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Canine substitution of congenitally missing maxillary lateral incisors in Class I and Class III malocclusions, using skeletal anchorage

Department of Orthodontics and Dentofacial Orthopedics
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within the range of dentistry

Promoter:
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Me tenant comme je suis, un pied dans un pays et l'autre en un autre, je trouve ma condition très heureuse, en ce qu'elle est libre *

René Descartes

* Staying as I am, one foot in one country and the other in another, I find my condition very happy, in that it is free

René Descartes, Letter to Elisabeth of Bohemia, Princess Palatine (Paris, June/July 1648)

ACKNOWLEDGMENTS

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This complete work is dedicated to my sons, **William** and **Andrew**.

Thank you, my Lord.

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LIST OF ABBREVIATIONS

BMLIA: bilateral maxillary lateral incisor agenesis
MLIA: maxillary lateral incisor agenesis
PAR: peer assessment rating
TAD: temporary anchorage device
TISAD: temporary intraoral skeletal anchorage device
UMLIA: unilateral maxillary lateral incisor agenesis
VAS: visual analog scale

1.8. Agenesis of the maxillary lateral incisor: epidemiology, etiology, and symptoms

Tooth agenesis affects 20% of the world's population, and maxillary lateral incisor agenesis (MLIA) is one of the most frequent subtypes. The prevalence of MLIA varies from 1.15% to 5% in different populations (Alves-Ferreira et al., 2014; Bassiouny et al., 2016; Kabbani et al., 2017). Bozga et al. (2014) report that the occurrence of MLIA is 25%, and is second only to mandibular second premolar hereditary absence, which comprises 44% of agenesis subtypes distribution; MLIA prevalence is two times higher in female individuals than in male individuals (Kiliaridis et al., 2016).

The abnormality, which is characterized by the lack of the formation of the deciduous or the permanent lateral incisors, results from impaired odontogenesis. This process is a complex mechanism regulated by sequential and reciprocal epithelial-mesenchymal interactions, which are controlled by activators and inhibitors involved in several pathways of the process. Disturbances in these signaling cascades can lead to abnormalities in odontogenesis, and alter the number of normal teeth. Alves-Ferreira et al. (2014) reported the first evidence of the involvement of sprouty genes in MLIA susceptibility; however, it is common for MLIA to be associated with multiple dentoalveolar and skeletal malformations (Woodworth et al., 1985; Alves-Ferreira et al., 2014). The craniofacial anomalies similar to those seen in individuals with a cleft palate may reflect an etiology of agenesis that is related to a developmental disturbance during the fusion of the facial processes in utero (Woodworth et al., 1985). Nonetheless, it has been shown that in cases of cleft lip and palate, MLIA on the affected side is a genetic anomaly associated with the cleft itself rather than occurring as a consequence of the palate malformation (Dentino et al., 2012). Therefore, the etiology of tooth agenesis remains multifactorial.

The aforementioned malocclusion may develop as unilateral MLIA (UMLIA) disorder or bilateral MLIA (BMLIA) disorder. In UMLIA, the left or right side is affected with no significant differences. Microdontia of the contralateral maxillary incisor occurs in 38.8%–55.5% of cases and is accompanied by other dental anomalies (Garib et al., 2010; Park et al., 2010; Tai et al., 2011; Mehmet et al., 2016; Kiliaridis et al., 2016; Buyuk et al., 2017). In patients with UMLIA, microdontia or diminished mesiodistal crown incidents may not be limited to only the front area of dentition. These incidents may affect any tooth, except for the maxillary first molars (Yaqoob et al., 2011; Mirabella et al., 2012). With regard to other symptoms, Woodworth et al. (1985) report that the mandibular incisors and molars in both jaws are larger in women than in men with MLIA. Maxillary lateral incisors agenesis is also accompanied by a high prevalence of tooth agenesis (except for the third molars), palatally impacted canines, and distally angulated mandibular second premolars (Garib et al., 2010; Kiliaridis et al., 2016).

In their search for other symptoms or aftermath, Pinho and Lemos (2012) studied the effect of MLIA on tooth position. Their sample consisted of 147 Portuguese patients, and they evaluated the upper midline deviation and the molar and the canine relationships. As expected, the authors found that the occurrence of midline deviation was significantly higher in patients with ULIA. Class II canine and molar relationship occurred significantly more often on the deviated side than in the healthy quadrant. Woodworth et al. (1985) studied a sample of 43 Europeans with BMLIA (mean age, 13.5 years). The patients had a relatively normal dental arch length and width, overjet, and overbite. With regard to the skeleton, the maxilla, mandible, anterior cranial base, and nasal bone were significantly smaller than those of the control group. The posterior and anterior upper and lower face heights were significantly decreased. The mandibular plane angle was more acute, but the nasolabial angle was more obtuse than normal. Altogether, these findings support the theory behind a strong association between agenesis of the maxillary lateral incisors and disturbances in cranial formation (Woodworth et al., 1985).

1.9. Conventional treatment of maxillary lateral incisors agenesis: approaches and their supporters' and opponents' studies

Treatment solutions for congenitally missing lateral incisors include single-tooth implants and tooth-supported restorations, and canine substitution. Treatment requires a few factors that clinicians should consider before choosing a certain option: the patient's age; the patient's motivation for treatment; the patient's treatment expectations; the patient's financial obligations; the patient's facial profile; the presence of dental crowding and thus the need for extractions; the position, shade, and size of the canines; the smile line; the posterior occlusal relationship; the periodontal health of the patient, and the gingival height (Miller et al., 1987; Czochrowska et al., 2003; Armbruster et al., 2005; Park et al., 2010; Kiliaridis et al., 2016; Silveira et al., 2016).

In general, space opening followed by a tooth-supported restoration and single-tooth implant is indicated for patients with Class I molar relationships with no malocclusion or for patients with Class III malocclusion with a concave profile (Tuverson, 1970; Park et al., 2010; Tai et al., 2011; Kiliaridis et al., 2016). It is noteworthy that a fixed bridge is the least conservative of all treatment options and extremely demanding, because the abutment teeth (i.e., the central incisors and the canines) should be well aligned and have their axes parallel (Kinzer and Kokich, 2005). Space closure is clearly indicated for patients with a straight profile, a Class I molar relationship, and severe lower anterior crowding; thus, the treatment of choice is canine mesialization and extraction of the lower first premolars. Otherwise, space closure is planned in patients with a Class II molar relationship without lower crowding or incisor protrusion (Tuverson, 1970; Park et al., 2010; Tai et al., 2011; Kiliaridis et al., 2016).

When replacing missing lateral incisors with single-tooth implants is planned, the alveolar ridge of the missing incisor site should be developed to hold the implant. Distal orthodontic movement of the canines may help to achieve this. The space created for the implant should be maintained until the completion of the skeletal maturation of the patient. Meanwhile, the newly formed alveolar bone undergoes some changes. Uribe et al. (2013) studied a sample of 11 patients with MLIA for whom the treatment plan was the distalization of the maxillary canines. The purpose of the Uribe study was to measure with cone-beam computed tomography the alveolar ridge width and height changes after space opening. They found that the labiopalatal width of the alveolar ridge decreases and its labial concavity increases. This factor should be resolved with bone grafting and labial inclination of the restoration crown (Uribe et al., 2013). Many authors cited in the paper by Zachrisson et al. (2011) indicated other issues related to single-tooth implants. With all changes occurring at the alveolar ridge and the adjacent teeth, the implant may be infraoccluded and protruded relative to the adjacent teeth that undergo natural eruption and uprighting. For this reason, this procedure is especially contraindicated in cases of gummy smiles because it will create disharmonious levels of the marginal gingiva (Kiliaridis et al., 2016). The labial bone will undergo resorption, which will cause a blue area on the gingiva. Gingival recession and dark margins along the crown may happen, along with changes in the interdental gingiva with incomplete filling of the interdental space by the papilla and with bone loss on the neighboring teeth (Silveira et al., 2016). Furthermore, a main problem with the single-tooth implant is maintaining the space created until the end of a patient's growth period. During the extended treatment time, patients with a lack of good esthetics experience lower self-esteem and psychosocial pressure (Turpin, 2004). Moreover, maintaining the space means tipping the canine and the central incisor apices towards each other (Silveira and Mucha, 2016), which can be avoided by a bonded lingual retainer with a prosthetic tooth (Kokich et al., 2011). In addition, Kokich et al. (2011) indicate that the most important advantages of the single-tooth implant are its high success rates and that it leaves the adjacent teeth untouched.

With space closure, the canine and first premolars are not in their normal position in the dental arch. Therefore, occlusion, shape, and esthetics are affected by this treatment option. However, authors and clinicians resort to different tips and tricks to avoid mediocre results. Biggerstaff (1992) preconized slightly distal bracket placement on the first premolars to rotate their palatal cusps distally, and thus help to eliminate working and balancing interferences. As a consequence, there is no need to minimize these cusps, although it is required in some cases of a negative crown torque of the first premolar to simulate the canine root eminence. The first premolar should also undergo labial offset to resemble the canine (Tuverson, 1970). Positive crown torque and labial offset of the canine are needed to have more palatal root torque to reduce the canine eminence, and thereby have better interproximal contact with the central incisors and to diminish occlusal stress on the mandibular incisors (Tuverson, 1970; Zachrisson et al., 2011; Lombardo et al., 2014; Kravitz et al., 2017). Zachrisson et al. (2011) and Lombardo et al. (2014) advise performing a customized intrusion of the first premolar and extrusion of the canine to have a correct gingival margin alignment. At the beginning of the treatment, grinding approximately 1 mm from the palatal surface of the canine is also advocated to prevent interference with the lower incisors (Tuverson, 1970; Lombardo et al., 2014). Reshaping the canine, namely: mesiodistal grinding, incisal tip reduction, and labial surface flattening is likewise required to simulate the shape of the lateral incisor (Tuverson, 1970; Zachrisson et al., 2011).

The permanent results with a stable alveolar ridge height and accomplishing treatment early in adolescence are the important advantages of space closure by canine substitution (Tuverson, 1970; Zachrisson et al., 2011). The need to wear a removable or bonded retainer to maintain the space created for the implant is thus eliminated; however, it is possible to place porcelain veneers on the anterior teeth because they are not contraindicated in teenagers (Zachrisson et al., 2016). It is noteworthy that this treatment option is cheaper than a dental implant (Kiliaridis et al., 2016). A disadvantage is the risk that the space closed by the mesialization of the canines may re-open. This problem can be avoided by using a fixed lingual retainer bonded to the anterior teeth and by restoring the first premolars and central incisors so that they have proper functional occlusion with a group function on the working side (Zachrisson et al., 2011). In addition, overjet and overbite increase with a large mesiodistal canine. For this reason, the canine size must be reduced (Kokich et al., 2011). Very prominent canine root eminence may also be an obstacle in some cases of a gummy smile (Henns, 1974; Senty, 1976). An increased nasolabial angle may be an esthetic issue, although efficient bodily retraction of the incisors with their inclination maintained seems to ease this problem (Woodworth et al., 1985).

For these cases, Woodworth et al. (1985) proposed the mechanics that opens the mandibular plane and increase the facial height. They suggested closing the space via mesialization of the posterior teeth to prevent retraction of the incisors and adversely favoring the nasolabial angle opening. A facial mask or a reverse-pull headgear seems to be the most suitable for the proposed protocol because they ensure vertical control during tooth mesialization (Woodworth et al., 1985; Tabuchi et al., 2010).

Many authors studied the post-treatment effects of cases of MLIA treated with prosthetics, implants, or space closure. Rosa et al. (2016), in their retrospective study evaluated the relationship between orthodontic space closure and periodontal changes during a 10-year post-treatment period. The sample was divided into two groups: (1) the agenesis group consisting of 26 young patients treated with space closure, intrusion of the first premolars, and extrusion of the canines and (2) the control group consisting of 32 orthodontic patients with no missing teeth and no extractions. The patients with MLIA treated with space closure had good and stable periodontal health for 10 years post-treatment, as did the control group; there was no attachment loss for the uneven bone crests. In addition, there were no reports of temporomandibular joint problems: both groups had the same normal occlusal function.

Schneider et al. (2016) proved in their study that orthodontists and dentists rank implants and canine substitution as equally pleasing, but laypeople prefer space closure. This study consisted of 87 orthodontists, 100 general dentists, and 100 laypersons who ranked nine post-treatment intraoral frontal photographs. These photographs were of dentition with a canine substitution or an implant-based crown for an absent lateral incisor. In the same year, a systematic review by Silveira et al. (2016) likewise concluded that tooth-supported dental prostheses for MLIA had worse scores in the periodontal indexes, compared with those of orthodontic space closure. Space closure is evaluated as better esthetically than prosthetic replacements, and the presence or absence of a Class I relationship of the canines showed no relationship with occlusal function or with signs and symptoms of temporomandibular disorders (Kokich et al., 2011; Kiliaridis et al., 2016). Moreover, Kiliaridis et al. (2016) deduced that "the orthodontic space closure is more preferable than space opening, due to its superiority in the periodontal health and aesthetic outcome"; Silveira et al. (2016) shared the same point of view in their systematic review.

In 2000, Robertsson and Mohlin conducted a study in which they evaluated the occlusal and periodontal states of 50 treated cases of MLIA in patients who underwent space closure for canine substitution and space opening for the prosthetic replacement. The sample was divided in two groups: 30 cases of space opening and 20 cases of space closure. The patients were requested to give their opinion about the esthetic results of their treatment. Most space closure group patients were satisfied with their appearance, although they were unhappy with the shade of their canines, which were darker than the adjacent teeth. By contrast, the space opening group patients were modestly satisfied. There were no significant differences in the prevalence of signs and symptoms of temporomandibular disorders between the two groups. However, there was more gingivitis and plaque accumulation in the space opening group. The space closure group seemed to have more stable results with better esthetics.

In a special article under the Point/Counterpoint Series published in the *American Journal of Orthodontics and Dento-Facial Orthopedics*, Zachrisson et al. (2011), who are the proponents of canine substitution, and Kockich et al. (2011), who are the proponents of restorative replacement, meticulously covered the topic of the treatment options in cases of congenitally missing maxillary lateral incisors. The teams showed the advantages and disadvantages, as well as the indications and contraindications, of each treatment option. They agreed on two points: (1) the use of an interdisciplinary treatment approach is beneficial to obtain the most predictable outcome and (2) the candidate for canine substitution should ideally have a nice profile, a Class II dental relationship, and no crowding in the mandibular arch.

Zachrisson et al. (2011) summarized well the dilemma between space closure and single-tooth implants: "An argument in favor of closure is that eventual complications with the noninvasive or minimally invasive procedures are relatively easy to redo, correct, or repair, whereas complications with implant crowns are difficult, if at all possible, to amend."

Continuing the debate on the pros and cons of canine substitution, Schneider et al. (2016) proved that orthodontists and dentists rank implants and space closure equally pleasing, but laypersons prefer canine substitution. Silveira et al. (2016) in their systematic review also found worse scores for periodontal indexes in cases of tooth-supported dental prostheses than in cases of orthodontic space closure. The second option was evaluated as better esthetically, compared with prosthetic replacements. Furthermore, presence or absence of Class I relationship of the canines showed no relationship with occlusal function or with signs and symptoms of temporomandibular disorders.

Nonetheless, implant replacement was favored in the evaluation of the dentoalveolar and skeletal widths in both unilateral (UMLIA) and bilateral (BMLIA) maxillary lateral incisor agenesis groups by Buyuk et al. (2017) and an investigation by Bassiouny et al. (2016) in the sagittal plane. Their results confirmed that the UMLIA and BMLIA groups, respectively, had statistically significantly smaller values for the maxillary intercanine, maxillary intercanine alveolar, and skeletal maxillary widths, compared with the control group, and that patients with MLIA had a significant tendency for skeletal Class III. This finding could be attributed to maxillary hypoplasia/retrognathia, which requires maxillary expansion rather than constriction. Thus, it may be concluded that whether to gain space or substitute in conventional treatment of MLIA apparently remains open and questionable.

