitation in the process of achieving beautiful results for all patients. Even with upper incisal lines with youthful and pleasant curvatures, the behavior of lips and commissures during smile is determined by the contraction pattern of perioral muscles and their morphological characteristics (volume, thickness, symmetry). That is to say, it seems that Orthodontics has little or no resources to change these characteristics. It is possible to observe some types of smile classified and described in the literature that favor or not the appearance of the smile curve. The most favorable are the Monalisa and Canine[18] types (Figs 17A and B), in which the commissures are moved upward, and the lower lip forms a curve accompanied by the upper incisal design. This is more rarely observed in smiles of Complex and Infinite (or mirror) types,[2,16] for example (Figs 17C and D).

Figure 17: The behavior of lips, during their "unveiling", has a favorable influence on the formation of smile arc of types "Monalisa" and "Canine" (**A, B)**. In smiles of the "Complex" and "Infinite or mirror" type, it is more difficult to achieve harmony between the upper incisal line and the lower lip. In these cases, Orthodontics faces its major limitation: alteration of the muscle and tissue pattern of the lips and perioral regions.

3 – POSTURAL AND RECORDING DETERMINANTS

These are related to possible changes in the visual perception of the smile arc, as well as its recording.[2]

» ***Change in patient's head position:*** The orthodontic photographic images should take as reference a position with good reproductive accuracy, which is the natural head position (NHP). The camera should be parallel to the latter and perpendicular to the true vertical line (imaginary line that crosses the line of view perpendicularly, dividing the face into right and left sides) (Fig 18).

Figure 18: Natural head position (NHP) and imaginary frontal line parallel to it. The camera should be positioned perpendicular to the latter.

By inclining the patient's head slightly up or down, it is also inclined in relation to the camera and, consequently, the visual perception of the smile arc curvature is changed. The described movement modifies the angle of the dental occlusal plane in relation to the observer, leading to a perception of flatter or more curved upper incisal line (Fig 19). The downward inclination of the head, together with the parallax factor, potentiates the formation of the smile arc. This condition needs to be carefully evaluated to avoid masking structural problems. The opposite is also true; the perception of the esthetic effect of correct dental leveling can be impaired by inclining the head upwards.

Figure 19: Changes in inclination of the patient's head during photographic recording: **A, B)** By inclining it downwards, the occlusal plane is angulated inferiorly, and the curvature of the upper incisal line is increased. **C, D)** By inclining it backwards, the occlusal plane is angulated superiorly, and the curvature of the upper incisal line is flattened or even inverted.

» ***Inclination of photographic camera:*** alike the change in position of the patient's head can modify the visualization of the smile arc, the position of the camera that records the smiles may also influence. Photographs taken with cameras angled from top to bottom produce images with more marked incisal and lip curvatures, while cameras angled from bottom to top may flatten them (Fig 20).

To record the smiles as accurately and reproducibly as possible, it is necessary to pay attention to this aspect and attempt to achieve the photographs in a manner as careful and standardized as possible.

Figure 20: Changes in perception of the smile arc, achieved with different camera inclinations in relation to the occlusal plane. **A)** Camera inclined upwards, planning the upper incisal line curvature. **B)** Camera parallel to the occlusal plane, allowing correct analysis of the smile arc; and **C)** Camera inclined downwards, increasing the upper incisal line curvature.

FINAL CONSIDERATIONS

The achievement of beautiful, natural and pleasant smiles has a direct correlation with the dental, skeletal and facial characteristics of each individual. Also, the artistic perception of the orthodontist, the individualization of the appliance placement/digital setup, as well as the knowledge on orthodontic mechanics, can favor or impair the treatment outcomes. The smile arc is one of the most important esthetic parameters for dentistry and should receive special attention in contemporary orthodontic planning. Understanding the factors that determine its appearance is essential for maximum use of its esthetic potential.

AUTHORS CONTRIBUTIONS

Mayra Reis Seixas (MRS)

Carlos Alexandre Câmara (CAC)

Conception or design of the study:

MRS.

Data acquisition, analysis or interpretation:

MRS, CAC.

Writing the article:

MRS.

Critical revision of the article:

MRS, CAC.

Final approval of the article:

MRS, CAC.

Overall responsibility:

MRS.

Patients displayed in this article previously approved the use of their facial and intraoral photographs.

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