1.10. Temporary intraoral skeletal anchorage devices or temporary anchorage devices: their role in contemporary orthodontics

Controversy over the choice of treatment method would probably be in vain. However, the fact cannot be ignored that TADs or TISADs have revolutionized what the treatment of malocclusion can do for patients, and thus expand the limits of conventional orthodontics.

Optimal locations for TADs are precisely determined, which facilitates predictable treatment outcomes. There appears to be more space for placement in the mandible than in the maxilla (Kau et al., 2010). Chaimanee et al. (2011) conducted a study to determine the safest zones for TAD placement in the maxilla and in the mandible. They analyzed the periapical radiographs of 60 patients and they measured at each interradicular site the interradicular space at different depths from the alveolar crest. They found that the safest zones are the spaces between the second premolar and the first molar in the maxilla, and between the first and second premolars and the first and second molars in the mandible. Eventually, they concluded that “greater dental inclination presented with less interradicular space, whereas more upright teeth presented with more interradicular space.” Thus, it may be stated that the availability of the interradicular space is influenced by the inclination of the adjacent teeth.

Wilmes et al. (2008), Wilmes and Drescher (2008), Baumgaertel (2008), Baumgaertel et al. (2008), and Wilmes et al. (2009) have described the miniscrew-supported T-wire, which is bonded on the palatal surface of the central incisors for indirect anchorage and thus avoids lingual tipping of these teeth during space closure. This noncompliance system utilizes a prefabricated, fixed U-shaped wire welded to a miniplate splinting the two palatally inserted miniscrews, and provides stationary skeletal anchorage for various forms of protraction mechanics. The T-wire maintains the incisor positions, while segmented mesial tooth movement from posterior to anterior enables minor space closure. For closing wider spaces and even incisor protraction, Wilmes and Drescher (2008) and Wilmes et al. (2009) proposed the miniscrew-supported Mesialslider. This noncompliance system utilizes a prefabricated, fixed U-shaped wire welded to a miniplate splinting two palatally inserted miniscrews, and provides stationary skeletal anchorage for various forms of protraction mechanics. In turn, Ludwig et al. (2013) later introduced the T-Mesialslider, which combines the elements and properties of the T-wire and the Mesialslider for treating patients with missing maxillary lateral incisors. The main advantage of a system using splinted palatal TISADs is that the stability and success rate are much greater for the screws than for labially inserted TISADs in the maxilla or mandible (Wilmes et al., 2009; Ludwig et al., 2013). This approach constituted a new concept of controlling reactive forces, which may shed new light also on the problem of MLIA.

2. AIM OF THE STUDY

The novel approach or new opportunities of anchorage reinforcement, and all hitherto presented evidence-based approaches to MLIA automatically provoke a scientific question: is it possible to substitute canines using TADs without compromising the dimension of the maxilla and achieve esthetically pleasing results if the patient with congenitally missing lateral incisors does not present with Class II malocclusion? To answer this question, I designed a randomized clinical prospective study to validate whether closing the space by protraction of the maxillary dentition with mandibular skeletal anchorage devices is a viable treatment option for patients with MLIA and Class I or Class III tendency.

In consideration of all contemporary techniques and approaches available, I established two null hypotheses related to the novel concept of MLIA treatment in Class I/III patients:

1. Protraction the maxillary dentition and thus obtaining functional and esthetic occlusion are possible, regardless of the deficiency of the maxilla and
2. Canine substitution of missing lateral incisors neither violates axial inclination of the central incisors, nor deteriorates the facial features.

3. MATERIALS AND METHODS

3.1. Selection of the study group and the treatment protocol

The study project obtained approval by two ethics committees: (1) the Ethics Committee of the Wroclaw Medical University (Wroclaw, Poland; no. 48/XV2/2011) on October 24, 2013 and (2) the Ethics Committee of the Lower Silesian Medical Union (no. KB/517/2013) on July 24, 2013.

The materials comprised generally healthy patients who met the following criteria:

a) Two congenitally missing upper lateral incisors or one missing upper lateral incisor and a riziform (i.e., peg-shaped) contralateral incisor (Figs. 1a and 1b).

a 

b 

Fig. 1. Initial intraoral pictures of randomly selected patients with: a) BMLIA, b) UMLIA
BMLIA, bilateral maxillary lateral incisor agenesis
UMLIA, unilateral maxillary lateral incisor agenesis

b) Skeletal Class I or Class III tendency or a mild skeletal Class III, which presented as follows (Fig. 2):
   i. an average ANB value of 0º (ranging from -12º to <4º)
   ii. an average Wits appraisal value of -3 mm (ranging from -14 mm to <4 mm).

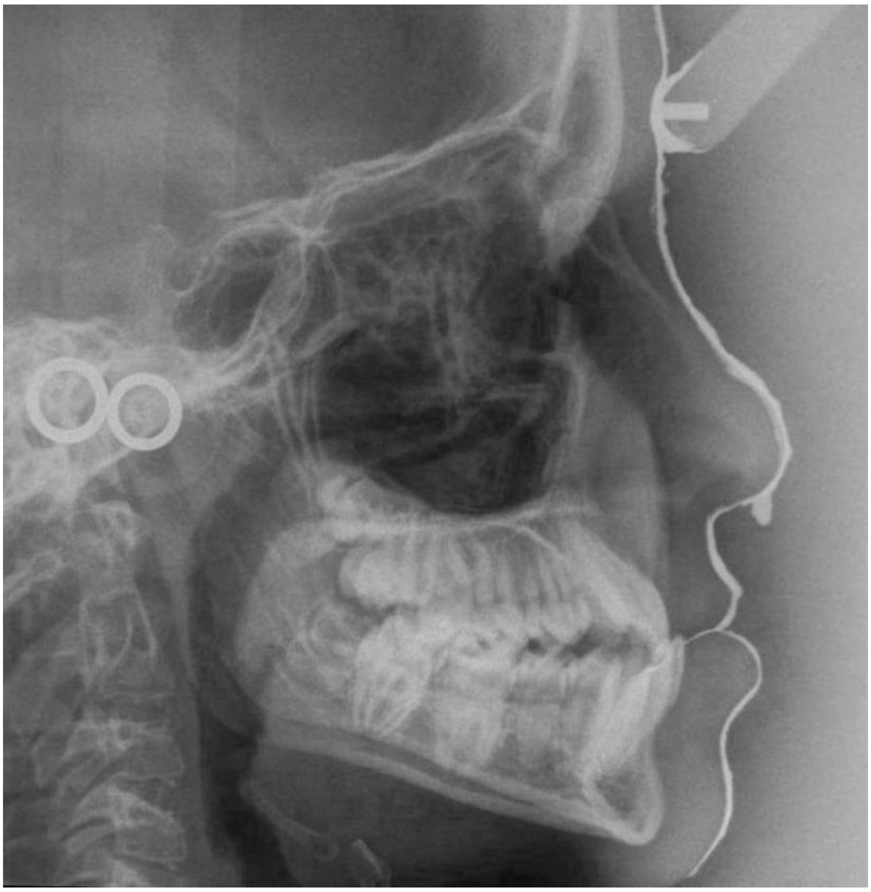


Fig. 2. The initial lateral cephalometric x-ray image of a randomly selected patient with Class III

c) A dentoalveolar discrepancy in the mandible of less than 5 mm (Fig. 3); no retraction was required in the mandible, except for the 3rd molars.

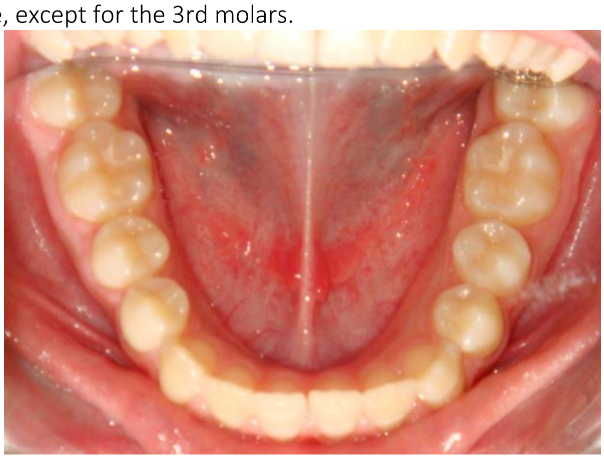
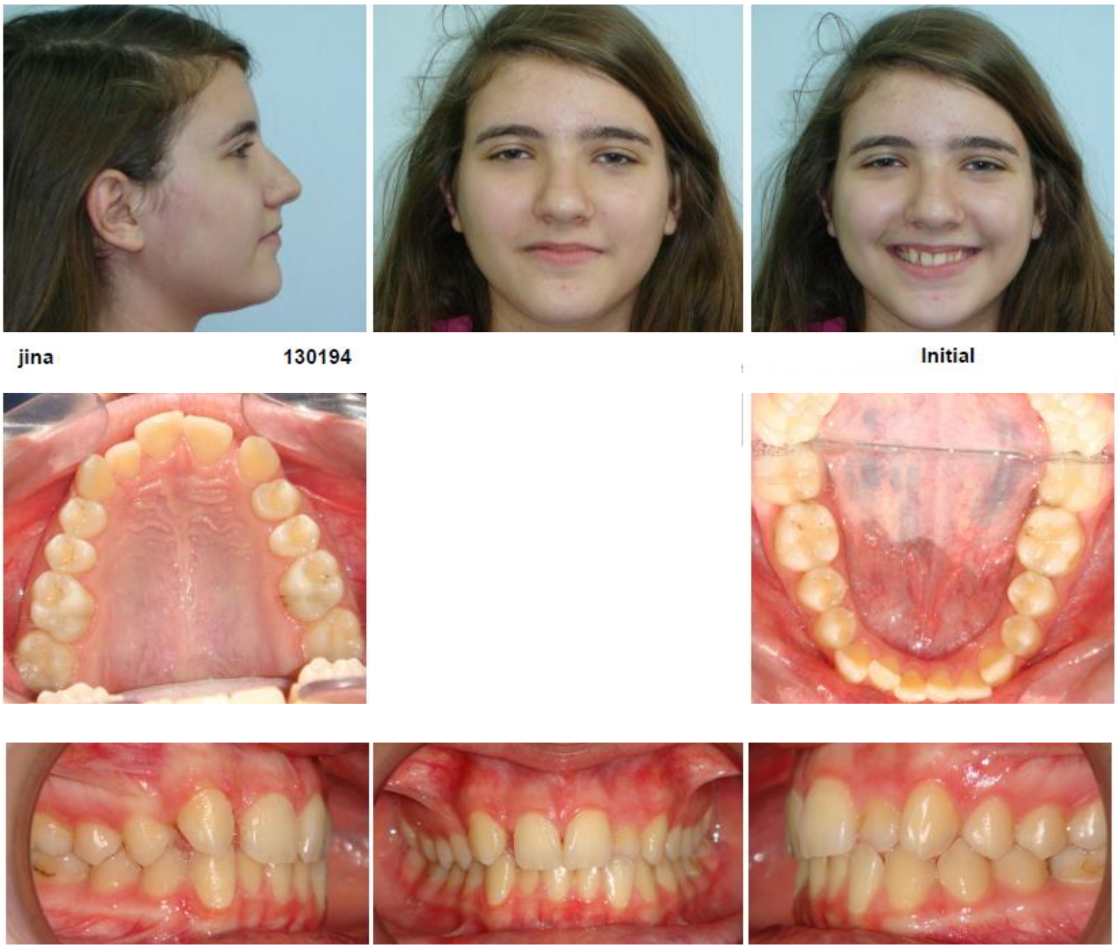


Fig. 3. Initial intraoral image of a randomly selected patient's mandibular arch without dentoalveolar discrepancy

After providing patients a detailed explanation of the advantages and disadvantages of the canine substitution versus conventional space opening for implant placement, based on the literature, I asked the patients to sign a consent form. The study group ultimately consisted of the first consecutive 30 individuals who accepted the treatment plan with canine substitution.

Before beginning treatment (T1) in all patients, I obtained initial records (Figs. 4a–4c), which included extra- and intraoral photographs. I obtained digital models via scanning the plaster models (TRIOS 3 Mono; 3Shape, Copenhagen, Denmark) and I took x-ray images: orthopantomogram and lateral cephalogram.



a

OrthoAnalyzer 3shape

PATIENT

- **ID:** 11
- **SSN:**
- **Name:** 11- jina
- **Address:**
- **City:**
- **Country:**
- **Clinic ID:**

CASE

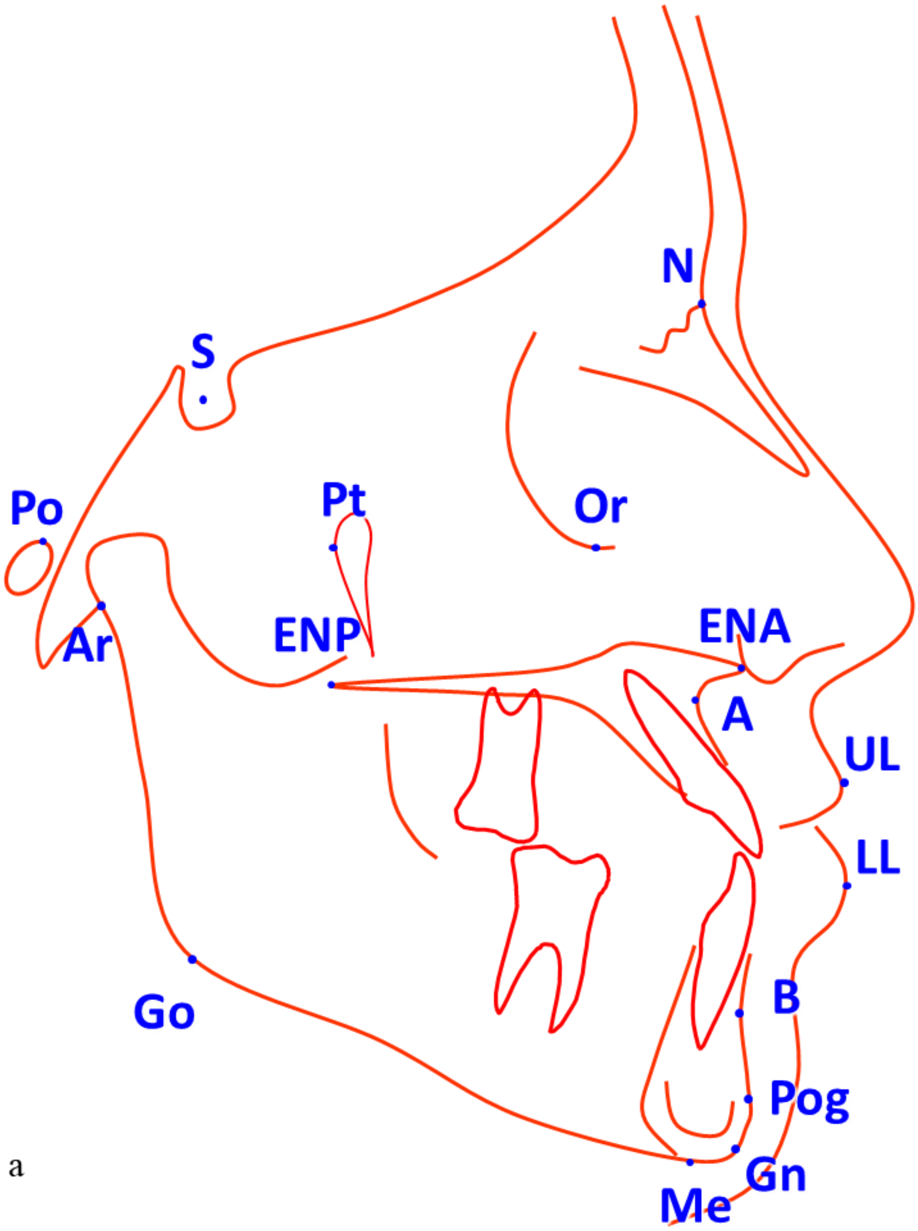
- **ID:** i
- **Operator:**
- **Comment:**
- **Date:**
- **Scan date:**

b

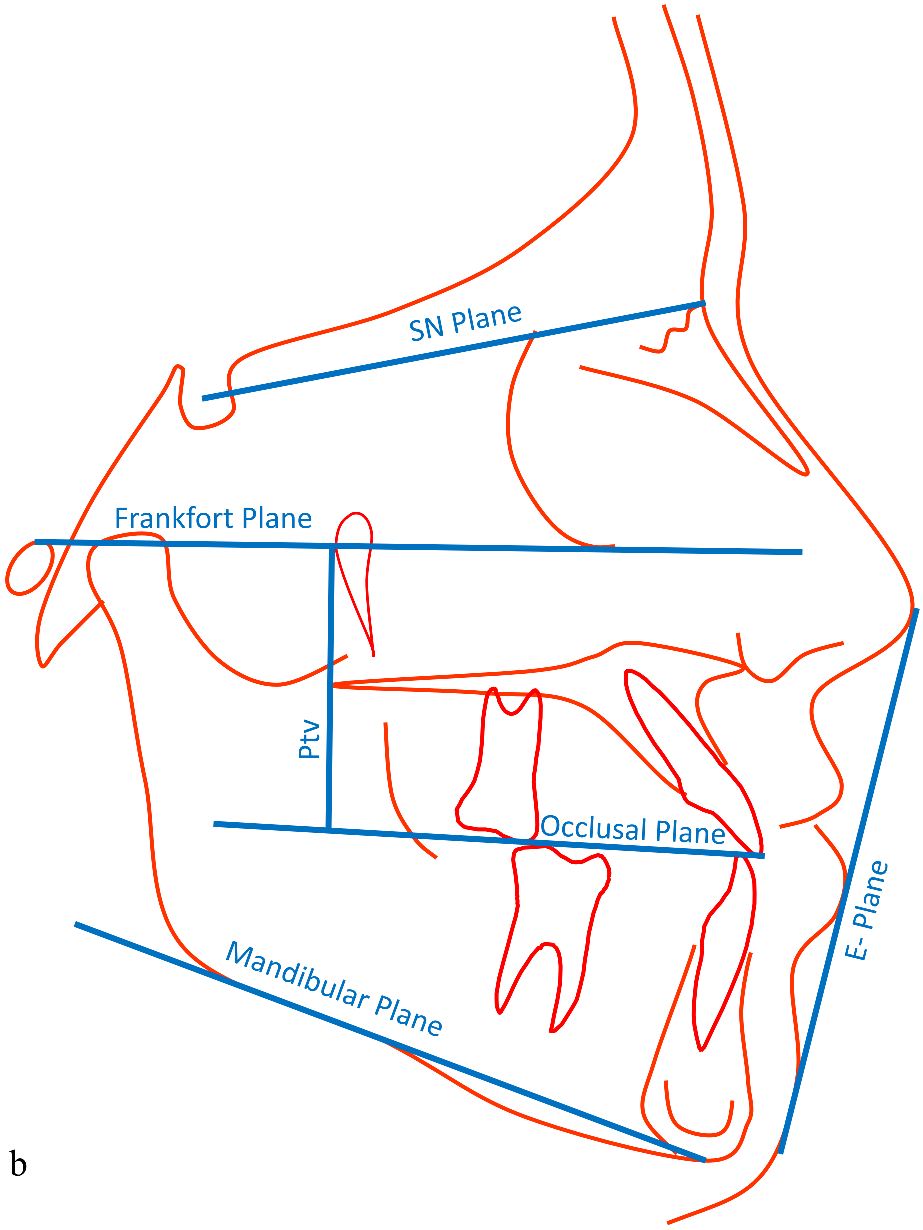
c 

Fig. 4. Initial (T1) records of a randomly selected patient (Patient #11) enrolled in this project. a) The patient's extra- and intraoral photos, b) the digital models, and c) the patient's orthopantomogram and cephalogram

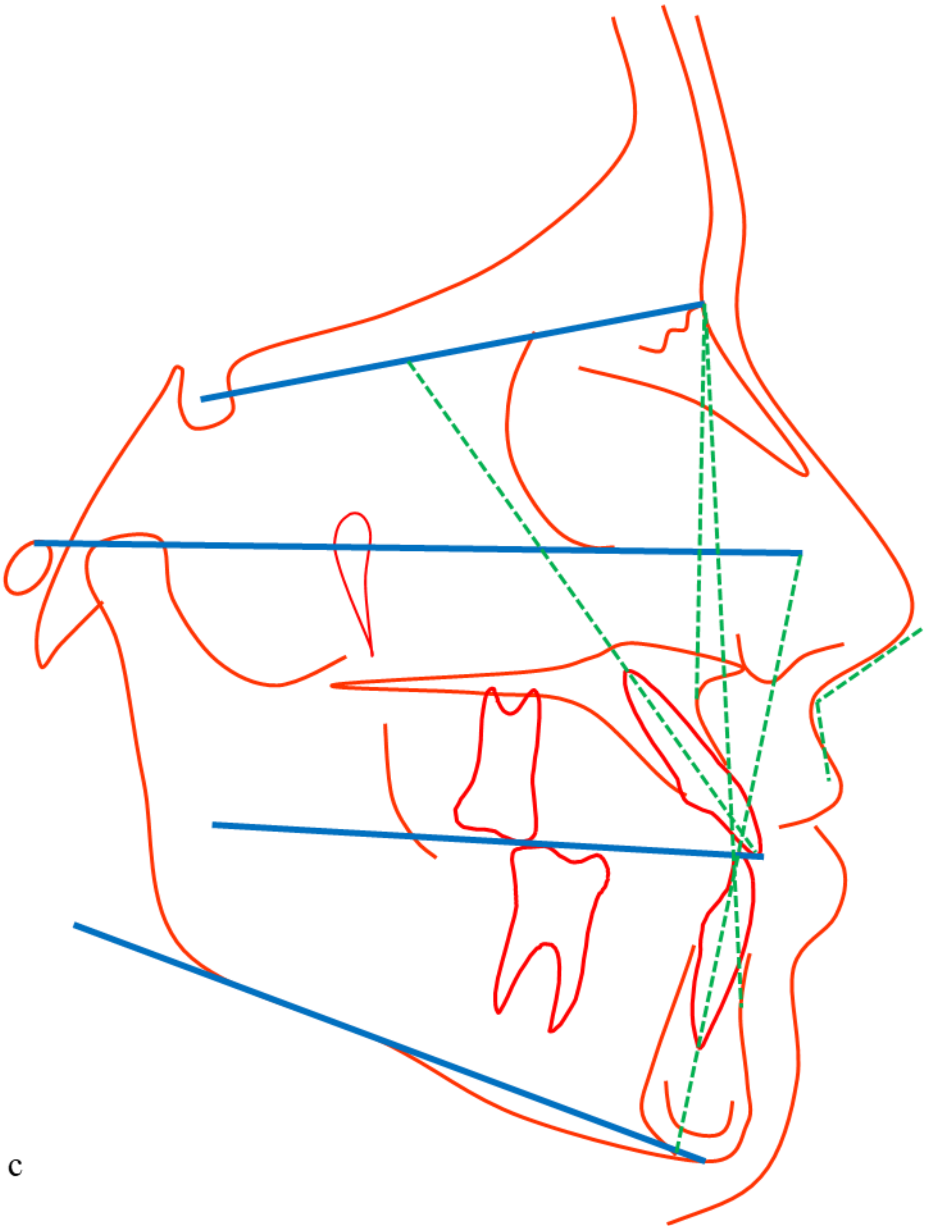
All lateral cephalograms were calibrated and introduced into the software for analysis (Joe Ceph; Rocky Mountain Orthodontics, Denver, CO, USA). A single operator took all measurements (Figs. 5a–5d), although 10 randomly selected x-ray images were cross-evaluated with regard to the points insertion accuracy.



a


SN Plane
Frankfort Plane
Ptv
Occlusal Plane
Mandibular Plane
E- Plane

b



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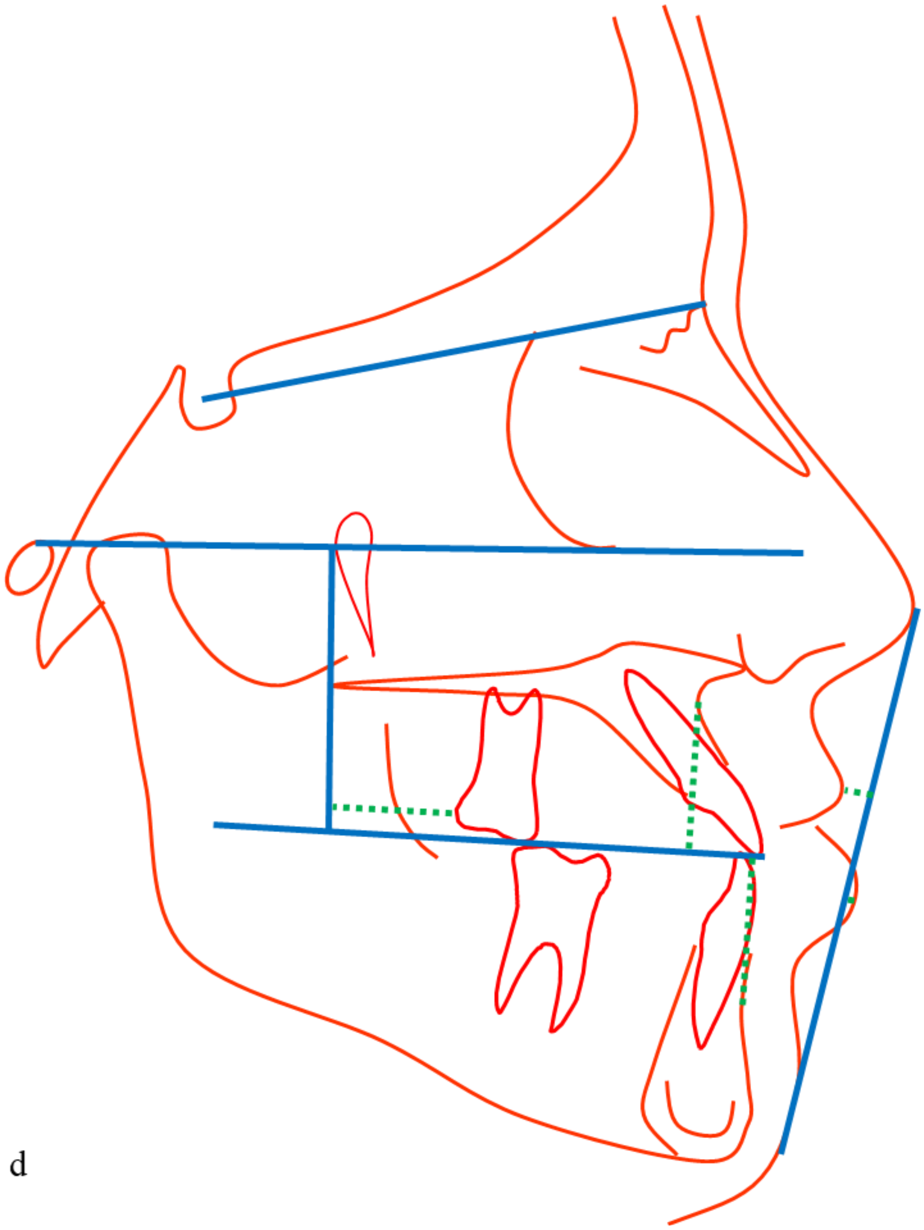


d

Fig. 5. Cephalometric analyses. a) The points, b) planes, and c) angles are as follows: sella–nasion–A point (SNA), sella–nasion–B point (SNB), A point–nasion–B point (ANB), Frankfort to mandibular plane (FMA), lower incisor axis to mandibular plane (IMPA), Frankfort plane to mandibular incisor axis (FMIA), occlusal to Frankfort plane (OccPl), lower incisor axis to NB line (LI-NB), upper incisor axis to SN line (UI-SN), upper incisor axis to NA line (U1-NA), and nasolabial angle (NL-Angle, which is formed by the bottom of the nose or subnasal and the upper lip). (d) The distances are as follows: AO-BO (Wits appraisal), distal surface of the maxillary first molar to the pterygoid vertical line (U6Ptv), lower lip to E-plane (E-LL), and upper lip to E-plane (E-UL)

Treatment began with a rapid palatal expander (RPE) mounted in the maxilla, and with banding and bonding the lower dental arch (i.e., single standard edgewise.022 brackets; canine brackets with hooks, when available; otherwise, a Kobayashi ligature was attached to the cuspid bracket), and with the insertion of an initial round nickel-titanium (NiTi) archwire (.016”). I subsequently asked the patients to wear Class III elastics (¼ inch, 6 oz) from the upper 1st molar hooks to the lower canines (Fig. 6), along with the activation of the RPE at .25 mm per day for 2 weeks (or until the lateral crossbite was corrected in patients who had a lateral crossbite).

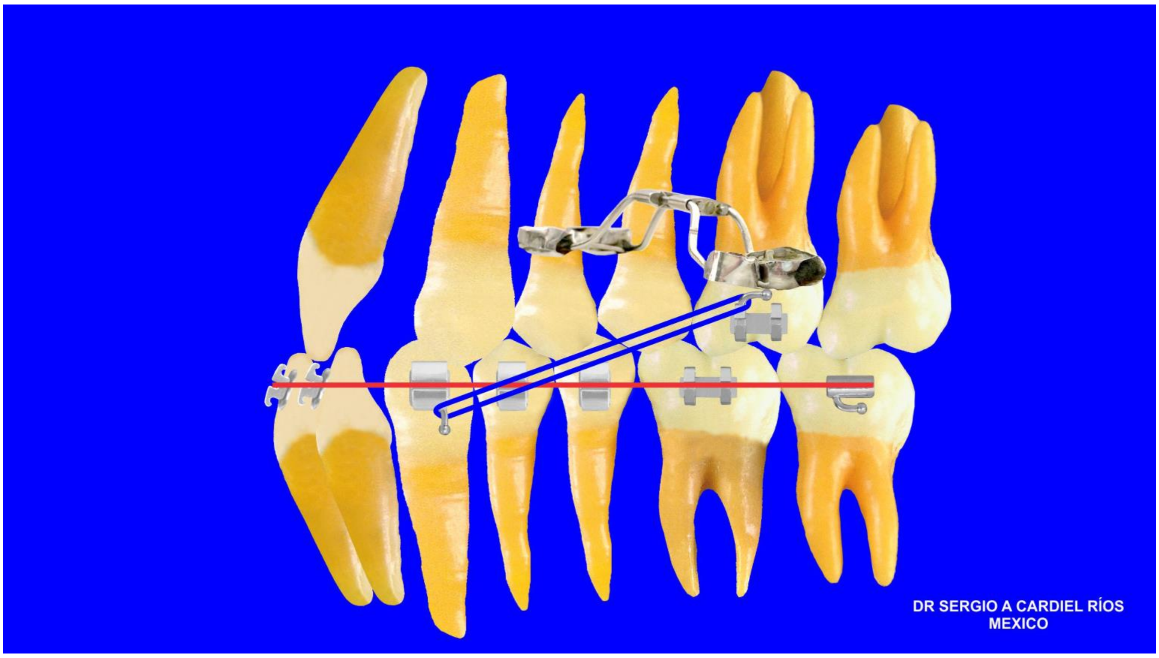


Fig. 6. A schematic drawing of an RPE and the Class III elastics
RPE, rapid palatal expander

Heat-activated NiTi wire (.019” ×.025”) was the second archwire. Patients continued to wear Class III elastics as needed to align and level the curve of Spee, with the control of the lower incisors. An SS archwire (.019” ×.025“) was inserted after the correction of all rotations. At this stage, I asked the patients to stop wearing the Class III elastics (Fig. 7).

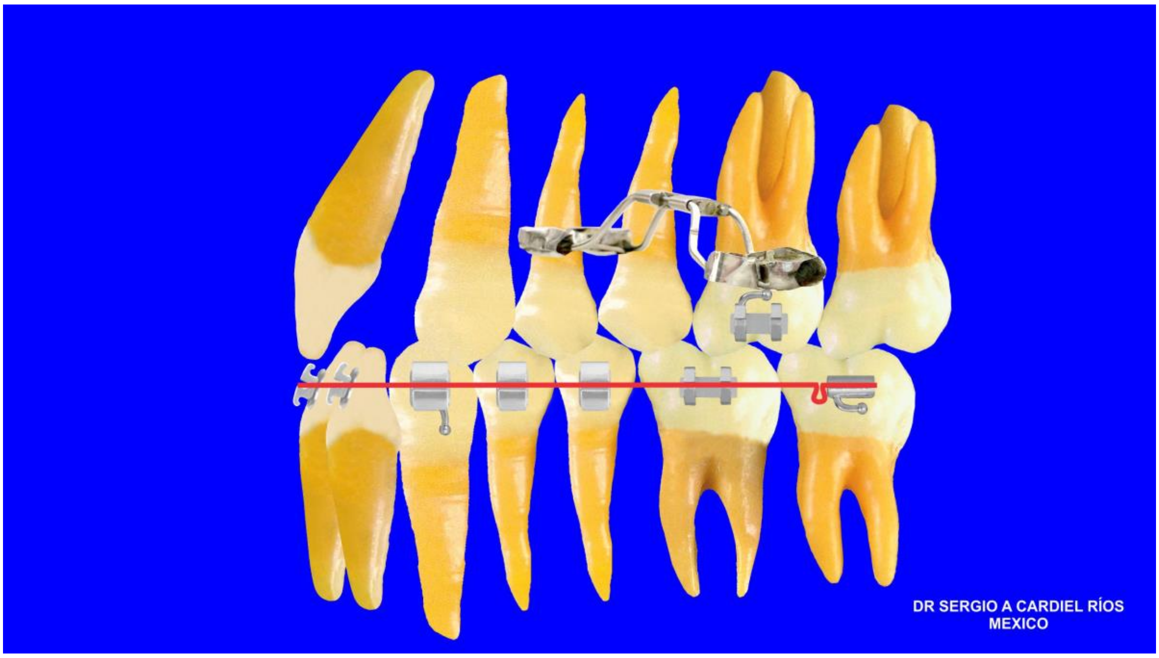
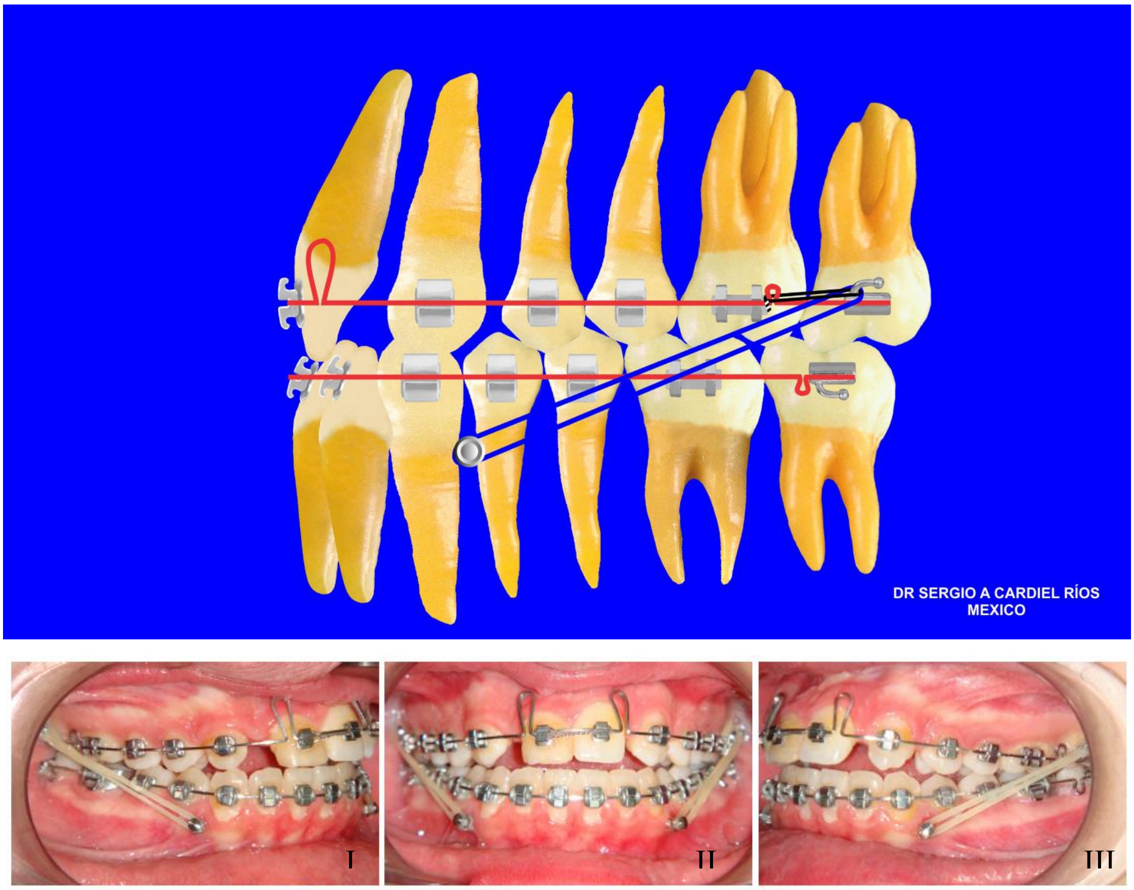


Fig. 7. A schematic drawing of the final levelling of the lower arch

A panoramic x-ray image enabled me to ensure there was (1) root parallelism and (2) sufficient space for placing the TISAD (FH 1817-08, AbsoAnchor; Dentos, Inc., Daegu, South Korea). At this stage, I removed the RPE and bonded the maxillary arch, and introduced the following archwire sequence: (1).016“ NiTi wire, (2).019” ×.025” heat-activated NiTi wire, and (3).020” ×.025” SS with closing loops positioned distally to the central incisors. Extraction of the peg-shaped contralateral lateral incisor (if present), correction of the upper midline, and placement of the TISAD preceded the insertion of the closing archwire.

Two TISADs were inserted in either of the following quadrants of the mandible: between the canine and the first bicuspid or between the bicuspids (depending on the root divergence). The TISADs were placed in the junction of attached gingiva and oral mucosa or shallower (towards the attached gingiva) in the vestibulum, with an inclination of approximately 45º to the dental axis. The TISADs loading took place 2 weeks later, with Class III elastics (¼ inch, 6 oz.) expanded to the upper second molars (Figs. 8a and 8b).



a

b

Fig. 8. Class III elastics on the TISADs and the closing upper archwire. a) A schematic drawing. (b) In-vivo intraoral images of (I) the right side, (II) en face, and (III) the left side
TISAD, temporary intraoral skeletal anchorage device

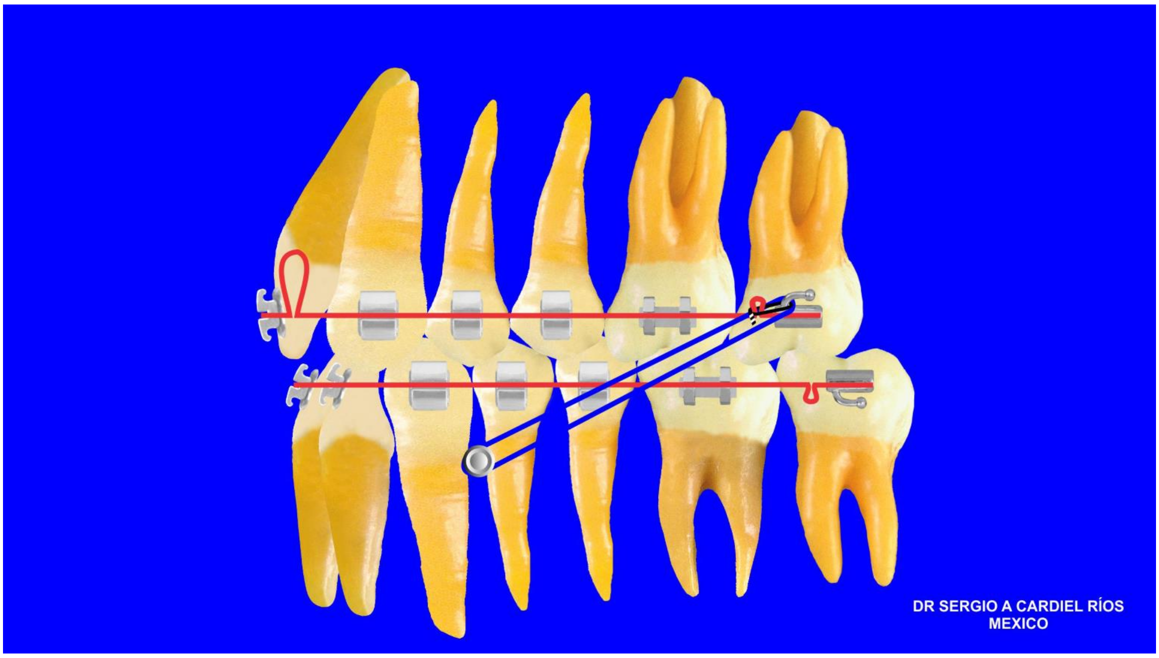


Fig. 9. Schematic drawings simulating Class III elastics on the TISAD and the closing upper archwire after a 1-mm to 2-mm overcorrection of overjet
TISAD, temporary intraoral skeletal anchorage device

On obtaining 1 to 2 mm or more of overjet overcorrection, I proceeded with the activation of the closing loops of the upper .020” ×.025” SS archwire (Fig. 9).

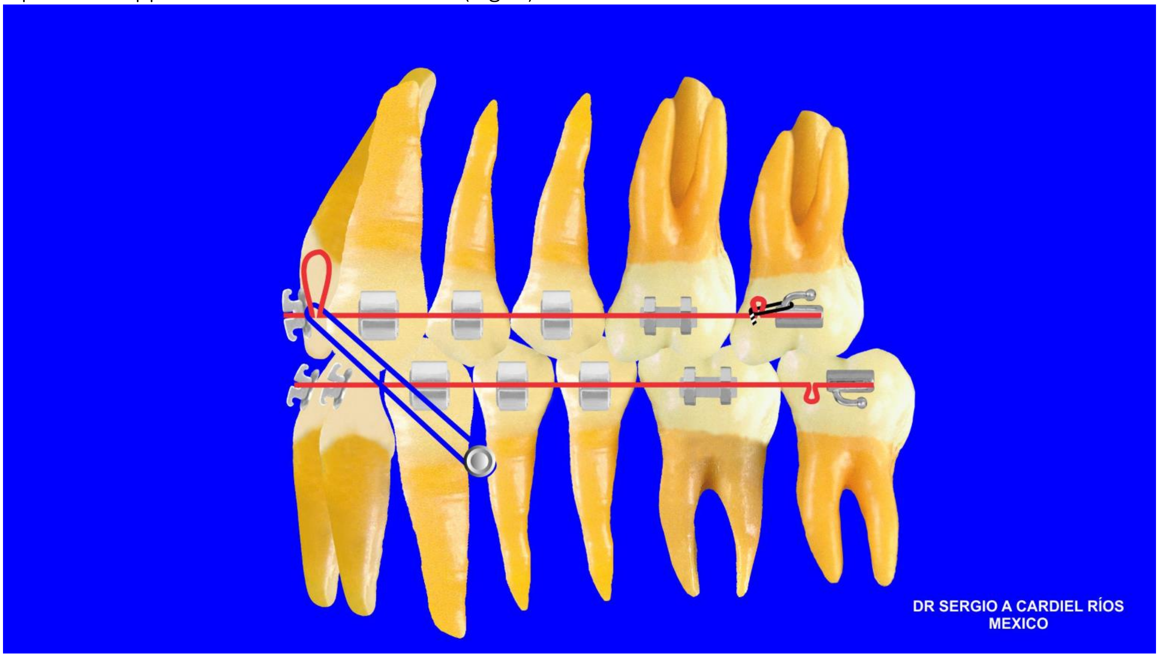


Fig. 10. A schematic drawing of the mechanics after the closure of spaces between the lateral and the central incisors: settling with “up and down” elastics from the upper loop to the TISAD
TISAD, temporary intraoral skeletal anchorage device

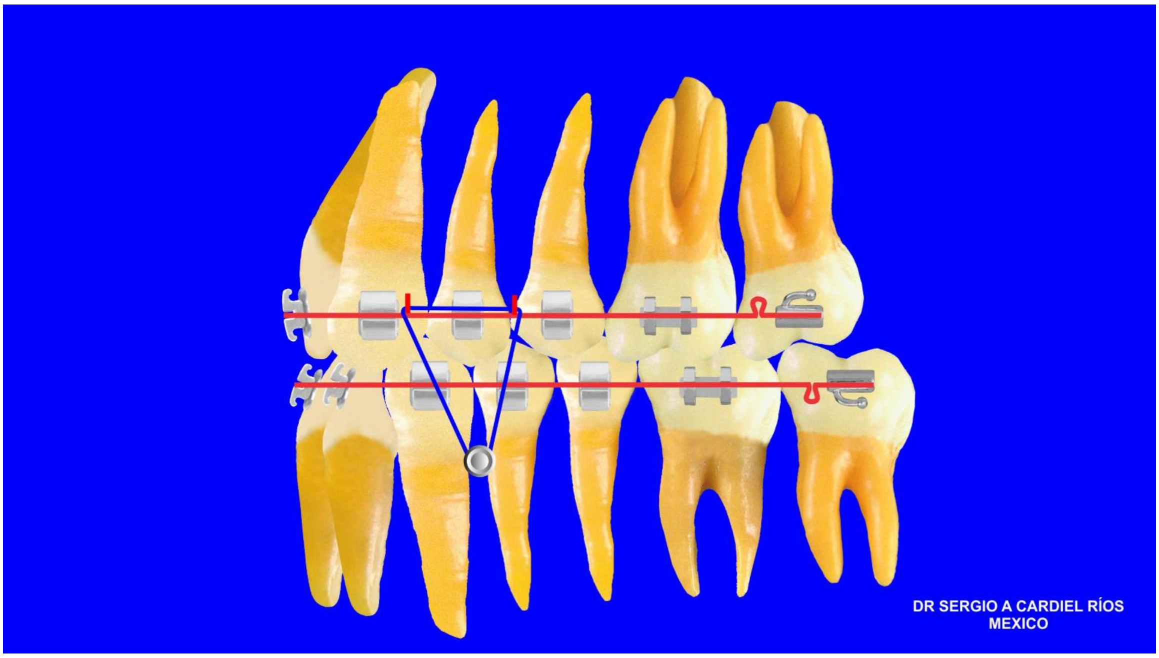


Fig. 11. The schematic drawing simulates “up and down” elastics from the upper archwire to the TISAD to monitor smile esthetics and the smile arc

TISAD, temporary intraoral skeletal anchorage device

After the closure of the spaces between the lateral and central incisors, “up and down” elastics with or without Class III ones on the TISADs (Fig. 10) helped to monitor the overjet and the overbite and to maintain an overcorrection of 1 mm to 2 mm. I finally introduced “up and down” elastics to seat the occlusion from the upper arch to the lower arch or to the TISADs (Fig. 11), based on the smile arc course and the need of egression the upper anterior teeth.

After removing the TISADs, I inserted upper and lower finishing archwires (.020” ×.025“) with intermaxillary elastics, if needed (Fig. 12), until finishing the case with a proper occlusion (Fig. 13).

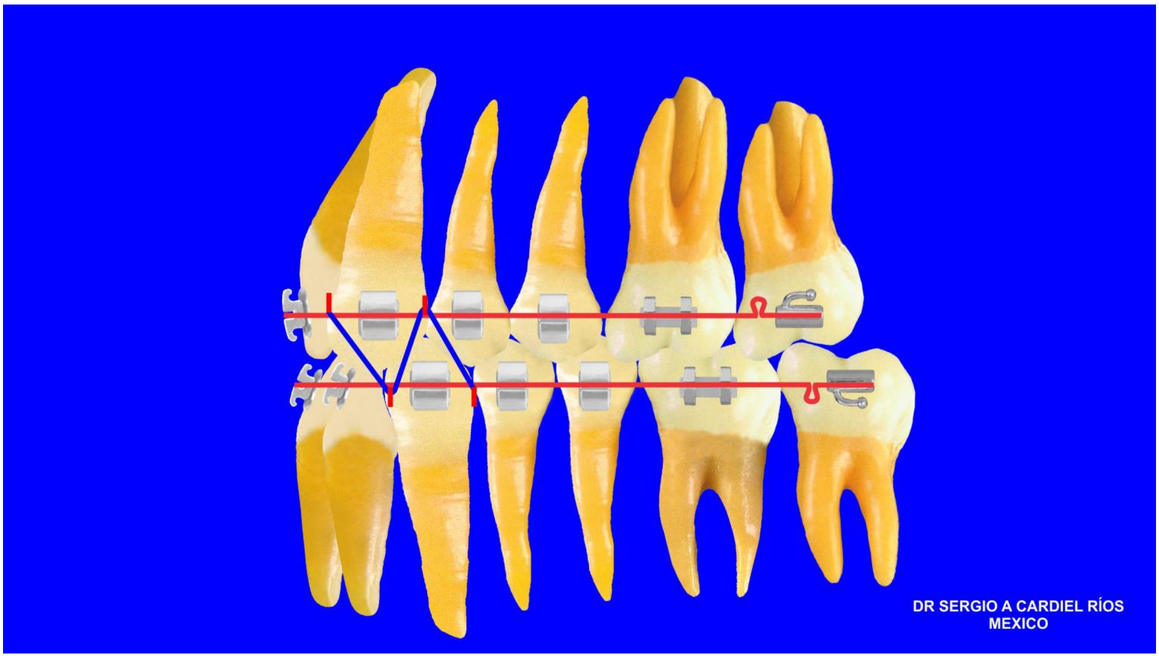


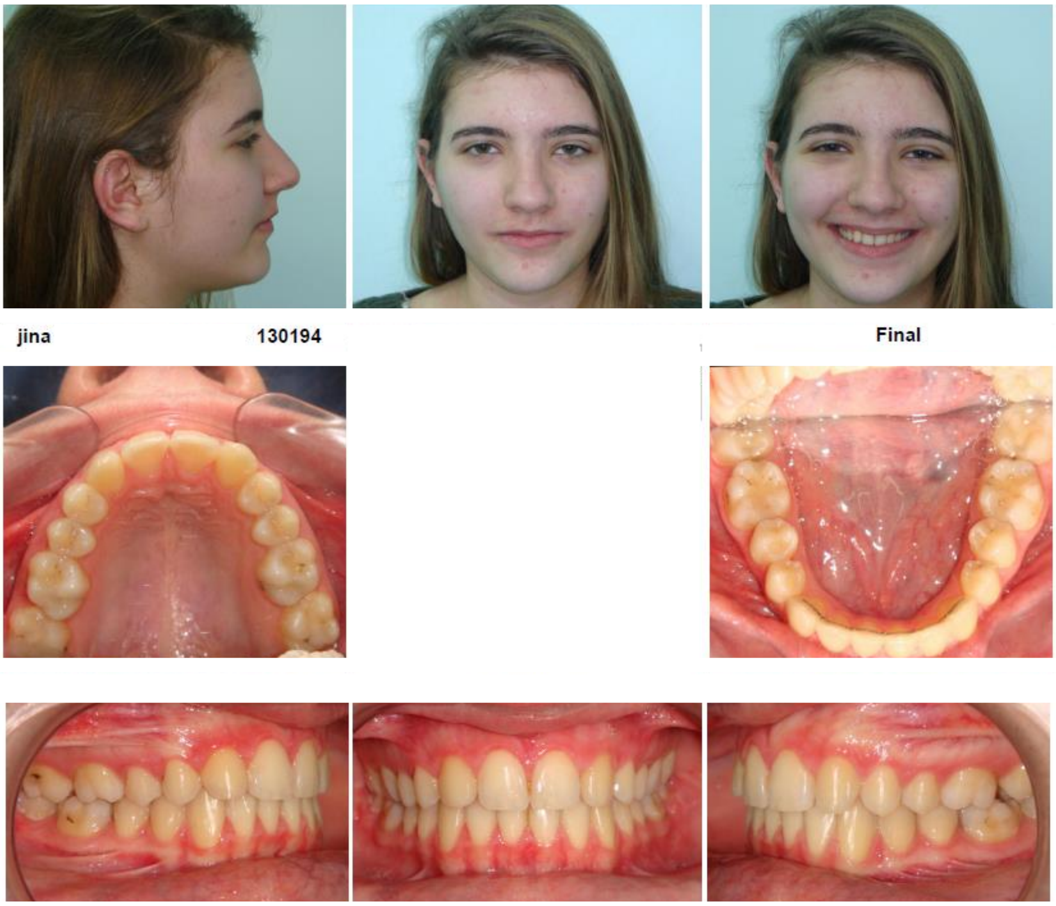
Fig. 12. Schematic drawing simulating the upper and lower finishing archwires (.020” × 025” SS archwires) with intermaxillary elastics (if needed) inserted after removing the TISADs

TISAD, temporary intraoral skeletal anchorage device

For the retention protocol, I applied a lingual retainer bonded from 33 to 43 and a removable thermoformed upper retainer.

One month after debonding (T2), I took the final records (Figs. 14a–14c) and applied the same protocol as at T1 stage.

Fig. 13. A schematic drawing simulating the end of treatment (T2), and shows the proper occlusion after the removal of the appliances



a

OrthoAnalyzer 3shape

PATIENT

- **ID:** 11
- **SSN:**
- **Name:** 11- jina
- **Address:**
- **City:**
- **Country:**
- **Clinic ID:**

CASE

- **ID:** f
- **Operator:**
- **Comment:**
- **Date:**
- **Scan date:**

b

c

Fig. 14. Final (T2) records of a randomly selected patient (Patient #11) enrolled in this project. The images show the patient's a) extra- and intraoral photos, b) digital models, and c) orthopantomogram and cephalogram

At this time, I provided a digital simulation of veneers to help patients decide whether they wanted composite restorations done by their restorative dentists.

3.2. Protocol for the evaluation of records

All patients after treatment presented with a harmonious face, normalized occlusion in terms of esthetics, functional triads and guidance, as well as with root parallelism and no signs of root resorption in the final orthopanthomograms. Figure 15 shows exemplary visualization of skeletal and dental configurations, based on the determined treatment goal, as a superimposition of the pre- and post-treatment cephalogram tracings.

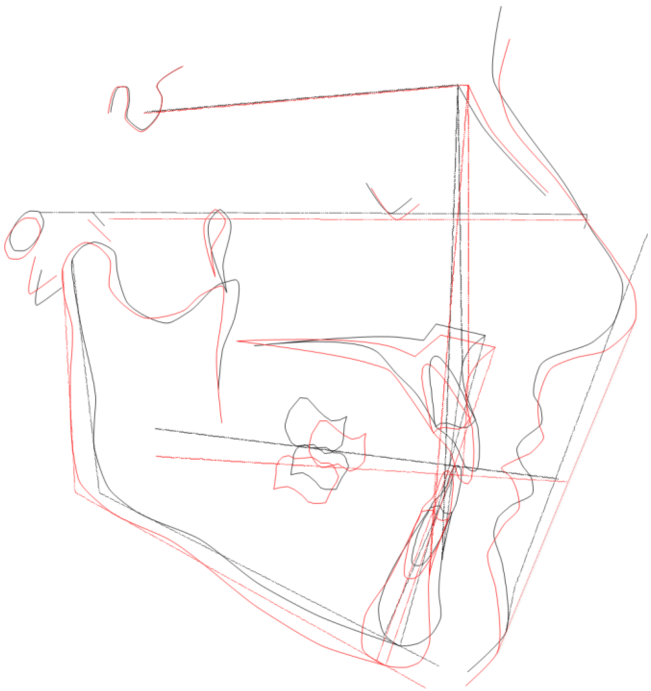


Fig. 15 Superimpositions of pre- and post-treatment cephalogram tracings of a randomly selected patient (Patient #11) enrolled in this project

All initial and final 3D model files were loaded into a software program (OrthoAnalyzer; 3Shape), which enabled the assessment of the occlusal treatment outcomes, based on the PAR index (Fig. 16).

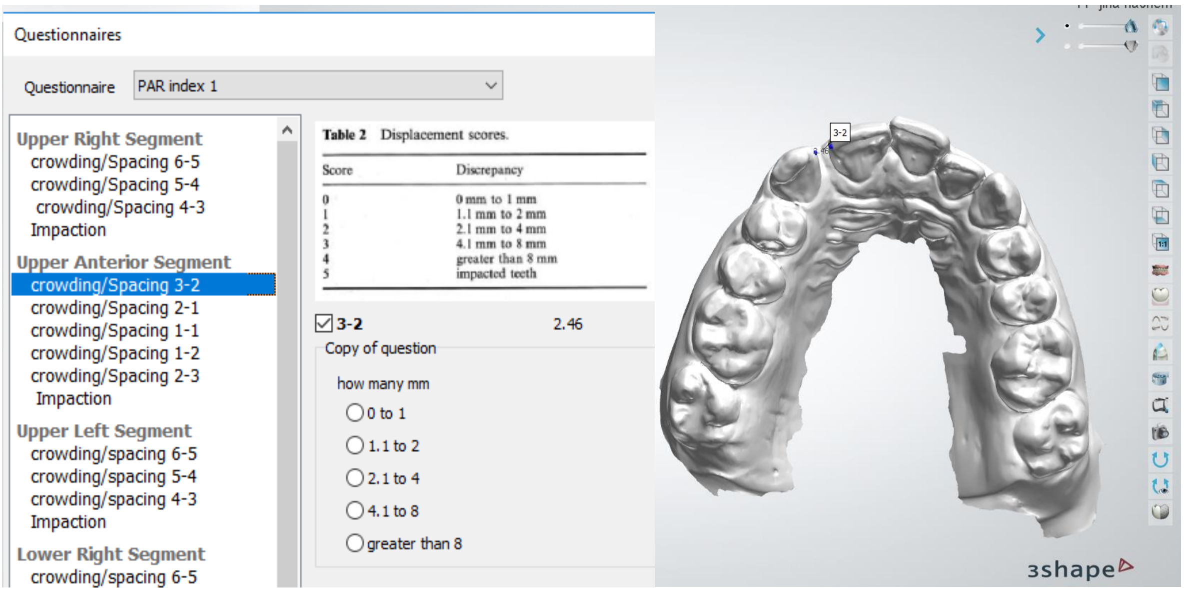


Fig. 16. A screenshot image taken during the PAR index measurements on the OrthoAnalyzer (3Shape, Copenhagen, Denmark)
PAR, peer assessment rating

At least 6 months after the end of treatment, two photographs of the close-up view of the patient's smile before and after treatment were sent to each patient, together with a visual scale with scores ranging from 0 to 10. To do so, we asked a third party to apply an instant messaging phone application (WhatsApp, Inc., Menlo Park, CA, USA). All patients were asked for a self-assessment of the treatment outcome in terms of smile esthetics (Figs. 17a and 17b).

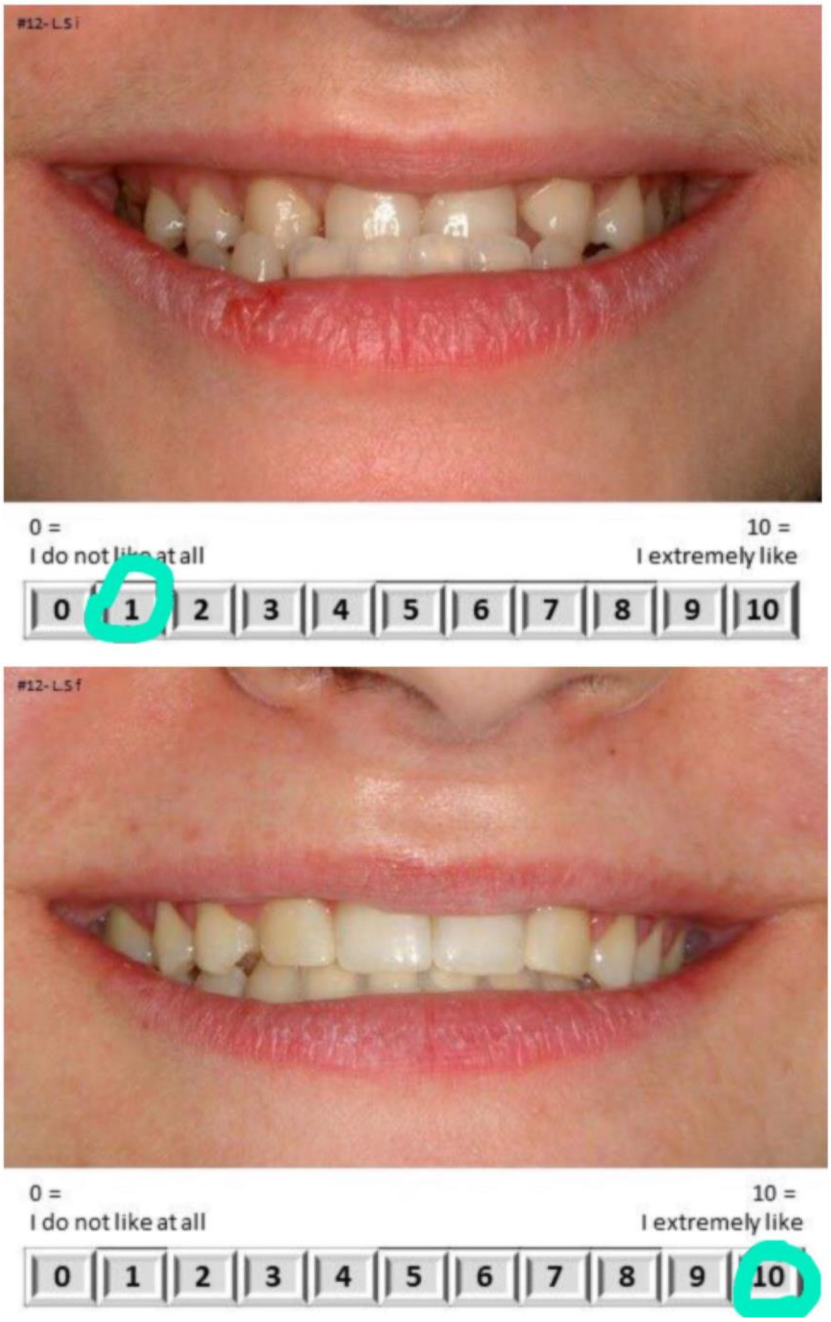


Fig. 17. Close-up views of the smile sent back by the patient through the WhatsApp phone application (Menlo Park, CA, USA) and after their evaluation using the VAS. a) initial and b) final images
VAS, visual analog scale

To verify the two null hypotheses of the aim of presented study, I compared and analyzed all pre- and post-treatment measurements (i.e., the measurement differences between the T1 and T2 stages).

3.3. Statistical analyses

Statistical analyses were performed using a software program (SPSS for Windows, version 22.0, Chicago, IL, USA). The level of significance was set at $p = 0.05$. Normality distribution was assessed using the Kolmogorov–Smirnov test. Paired Student *t* tests or Wilcoxon tests were used to compare continuous variables before and after treatment. The 95% confidence interval of the mean measurements for each parameter was also calculated.

4. RESULTS

Thirty patients (12 male patients and 18 female patients; mean age, 16.3 ± 4.9 years) were included in this study. The mean age of the male patients and female patients was 15.4 ± 4.6 years and 16.9 ± 5.2 years, respectively. The mean effective treatment time lasted 32 ± 6.2 months, and ranged 22–43 months (Table 1). Eight patients decided to have their canines recontoured. All variables studied in this project had a normal distribution, based on the Kolmogorov–Smirnov test (Table 2).

Table 1. Descriptive results of the sample size, based on the sex, age, and treatment time

#	Patient's initials	Sex	Age (years)	Effective treatment time (months)
1	ah	F	12.5	39
2	bh	F	13.75	22
3	ca	F	17.25	33
4	cc	F	15	43
5	cb	F	13.08	36
6	ec	M	15.33	26
7	ge	M	13.41	29
8	gk	M	11.5	36
9	ha	M	28.75	33
10	jz	M	18.08	30
11	jh	F	14.91	24
12	ls	F	23.08	25
13	mz	M	15.58	42
14	mn	F	11.75	40
15	mh	M	12.16	40
16	mh	F	15.66	31
17	rh	F	28.41	39
18	sk	F	15.25	34
19	sa	F	18.25	30
20	yj	F	10.33	27
21	yk	F	13.08	35
22	ym	M	13.33	27
23	zz	M	17	43
24	cf	M	13.16	23
25	ck	F	14.83	30
26	mf	M	13.25	27
27	mb	F	16.5	24
28	ab	F	27.08	32
29	ra	F	23.08	31
30	gc	M	13	29

Table 2. Normality distribution of all continuous variables in the sample size

Normality distribution of variables	Kolmogorov-Smirnov		
	test result	Degree of freedom (df)	p value
SNA i	.093	30	.200
SNA f	.094	30	.200
SNB i	.105	30	.200
SNB f	.132	30	.196
ANB i	.217	30	.001
ANB f	.130	30	.200
FMA i	.077	30	.200
FMA f	.103	30	.200
IMPA i	.138	30	.149
IMPA f	.110	30	.200
FMIA i	.150	30	.085
FMIA f	.145	30	.108
OccPl i	.111	30	.200
OccPl f	.097	30	.200
L1-NB i	.134	30	.180
L1-NB f	.085	30	.200
U1-SN i	.120	30	.200
U1-SN f	.148	30	.091
U1-NA i	.100	30	.200
U1-NA f	.126	30	.200
NL-Angle i	.104	30	.200
NL-Angle f	.130	30	.200
AO-BO i	.143	30	.121
AO-BO f	.132	30	.196
U6ptv i	.136	30	.163
U6ptv f	.150	30	.085
E-LL i	.157	30	.058
E-LL f	.158	30	.055
E-UL i	.141	30	.131
E-UL f	.116	30	.200
And U6ptv LL-UL i	.146	30	.102
LL-UL f	.159	30	.053
PAR i	.102	30	.200
PAR f	.263	30	.000
PARW i	.268	30	.000
PARW f	.400	30	.000
Smile VAS i	.299	30	.000
Smile VAS f	.254	30	.000

4.1. Radiological and cephalometric changes

All cephalometric measurements of the complete sample size are demonstrated in Tables 3a–3c.

Table 3a. Cephalometric measurements of the complete sample size: angles (part 1)

SNA i	SNA f	SNB i	SNB f	ANB i	ANB f	FMA i	FMA f	IMPA i	IMPA f
83	82	78	74	4	8	29	37	89	92
81	81	79	79	2	1	19	15	97	92
79	79	78	76	1	3	35	35	89	81
83	81	83	81	0	0	20	17	102	92
84	84	85	84	-1	0	17	15	81	85
77	77	77	77	0	1	26	26	94	91
76	75	74	74	2	1	23	21	97	91
79	77	77	75	2	2	32	34	87	83
72	79	75	78	-3	1	14	14	107	104
77	77	78	77	-1	0	12	11	111	104
86	85	83	80	3	5	27	29	86	82
75	80	84	84	-10	-4	24	21	88	78
74	78	75	75	-1	3	22	22	109	92
82	82	80	82	1	0	22	21	98	83
80	89	85	87	-4	2	21	20	103	96
72	77	74	75	-2	2	23	24	93	99
82	84	80	80	1	4	31	31	97	98
79	79	80	75	-1	3	17	21	98	98
80	83	78	80	2	3	14	16	100	102
83	83	81	80	2	3	24	23	95	89
84	83	81	79	4	4	26	24	90	91
78	78	74	75	4	3	20	16	95	93
75	81	87	85	-12	-4	16	13	83	83
76	74	75	71	0	3	26	28	97	90
85	84	83	80	2	4	25	25	89	89
78	82	76	81	1	1	15	14	97	106
82	82	81	78	1	4	21	26	98	85
81	81	80	79	1	2	21	18	98	96
81	80	77	75	4	5	27	29	92	93
80	86	80	84	0	2	26	20	90	81

Table 3b. Cephalometric measurements of the complete sample size: angles (part 2)

FMIA i	FMIA f	OccPl i	OccPl f	L1-NB i	L1-NB f	U1-SN i	U1-SN f	U1-NA i	U1-NA f	NL-Angle i	NL-Angle f
63	52	1	12	26	32	103	94	20	12	107	106
64	73	3	-2	29	21	101	110	19	29	109	92
56	64	17	9	30	18	103	102	24	23	103	104
58	71	6	1	29	19	105	104	22	23	88	124
83	80	4	1	10	12	104	110	21	27	120	116
60	64	1	0	28	25	106	106	29	29	87	84
60	67	4	3	28	21	101	97	25	22	127	106
61	63	9	8	27	23	102	99	22	22	114	100
59	63	4	-3	27	20	107	106	35	28	105	118
57	65	2	-5	31	25	104	109	27	32	111	106
67	69	7	3	21	16	104	105	19	19	106	121
68	81	10	2	20	9	105	118	30	39	106	107
50	65	7	5	37	19	105	106	31	28	95	107
60	76	3	-2	31	17	113	104	32	22	108	101
56	64	5	2	35	26	114	131	34	42	94	92
64	57	3	6	19	26	101	98	29	22	114	107
52	51	11	12	34	31	106	97	24	13	115	119
65	62	8	5	25	24	96	98	17	19	100	108
65	62	-1	2	26	28	103	103	24	20	115	108
61	67	12	3	26	19	112	101	29	17	101	101
64	65	15	-1	19	24	100	103	15	20	117	87
66	71	6	-4	20	17	91	104	13	27	115	119
81	85	-5	-8	14	11	116	120	41	40	83	87
56	62	5	1	28	19	99	97	23	23	126	120
66	66	6	6	22	22	107	98	22	14	117	104
68	60	7	-2	19	31	103	110	25	28	103	109
61	69	8	4	30	18	106	108	24	26	118	115
62	66	8	4	28	22	109	107	27	27	105	116
61	58	8	14	25	24	100	97	18	18	91	89
64	79	11	0	21	10	109	117	29	31	108	110

Table 3c. Cephalometric measurements of the complete sample size: distances

AO-BO i	AO-BO f	U6 ptv i	U6 ptv f	U6 mvt	E-LL i	E-LL f	E-UL i	E-UL f	LL-UL i	LL-UL f
4	4	14	18	4	-2	-1	-3	-1	1	0
-1	0	15	25	10	1	-1	-4	-4	5	3
-10	3	19	19	0	-1	-1	-7	-5	6	4
-2	0	16	25	9	-7	-6	-11	-7	4	1
-6	-2	18	24	6	-5	-6	-7	-7	2	1
0	3	20	26	6	-3	-4	-5	-7	2	3
0	0	20	25	5	1	-1	-2	-2	3	1
-4	-1	21	23	2	-4	-5	-5	-7	1	2
-4	8	24	24	0	-2	-3	-9	-5	7	2
0	3	23	24	1	-3	-6	-6	-8	3	2
-1	5	16	19	3	-4	-7	-6	-6	2	-1
-14	-5	14	19	5	-7	-8	-15	-10	8	2
-3	3	20	21	1	-2	-2	-3	-3	1	1
-2	0	22	28	6	1	-1	-1	-2	0	1
-7	2	17	28	11	1	1	-4	-1	3	0
0	2	15	20	5	-5	-3	-8	-5	3	2
-4	1	18	21	3	-2	-4	-6	-6	4	2
-6	3	20	22	2	-8	-8	-9	-5	1	-3
2	2	20	21	1	-8	-8	-9	-8	1	0
-4	3	16	20	6	-1	-4	-4	-3	3	-1
-1	7	12	23	11	-4	-7	-5	-10	1	3
2	6	15	24	9	-5	-4	-7	-7	2	3
-11	-2	20	30	10	-6	-8	-11	-9	5	1
1	9	13	19	6	0	-3	-2	-2	2	-1
-1	2	18	20	2	-3	-3	-3	-3	1	0
-1	1	21	27	6	-2	-4	-2	-4	1	0
-6	3	18	21	3	-1	-3	-5	-6	4	3
-5	0	8	20	12	-1	-3	-5	-4	4	1
2	2	18	19	1	-1	-2	-4	-3	3	1
-4	5	9	23	14	-2	-10	-6	-8	4	-2

I obtained the mean changes in the cephalometric values that were achieved during orthodontic treatment by comparing the initial (T1) and final (T2) measurements (Tables 4 and 5). A significant increase in the SNA by 1.3º ($p = 0.025$), ANB by 2º ($p < 0.001$), and Wits appraisal by 5.27º ($p < 0.001$) coincided with an insignificant decrease in the SNB by 0.6º ($p = 0.179$). These findings altogether proved (1) the efficient forward movement of the A point and (2) the simultaneous maintenance of the B point position. Mesial movement of the maxilla was eventually confirmed by a significant increase of in the U6Ptv ($p < 0.001$). The mean value of the mesialization of the molars reached 5.27 mm (Table 5).

A significant increase of the Frankfort plane to mandibular incisor axis (FMIA) by 3.97º ($p = 0.004$) together with a significant decrease in both the lower incisor axis to mandibular plane (IMPA) by 3.7º (p =

0.002) and the lower incisor axis to NB line (L1-NB) (p = 0.001) showed favorable retroclination and the distal movement of the lower incisors after the orthodontic treatment. The upper incisors also demonstrated favorable displacement; however, none of the changes were statistically significant: upper incisor axis to SN line (U1-SN) by 0.8º (p = 0.533), upper incisor axis to NA line (U1-NA) by 0.27º (p = 0.820), nasolabial angle (NL-Ang) by 0.83º (p = 0.712), and upper lip to E-plane (E-UL) by 0.53 mm (p = 0.202).

A significant increase of the lower lip to E-plane (E-LL) by 1.34 mm (p < 0.001) and a decrease of the LL-UL by 1.87 mm (p < 0.001) favorably changed the lip profile due to my biomechanics, wherein the upper lip remained unaffected. No significant changes of the E-UL and NL-Angle parameters occurred (p > 0.05).

Table 4. The mean values of the cephalometric parameters measured at the T1 and T2 stages

	N	Initial (T1)		Final (T2)		p value
		Mean value	95% confidence interval of mean	Mean value	95% confidence interval of mean	
SNA	30	79.47 ± 3.72	78.14;80.80	80.77 ± 3.36	79.57;81.97	**.025**
SNB	30	79.27 ± 3.58	77.99;80.55	78.67 ± 3.82	77.30;80.03	.179
ANB	30	.07 ± 3.62	-1.23;1.36	2.07 ± 2.42	1.20;2.93	**.000**
FMA	30	22.50 ± 5.59	20.50;24.50	22.20 ± 6.84	19.75;24.65	.576
IMPA	30	95.00 ± 7.18	92.43;97.57	91.30 ± 7.49	88.62;93.98	**.002**
FMIA	30	62.60 ± 6.88	60.14;65.06	66.57 ± 7.97	63.71;69.42	**.004**
OccPl	30	6.17 ± 4.58	4.53;7.81	2.53 ± 5.12	0.70;4.36	**.001**
L1-NB	30	25.50 ± 6.06	23.33;27.67	20.97 ± 5.94	18.84;23.09	**.001**
U1-SN	30	104.50 ± 5.22	102.63;106.37	105.30 ± 8.13	102.39;108.21	.533
U1-NA	30	25.00 ± 6.23	22.77;27.23	24.73 ± 7.39	22.09;27.38	.820
NL-Angle	30	106.93 ± 11.14	102.95;110.92	106.10 ± 11.03	102.15;110.05	.712
AO-BO	30	-2.87 ± 4.08	-4.33;-1.41	2.23 ± 3.03	1.15;3.32	**.000**
U6ptv	30	17.33 ± 3.81	15.97;18.70	22.60 ± 3.18	21.46;23.74	**.000**
E-LL	30	-2.83 ± 2.65	-3.78;-1.88	-4.17 ± 2.72	-5.14;-3.19	**.000**
E-UL	30	-5.80 ± 3.13	-6.92;-4.68	-5.27 ± 2.57	-6.19;-4.35	.202
LL-UL	30	2.90 ±1.936	2.21 ; 3.59	1.03±1.629	0.45 ; 1.61	**.000**

Table 5. The results of subtracting the initial mean values from the final mean values of the cephalometric parameters measured at the T1 and T2 stages

	Mean value initial	Mean value final	Mean difference (final – initial)
SNA f – SNA i	79.47	80.77	1.3
SNB f – SNB i	79.27	78.67	-0.6
ANB f – ANB i	.07	2.07	2
FMA f – FMA i	22.50	22.20	-0.3
IMPA f – IMPA i	95.00	91.30	-3.7
FMIA f – FMIA i	62.60	66.57	3.97
OccPl f – OccPl i	6.17	2.53	-3.64
L1-NB f – L1-NB i	25.50	20.97	-4.53
U1-SN f – U1-SN i	104.50	105.30	0.8
U1-NA f – U1-NA i	25.00	24.73	-0.27
NL-Angle f – NL-Angle i	106.93	106.10	-0.83
AO-BO f – AO-BO i	-2.87	2.23	5.1
U6Ptv f – U6Ptv i	17.33	22.60	5.27
E-LL f – E-LL i	-2.83	-4.17	-1.34
E-UL f – E-UL i	-5.80	-5.27	0.53
LL-UL f – LL-UL i	2.90	1.03	-1.87

4.2. Peer assessment rating scores

Descriptive statistics of weighted and nonweighted PAR indexes are presented in Table 6a.

Table 6a. The PAR and PAR weighted (PAR w) indices: descriptive statistics
PAR, peer assessment rating

	Minimum	Maximum	Mean ± SD
PAR i	12	34	21.87 ± 6
PAR f	0	5	0.8 ± 1
PAR i – PAR f	11	32	21.07 ± 6
PAR w i	4	181	56.8 ± 6
PAR w f	0	17	1 ± 3
PAR w i – PAR w f	-13	181	55.8 ± 52

The mean measurements of the weighted PAR index and nonweighted PAR index significantly decreased after orthodontic treatment ($p < 0.001$) (Table 6b).

Table 6b. Statistical evaluation of the occlusal changes after orthodontic treatment

	N	Initial (T1)		Final (T2)		p value
		Mean value	95% confidence interval of mean	Mean value	95% confidence interval of mean	
PAR	30	21.87 ± 6.02	19.72; 24.02	.77 ± 1.07	0.38; 1.15	.000
PAR w	30	56.80 ± 51.39	38.41; 75.19	1.00 ± 3.11	-0.11; 2.11	.000

4.3. Smile changes

The descriptive statistics of the visual analog scale (VAS) scores are presented in Table 7a.

Table 7a. The VAS evaluation: descriptive statistics

	Minimum	Maximum	Mean ± SD
VAS i	0	6	1.1 ± 1.6
VAS f	7	10	9 ± 1

The letter “i” is the initial evaluation and “f” is the final evaluation
VAS, visual analog scale

Table 7b presents the comparison of the initial and final smile evaluations. In general, the mean VAS scores significantly increased after orthodontic treatment ($p < 0.001$).

Table 7b. Statistical evaluation of the smile changes after an orthodontic treatment

	N	Initial (T1)		Final (T2)		p value
		Mean value	95% confidence interval of mean	Mean value	95% confidence interval of mean	
VAS	30	1.13 ± 1.63	0.55; 1.72	9.03 ± 1.03	8.66; 9.40	.000

5. DISCUSSION

In this study, I proved the both null hypotheses.

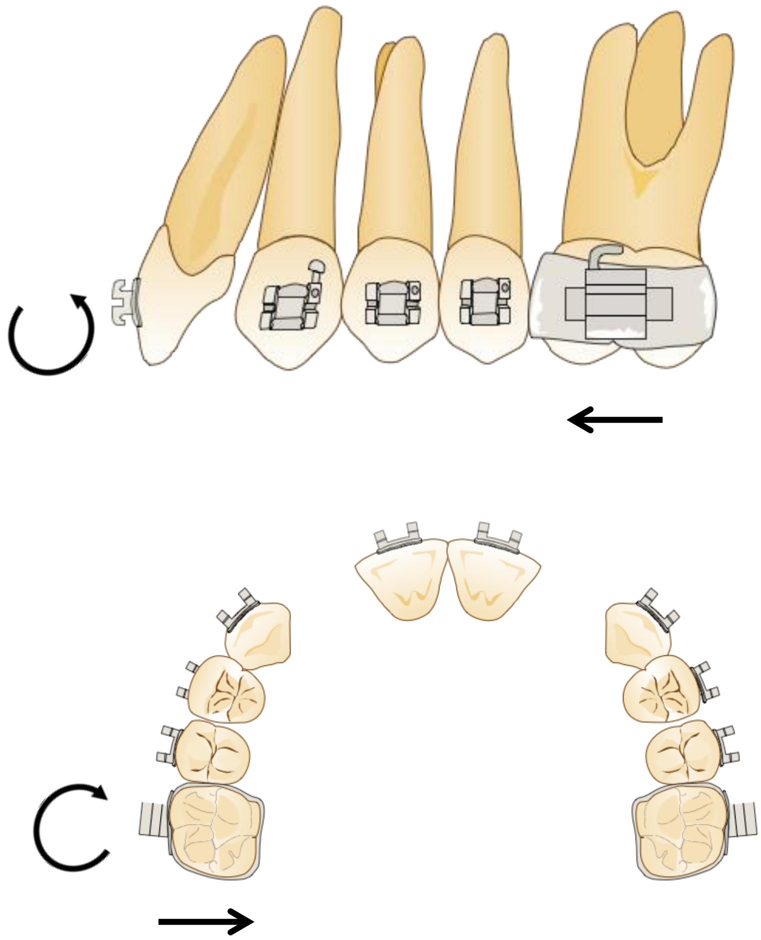
As previously emphasized, multiple studies existing in the scientific database over the years have compared the major alternatives for MLIA treatment—canine substitution or restorative replacement. Regardless of advanced and evidence-supported dispute, no clear conclusion has been determined (Zachrisson et al., 2011; Kokich et al., 2011). Therefore, the objective of my study was not to compare these options or to determine the superiority of one treatment option over the other. On the contrary, my prospective clinical objectives focused on assessing the cephalometric, dental and occlusal changes, the soft tissue profile, and the smile esthetics in Class I and Class III patients with MLIA who were treated by canine substitution. Thus, my goal was to determine whether such an approach could support functional occlusion and esthetically pleasing results, and could therefore be adopted as a viable and efficient treatment protocol in the aforementioned cases.

In the literature regarding the epidemiology of MLIA, reports exist proving that this abnormality or disturbance is not always bilateral. On the contrary, it is not rare to find peg-shaped lateral incisors when the contralateral incisor is congenitally missing (Garib et al., 2010; Park et al., 2010; Tai et al., 2011; Kiliaridis et al., 2016; Mehmet et al., 2016; Buyuk et al., 2017), which I also observed in my study group. If MLIA occurs in Class I or Class III patients, the conventional protocol is to maintain a conically shaped incisor, which subsequently undergoes prosthetic or conservative recontouring. However, because my treatment approach assumed canine substitution, I decided to extract the microdontic teeth and to treat these cases as bilateral agenesis. This concept was aimed at (1) saving the patient from invasive restorations and (2) maintaining symmetrical biomechanics.

Agenesis of the lateral incisors in Class I or Class III malocclusions, especially in patients with a narrow maxilla and pronounced space between the central incisors and the canines, has traditionally been regarded as an indisputable indication for space reopening and prosthetic rehabilitation. Even recently published results of the evaluation of sagittal discrepancy in MLIA cases (Bassiouny et al., 2016), and the assessment of the transverse dimension of the dentoalveolar and skeletal widths in uni- and bilateral MLIA cases (Buyuk et al., 2017) still favor the treatment goal towards implant restoration. In the aforementioned studies, the patients had statistically significantly smaller values for maxillary intercanine widths measured at the levels of the crowns and the dentoalveolar support, and had reduced maxillary width measured at the level of the skeletal bone, compared with these measurements in the control group that consisted of nonagenesis patients. Furthermore, the patients with MLIA demonstrated a significant tendency towards skeletal Class III, which is quite likely attributable to maxillary hypoplasia/retrognathia. These findings altogether support the idea of space gaining instead of space reduction in skeletal Class III or Class I patients with a straight profile.

It is also believed that the reopening of spaces facilitates the expansion of the maxillary arch and provides dentoalveolar compensation, and significantly maintains or improves the patient’s profile (Rosa and Zachrisson, 2010). For this reason, maxillary expansion rather than reducing the arch perimeter to restore its continuity is advocated in such cases. This protocol discernibly results from the biomechanics and its reactive, uncontrolled forces. The mesialization of the lateral teeth can very likely retrude the incisors, which deteriorates the face profile features and reduces the dental arch width because of the mesial rotation of the molars (Figs. 18a and 18b).

a



b

Fig. 18. Reactive forces resulting from the molar mesialization. a) the retroclining of the incisors and b) the decrease in the intermolar width

In 1985, Woodworth et al. (1985), after analyzing 43 patients exhibiting BMLIA, proposed a different protocol that, in some ways, overcomes the abobe-mentioned biomechanical limitations. The authors state that, in such cases, mechanotherapy designed to open the mandibular plane and thus increase the vertical dimension, as well as mesialization of the lateral teeth, is recommended. Such mechanism prevents worsening the Class III tendency; it also minimizes retraction of the maxillary incisors, which adveresely opens the nasolabial angle. This goal may be achieved using a facemask or a reverse-pull headgear (Woodworth et al., 1985; Tabuchi et al., 2010). Nevertheless, because I designed a novel treatment concept and followed the "*primum non nocere*" standard, I applied a 21st century modality: orthodontic fixed appliances supported by TISADs, which have been proven to efficiently eliminate the adverse results of reaction forces in the treatment of many types of malocclusions (Park et al., 2001; Bae et al., 2002; Park et al., 2002; Giancotti et al., 2004; Park and Kwon, 2004; Zaleska, 2004; Antoszewska, 2007a; Antoszewska, 2007b; Papadopoulos and Tarawneh, 2007; Park et al., 2008; Papadopoulos, 2008; Wilmes et al., 2008; Antoszewska, 2009). In this manner, I may have realized the concept of Woodworth et al. (1985) by applying Class III elastics from the maxillary molars to the mandibular TISADs, and thereby replacing the facemask.

By choosing my approach, I have challenged the generally approved protocol of managing MLIA in Class I or Class III patients who have no indications for tooth extraction in the mandible where space opening and restorative/implant replacement of the missing lateral incisor are theoretically the only therapeutic solutions. By contrast, I proved that closing the space resulting from agenesis of the lateral incisors with the aid of TISADs provides satisfactory results, even when the patient has a concave profile.

My results evidently validated the concept and the goal of the study. An increase in the ANB and the Wits appraisal from before to after the treatment of my patients, and the maintenance of the SNB value evidently helped to correct the skeletal Class III malocclusion (i.e., mesialization of the maxilla without violating the position of the mandible). Furthermore, statistically significant mesial movement of the maxillary first molars by 5.27 mm allows stating that this movement is the forward displacement of the maxillary lateral teeth that primarily contributed to the space closure. If so, then preserving the distal movement of the maxillary incisors helped to control the upper lip position and the profile. My treatment protocol therefore efficiently closed the space of the missing maxillary lateral incisors and improved the sagittal position of the whole maxilla.

An insignificant difference in the values, especially the U1-SN, the U1-Na, NL-Ang and E-UL parameters, was entirely inconsistent with what for years has been the main contraindication for canine substitution in patients with MLIA and skeletal Class I or Class III. Woodworth et al. (1985) analyzed the effects of space closure in such cases. They compared the pre- and post-treatment records of 22 patients who underwent bilateral space closure. They admittedly found that the inclination of the incisors did not change; however, they experienced some bodily movement that resulted in the retraction of the upper lip (which was more significant in female patients) and consequently an increase in the nasolabial angle by 5° to 10º. In my sample, the upper incisors did alter their inclinations but not in relation to the NA or SN lines; the nasolabial angle also remained unchanged. Even if the stable position of the incisors primarily resulted from the application of TISADs in my treatment protocol, the use of standard edgewise brackets with zero torque, which counteracts labial protrusion (an adverse effect of the mesializing forces), may also have a beneficial role.

The E-UL parameter did not change with treatment, but E-LL parameter significantly decreased at the T2 stage, as did the LL-UL parameter. My treatment approach consequently preserved the profile and improved it in justified cases by securing a more harmonious relationship between the upper lip, lower lip, and the E-plane of Ricketts (Fig. 15).

With regard to biomechanics, mesial movement of the maxillary dentition without violation of the maxillary incisor torque and with simultaneously occurring efficient retroclination of the mandibular incisors secured an appropriate overbite. This finding proved that my protocol helped to achieve normal occlusion and esthetic facial features in patients with MLIA and Class I or Class III malocclusions. Using Class III elastics and the RPE at the initial treatment stage undoubtedly and efficiently contributed to the success of my approach, although its undeniable advantages may be utilized only provided excellent patient's cooperation. Applying the Class III elastics early in the treatment allowed me to maintain the mandibular incisor sagittal position during the levelling of the lower Spee curve – the mean IMPA value significantly decreased after the orthodontic treatment. This finding is in contrast with the other systems discussed in my thesis such as those described by Wilmes et al. (2009) and Rosa et al. (2010), which provoke and favor labial proclination of the lower incisors. Furthermore, my early use of the RPE corrected the crossbite and the skeletal Class III, which are not rare in cases of lateral incisor agenesis (Bassiouny et al., 2016; Buyuk et al., 2017).

I certainly could apply skeletally anchored palatal expanders, while utilizing splinted palatal TISADs (Wilmes et al., 2008; Wilmes and Drescher, 2008; Wilmes et al., 2009; Baumgaertel et al., 2008; Baumgaertel, 2008; Ludwig et al., 2013). A compliance-free design with the stability of the palatally inserted screws securing the devices is their distinct advantage. However, my protocol not only did focus on space closure but on bite jumping as well. Therefore, applying Class III elastics was necessary to correct the intermaxillary relationship. The reported success rate of miniplates (De Clerck, 2009; Ludwig et al., 2010, Wilmes et al., 2011) and their customized placement mode (Hourfar et al., 2014) suggests they can be used to apply traction. However, it has been proven that microscrews inserted in the interradicular spaces of the mandible efficiently withstand orthodontic loading (Sung et al., 2006, Antoszewska et al., 2009). Furthermore, invasive surgery related to the miniplates still does not exempt patients from the conscientious wearing of Class III elastics. For this reason, considering that I meticulously followed the insertion protocol, which reportedly provided the high success rate of TISADs in my sample, and judging by the treatment results, I will dare to sustain my humble opinion. General anesthesia performed with more invasive surgical procedure guarantees achieving the same treatment goal as when using single microscrews, the application of which necessitates no special expertise other than knowing how to insert these devices.

Chaimanee et al. (2011) conducted a study to find the zones for TADs placement that had a low risk of the dental root injury in the maxilla and in the mandible. The authors analyzed the periapical radiographs of 60 patients, and measured each interradicular space at the different distances from the alveolar crest. They found that the spaces between the second premolar and the first molar in the maxilla, and between the first and the second premolars, and the first and the second molars in the mandible were the widest or the most suitable areas for the TADs insertion. In the same study (Chaimanee et al., 2011), I also found evidence that the availability of the in-between root space is influenced by the inclination of the adjacent teeth: tipped teeth are associated with a reduced interradicular space; however, this space is increased if the teeth are upright. Therefore, in my sample, I took x-ray images just before the insertion of the TISADs to ensure that the root divergence secured the space necessary for the placement of the screws between the canine and the first premolar. This location ensured that as much a horizontal force vector as possible was delivered by the Class III elastics attached to TISADs inserted in the compact mandibular bone. On evaluating the orthopantomogram, I rebonded brackets if it was necessary and I subsequently delayed inserting the screw no sooner than the required alignment of the roots had occurred.

It has been reported that, with canine substitution, a tooth size discrepancy is created and this factor may affect occlusion (Robertsson et al., 2000; Kokich et al., 2011; Kiliaridis et al., 2016). In my study, some patients did not have perfect interdigitation; however, the PAR and the weighted PAR indexes significantly decreased after orthodontic treatment ($p < 0.001$). Therefore, the occlusion was satisfactorily corrected and improved.

With regard to post-treatment evaluation, periodontal status or issues influencing the temporomandibular joint may be another concern in my study, which I need to discuss. Rosa et al. (2016) reported a 10-year follow-up of patients with MLIA treated with the canine substitution. All of these patients had good and stable periodontal tissues, as did the individuals with no missing teeth and no need for extraction in the control group; there was no attachment loss for the uneven bone crests. Silveira et al. (2016) also concluded in their systematic review that tooth-supported dental prostheses of the maxillary lateral incisor had worse scores for the periodontal indexes, compared with the scores for orthodontic space closure. It has also been proven that the signs and symptoms of temporomandibular disorder or occlusal function show no association with the presence or absence of a Class I relationship of the canines (Kokich et al., 2011; Kiliaridis et al., 2016; Rosa et al., 2016; Silveira and Mucha, 2016). None of my patients presented with periotreatment or temporomandibular disorder post-treatment symptoms; therefore, I cautiously suggest that the treatment method proposed in the current study does not seem to jeopardize periodontal health or normal function of the temporomandibular joint.

With regard to esthetics, Robertsson and Mohlin (2000) conducted a study in which they evaluated the occlusal and periodontal status of 50 MLIA patients treated with space closure/canine substitution or treated with space opening for prosthetic replacement. The patients were surveyed about the esthetics of their treatment results. Most patients from the group with the space closure were satisfied with their appearance, although they disliked that the canine shade that was darker than the adjacent teeth. By contrast, the other group where the space was re-opened was modestly satisfied. Gingivitis and plaque accumulation that was observed more frequently in the latter group may have contributed to the deterioration in esthetic perception.

All of my patients were satisfied with their smile restoration. The subjective evaluation of the treatment outcomes, based on the VAS of the pre- and post-treatment smile photographs (i.e., after composite restorations if the patient chose this option) were significantly different, which demonstrated a final improvement of their smile esthetic perception.

It must be noted that, with space closure, the canines and the first premolars are not in the positions that they would normally occupy in the dental arch. Therefore, occlusion, shape, and esthetics are affected by this treatment option. However, clinicians resort to different tips and tricks to avoid mediocre results. Biggerstaff (1992) proposed using slightly distal placement of the bracket on the first premolars, to rotate the palatal cusps distally. This method eliminated working and balancing interferences and the need to minimize these cusps. Tuverson (1970) also suggested inserting negative (i.e., palatal) crown torque on the first premolar to simulate the canine root eminence; he also recommended a pronounced labial offset of the first premolar to better resemble the canine. Palatal root torque on the canine reduces its eminence, improves interproximal contact of the canine with the central incisor, and diminishes occlusal stress on the mandibular incisors (Tuverson, 1970; Park et al., 2010; Lombardo et al., 2014; Kravitz et al., 2017). It has also been recommended that customized intrusion of the first premolar and extrusion of the canine should be performed to correct the alignment of the gingival margin (Park et al., 2010; Lombardo et al., 2014). Grinding approximately 1 mm from the palatal surface of the canine should be performed at the beginning of treatment to prevent interfering with the lower incisors (Tuverson, 1970; Lombardo et al., 2014). Recontouring of the canine (i.e., mesiodistal grinding, incisal tip reduction, and labial surface flattening) is also required to simulate the shape of the lateral incisor (Tuverson, 1970; Park et al., 2010).

In my study group, I introduced palatal root torque on the canine to efficiently resemble the lateral incisor. I levelled the gingival margins and limited reshaping to merely grinding the canine tip. In this manner, I achieved occlusal equilibrium in patients in whom the palatal surface was interfering with the lower incisors. Neither mesiodistal nor labial surfaces needed enamel reduction. The final restoration of the canine with composites followed each patient's preferences, which were determined after my digital simulation.

The present study demonstrated that canine substitution to treat MLIA in patients presenting with Class I or Class III skeletal patterns could be a viable treatment option when administered with mandibular TISADs and Class III elastics.

6. CONCLUSIONS

As previously believed, agenesis of the lateral incisors in skeletal Class I or Class III patients, especially in those with a narrow maxilla, required space reopening for implant replacement or other mode of prosthetic treatment of the gap. The objective was to facilitate expansion of the maxillary arch, provide dentoalveolar compensation, and maintain or improve the profile.

My study proved that closing the space in these patients and using TISADs in the mandible along with Class III elastics achieves comparable results. I established proper occlusion by mesialization of the maxillary teeth. I corrected the intermaxillary discrepancy and thereby attained beneficial significant cephalometric changes after the treatment. I maintained the soft tissue profile when it was harmonious before the treatment, and I improved the soft tissue profile after the treatment in patients in whom it was initially discordant. All occlusions unquestionably improved, which I objectively verified using the PAR index. I eventually helped to enhance poor smile esthetics, which was significantly more pleasing after orthodontic treatment for all patients in the sample.

As clinical implication, closing the space of the agenesic lateral incisor is now possible with wider range of indications. Certainly, future studies comparing my results with results obtained using other biomechanical techniques to close the spaces (e.g., palatally inserted skeletally anchored devices, or different bracket system) may be needed to better understand this area of orthodontics. Also, it would be beneficial to study the results comparing adult patients with growing patients, and therefore asses the skeletal correction of the class III discrepancy; this technique could be advantageous in treatment of the skeletal class III malocclusion in growing patients.

To conclude, the approach I proposed in this prospective clinical study was virtually efficient. Therefore, I dare state that canine substitution may be recommended for patients with agenesis of maxillary lateral incisors, even if they are characterized as having the Class III skeletal pattern.

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8. ABSTRACTS

8.1. Abstract

Introduction: Maxillary lateral incisors agenesis (MLIA) is one of the most frequent subtypes of tooth agenesis. Current practice trends for the treatment of such anomaly, generally advocate two options: "opening" the space for the missing tooth and replace it with a single-tooth implants or tooth-supported restorations, otherwise "closing" of the space and replace the missing incisor with the canine, better known as the canine substitution. The preference of one treatment option over the other was never a clear-cut decision, and no superiority of any of those options was proven in the literature. But, so far, everybody agrees that it is not indicated to close the space when the patient presents with a skeletal class I or III, since canine substitution in such cases may lead to overconstriction of the maxilla and therefore – destroy the patient's profile. Nevertheless, in today's era when skeletal anchorage can be utilized, it is time to check the validity of this concept when we have tools that weaken undesirable reaction forces.

Aim: The aim of my prospective clinical study was to evaluate whether the canine substitution supported with the skeletal anchorage is a viable treatment protocol in the patients with the maxillary lateral incisor agenesis and Class I or Class III skeletal pattern.

Material and methods: For the purpose of my project, I selected 30 patients meeting the following criteria:

- Two congenitally missing upper lateral incisors or one missing upper lateral incisor and a riziform (peg-shaped) contralateral,
- Skeletal Class I/Class III tendency or a mild skeletal Class III,
- The mandibular arch requiring no extractions, except for the 3rd molars.

In order to accomplish all the objectives of my study, as well as to meet the criteria of the nowadays biomechanics I introduced the mandibular Temporary Intraoral Skeletal Anchorage Devices (TISADs) to mesialize the whole maxillary dentition, as well as RME (Rapid Maxillary Expander) to broaden the maxilla, combined with the Class III elastics applied on the mandibular TISADs, between the canine and the 1st bicuspid, toward the upper terminal molars.

I evaluated the skeletal changes, dental movements and the soft tissue profile behavior after the proposed orthodontic treatment, by mean of cephalometric software to analyze initial (T1) and final (T2) variables in cephalograms.

All plaster models were 3D scanned, then uploaded to a special software where the PAR and PAR weighted were investigated to assess the occlusion improvement.

Six months after the end of treatment, all patients were asked to answer a self-perception survey by rating their smile before and after the treatment using a ten-degree visual scale analogue (VSA) sent via a social media platform.

Statistical analyses were performed using a software program (SPSS for Windows, Version 22.0, Chicago, IL). The level of significance was set at $\alpha = 0.05$. Normality distribution was assessed using the Kolmogorov-Smirnov tests. Paired Student t tests or Wilcoxon tests were performed to compare continuous variables before and after treatment. 95% confidence interval of mean measurements for each parameter was also calculated.

Results: All main variables changed their values in a favorable manner. I noted: significant increase of SNA by 1.3º ($p = 0.025$), ANB by 2º ($p < 0.001$) and Wits appraisal by 5.27 mm ($p < 0.001$). The maxillary dentition moved mesially, which was confirmed by significant increase of U6Ptv ($p < 0.001$) and the mean value of the molars mesialization reached 5.27 mm. The upper incisors moved forward changing their inclination insignificantly: U1-SN by 0.8º ($p = 0.533$), U1-NA by 0.27º ($p = 0.820$).

Meaningful increase of E-LL by 1.34 mm ($p < 0.001$) and decrease of LL-UL by 1.87 mm ($p < 0.001$) fairly changed the lip profile, although the upper lip remained unaffected by my biomechanics: no significant changes ($p > 0.05$) of E-UL and NL-Angle parameters occurred.

Both the PAR index and the weighted PAR index were significantly decreased after the orthodontic treatment ($p < 0.001$), confirming that the occlusion was evidently corrected.

The mean VAS scores have significantly increased after orthodontic treatment ($p < 0.001$) proving that patients highly appreciated their smile esthetics achieved after my treatment protocol.

Conclusions: My study proved that closing the space in Class I or Class III cases, using TISADs in the mandible along with Class III elastics, secures achievement of the satisfactory results. Not only I established proper occlusion by mesialization of the maxillary teeth, but I also corrected the intermaxillary discrepancy attaining beneficial, significant cephalometric changes after the treatment. I maintained the soft tissue profile when it was harmonious before the treatment, and I improved it after the treatment in cases when

it was initially discordant. All occlusions unquestionably improved, which I objectively verified using the PAR index. Eventually, I helped to enhance the poor smile esthetics, which – after an orthodontic treatment – was significantly more pleasing for all the patients in the sample.

Summing-up, my approach proposed in this prospective clinical study, turned out to be virtually efficient, therefore I will dare to say that the canine substitution may be boldly recommended in patients with agenesis of maxillary lateral incisors, even if they are characterized as the Class III skeletal pattern.

8.2. Streszczenie

Wstęp: Niedorozwój bocznych siekaczy szczęki (ang.: maxillary lateral incisor agenesis, MLIA) jest jedną z najczęstszych hipodoncji. Aktualne trendy stosowane w leczeniu takiej anomalii, ogólnie rzecz biorąc, opowiadają się za dwiema możliwościami: za odtworzeniem miejsca na brakujący ząb i zastąpienie go albo implantem, albo mostem bądź też za zamknięciem przestrzeni i zastąpieniem brakującego zęba kłem. W literaturze nigdy nie znaleziono dowodu na przewagę zalet jednej czy drugiej metody. Jednak jak dotąd, wszyscy klinicyści zgadzają się, że w przypadku pacjenta z I lub III klasą szkieletową zamykanie przestrzeni jest niewskazane, bowiem substytucja zębów siecznych kłami w takich przypadkach może prowadzić do nadmiernego zwężenia szczęki, a tym samym – zniszczyć profil pacjenta. Niemniej jednak, w dzisiejszej dobie, kiedy można wykorzystać zakotwienie szkieletowe, nadszedł czas, aby sprawdzić zasadność tej koncepcji. Szczególnie, że dysponujemy narzędziami, które osłabiają niepożądane siły reakcji.

Cel: Celem mojego prospektywnego badania klinicznego była ocena, czy substytucja kłowa wspomagana zakotwieniem szkieletowym może stanowić dobrą metodę leczenia pacjentów z MLIA i I lub III klasą szkieletową.

Materiał i metody: Do realizacji celów mojego projektu wybrałem 30 pacjentów spełniających następujące kryteria:

- Brak dwóch zawiązków górnych, bocznych zębów siecznych bądź brak jednego i obecny stożkowy ząb jednoimienny,
- Tendencja do I lub III klasy szkieletowej, bądź słabo nasilona klasa III,
- Brak wskazań do ekstrakcji w łuku dolnym, za wyjątkiem zębów mądrości.

Aby osiągnąć wszystkie cele badań, a także – by spełnić wymogi współczesnej biomechaniki, zastosowałem elementy tymczasowego, wewnątrzustnego zakotwienia szkieletowego (ang.: Temporary Intraoral Skeletal Anchoring Devices, TISADs) do mezjalizacji wszystkich zębów górnych oraz aparat do szybkiego poszerzania szczęki (ang.: Rapid Maxillary Expander, RME) połączony z wyciągami klasy III biegnącymi od TISADs wszczepionych między dolnymi kłami i pierwszymi zębami przedtrzonowymi do ostatnich zębów trzonowych w szczęce.

Zmiany szkieletowe, zębowe oraz profilu po leczeniu ortodontycznym oceniłem porównując i analizując zmienne na cefalogramach początkowych (T1) i końcowych (T2).

Wszystkie modele gipsowe zeskanowano techniką 3D, a następnie zmierzono za pomocą programu komputerowego obliczającego wskaźnik PAR i wagowy wskaźnik PAR, co pozwoliło ocenić poprawę okluzji

Sześć miesięcy po zakończeniu leczenia wszystkich pacjentów poproszono o samoocenę uśmiechu przed terapią i po niej. Wykorzystano do tego 10.stopniową wizualną skalę analogową (ang.: Visual Analogue Scale, VAS) wysłaną za pomocą platformy społecznościowej.

Analizy statystyczne przeprowadziłem za pomocą oprogramowania SPSS dla Windows (wersja 22.0, Chicago, IL). Poziom istotności ustaliłem na poziomie $\alpha = 0,05$. Rozkład normalności oceniałem za pomocą testów Kołmogorowa-Smirnowa. Przeprowadziłem test t Studenta parami lub testy Wilcoxona w celu porównania zmiennych ciągłych przed i po leczeniu. Obliczyłem także przedział ufności 95% średnich pomiarów dla każdego parametru.

Wyniki: Wszystkie główne parametry zmieniły swoje wartości w korzystny i istotnie statystyczny sposób. Zauważyłem wzrost: wartości kąta SNA o 1,3º ($p = 0,025$) i ANB o 2º ($p < 0,001$) oraz parametru Wits o 5,27 mm ($p < 0,001$). Zęby szczęki przesunęły się do przodu, co zostało potwierdzone znacznym wzrostem wartości zmiennej U6Ptv ($p < 0,001$) i średnią wartością mezjalizacji zębów trzonowych o 5,27 mm. Górne zęby sieczne przesunęły się do przodu, nieistotnie zmieniając swoje nachylenie: U1-SN o 0,8º ($p = 0,533$), U1-NA o 0,27º ($p = 0,820$).

Znaczący wzrost E-LL o 1,34 mm ($p < 0,001$) i spadek LL-UL o 1,87 mm ($p < 0,001$) ewidentnie zmieniły profil warg, chociaż moja biomechanika nie wpłynęła na lokalizację wargi górnej. Potwierdził to brak istotnych zmian ($p > 0,05$) parametrów E-UL i NL-Angle.

Zarówno wskaźnik PAR, jak i wagowy wskaźnik PAR uległy znacznemu zmniejszeniu po leczeniu ortodontycznym ($p < 0,001$), potwierdzając widoczną poprawę okluzji.

Średnie wyniki VAS istotnie wzrosły po leczeniu ortodontycznym ($p < 0,001$), co dowodzi, że pacjenci wysoko cenili sobie estetykę uśmiechu osiągniętą po moim protokole leczenia.

Wnioski: Moje badania dowiodły, że zamknięcie przestrzeni w przypadkach klasy I lub klasy III, przy użyciu TISADs w żuchwie i wyciągów klasy III, zapewnia otrzymanie zadowalających wyników. Nie tylko odtworzyłem prawidłową okluzję poprzez mezjalizację zębów szczęki, ale także skorygowałem rozbieżności międzyszczękowe uzyskując korzystne, istotne zmiany cefalometryczne po leczeniu. Zachowałem profil tkanek miękkich, gdy był harmonijny przed zabiegiem, i poprawiłem go w przypadkach, gdy początkowo był

nieprawidłowy. Warunki zgryzowe u wszystkich pacjentów zostały bezsprzecznie skorygowane, co obiektywnie zweryfikowałem za pomocą wskaźnika PAR. Ostatecznie, poprawiłem słabą estetykę uśmiechu, która- po leczeniu ortodontycznym- była znacznie bardziej zadowalająca dla wszystkich badanych.

Podsumowując, mój protokół zaproponowany w tym prospektywnym badaniu klinicznym okazał się ewidentnie skuteczny, dlatego pozwolę sobie powiedzieć, że substytucja kłem może być śmiało polecana w przypadkach braków górnych, bocznych zębów siecznych, nawet u pacjentów z III klasą szkieletową.