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1 Long Term Impact of Microimplant Assisted Rapid Palatal Expansion on Soft Tissue Nasal Morphology

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LONG TERM IMPACT OF MICROIMPLANT ASSISTED RAPID PALATAL EXPANSION ON SOFT TISSUE NASAL MORPHOLOGY

by

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ABSTRACT

Introduction: When skeletal transverse discrepancies exist between the maxilla and mandible, they commonly manifest in dental malocclusion. If left uncorrected, the malocclusion can lead to periodontal issues, tooth fractures, tooth loss, or other significant dental problems. Utilization of microimplants in palatal expansion aims to correct transverse discrepancies between the maxilla and mandible by separating the palatal suture in a parallel manner aimed at maximizing skeletal changes and minimizing dental side effects. Overlying soft tissue changes can be affected by the induced skeletal changes. The purpose of this study is to evaluate skeletal expansion and the overlying soft tissue change that occurs using MARPEs (microimplant assisted rapid palatal expanders) at the end of orthodontic treatment in skeletally mature (Cervical Vertebral Maturation (CMV) ≥ 5) patients using cone-beam computed tomography (CBCT) imaging and to evaluate soft tissue changes that occur at the time of orthodontic treatment completion using CBCT imaging.

Materials and Methods: CBCT scans from 19 patients who were treated using microimplant assisted rapid palatal expanders were traced and evaluated at three time points: Before orthodontic treatment (T1), post MARPE expansion with MARPE in place (T2), and after orthodontic treatment with MARPE removed. Fourteen hard tissue landmarks and six soft tissue landmarks in the midface and nasal cavity regions were traced by three judges at each time point. The traced landmark points were averaged among all three judges and comparisons were made between the three time points to see the amount of expansion that occurred at various anatomical regions. Intraclass correlation coefficient (ICC) was used to evaluate inter-judge reliability for all measurements. A repeated measures ANOVA test was used for statistical comparison across all three time points and a Tukey post hoc test was used for comparison between time points. Significance was set to .05 and ICC was set to >.70.

Results: Expansion with microimplant assisted rapid palatal expanders can affect the hard tissue of the midface region as well as the overlying soft tissue. Increases in skeletal width from the ANS down to the maxillary alveolar bone were statistically significant in both the short term (T1-T2) and long term (T1-T3). The nasal cavity width at inferior turbinate area increased significantly after expansion (T2) and remained increased at treatment completion (T3) and the increased soft tissue width of the alar base that presented after expansion therapy remained increased at treatment completion.

Conclusion: Maxillary expansion with microimplant assisted expanders resulted in skeletal changes throughout the maxilla and led to a significant long-term increase in nasal cavity width. The soft tissue changes associated with MARPE treatment show that a widening of the base of the nose may be expected after expansion and can remain at treatment completion.

INTRODUCTION

When skeletal transverse discrepancies exist between the maxilla and mandible, they commonly manifest in dental malocclusion. Frequently, a narrow maxilla gives rise to posterior dental crossbite with buccally-flared upper molars and lingually-tipped lower molars that are uncentered in the alveolar housing. If left uncorrected, the malocclusion can lead to periodontal issues, tooth fractures, tooth loss, or other significant dental problems. The orthodontist is faced with the challenge of developing harmony between the two jaws to facilitate dental health and occlusal function.

Depending on the patient's skeletal maturity and the extent of the transverse discrepancy, correction can be obtained by an orthodontic approach, an orthopedic approach, or a combination of both. An orthodontic approach will attempt to resolve posterior crossbite dentally by tipping the molars; however, it will not address the skeletal transverse discrepancy. An orthopedic approach will skeletally expand the maxillary alveolar housing and move the molars into the proper position over the mandibular arch. Maxillary expansion therapy involves splitting the mid-palatal suture to gain necessary transverse width. The patient's age, gender, and severity of dental and orthopedic malocclusion dictates the type of maxillary expansion that the orthodontist will use to achieve the desired outcome.

Researchers once believed that the extent of the interdigitation that existed between the two halves of the maxilla were directly linked to the facility of maxillary expansion.[1] It was later discovered that the articulations between the maxilla and neighboring bones were greater sources of resistance to expansion than the interdigitation in the mid-palatine suture. Thus, researchers discovered that the non-parallel expansion achieved by a rapid palatal expander can be partly attributed to the zygomatic and sphenoid articulations within the maxilla that act as the resistant forces to maxillary skeletal expansion.[1] The resisting forces from the zygomatic and sphenoid articulations in addition to the pterygoid plates create a center of resistance that is superior and posterior to the applied forces from the rapid palatal expander.[2] The shape of expansion that results is triangular (more expansion anteriorly than posteriorly) and the separated maxillary halves move forward and downward.[3,4,5] Furthermore, soft tissue tension that results from expansion and bone-bending of the alveolar housing can often lead to loss of maxillary expansion and skeletal relapse during retention.[6,7,8,9,10] In 2011, Sun et al. showed in a study on rapid palatal expansion that once the expander is removed, the transverse correction at the mid-palatal suture can relapse as much as 50%, thus losing a significant amount of the desired transverse width initially gained.[9]

In an attempt to mitigate many of the dental side effects that accompany rapid palatal expansion, microimplants are used along with palatal expanders to obtain a higher degree of pure orthopedic movement. Microimplant assisted rapid palatal expanders (MARPE) apply forces directly into the palate, helping to avoid excessive dental molar tipping and mandibular autorotation.[11] Furthermore, MARPEs can be used in older patients whose mid-palatal suture will not separate by a tooth-borne expander alone. The location of the microimplant placement in a MARPE allows for more parallel separation of the mid-palatal suture as forces are distributed more evenly along the suture line as compared to a palatal expander without microimplants. The absolute skeletal anchorage provided by the MARPE can maintain full skeletal expansion and minimize relapse while bone apposition and stabilization can occur at the site of the separated suture.[11,12,13] Not only can a MARPE provide absolute skeletal anchorage, but also it aids in creating a more parallel split of the mid-palatal suture. In 2017, Cantarella et al. used high-resolution CBCT imaging to evaluate the magnitude and sagittal parallelism of mid-palatal suture opening following MARPE treatment. They discovered that the amount of opening at the posterior nasal spine was 90% of that at the anterior nasal spine.[11]

Previous literature investigates relapse in maxillary expansion that was achieved via surgically assisted rapid maxillary expansion (SARME). Kayalar et al. (2019) found an increase in mean piriform aperture width of 2.17 mm from the start of treatment to 6 months post-surgical maxillary expansion (SARME).[14] Soft tissue changes corresponded with the observed skeletal changes as the alar base width increased 2.78 mm and the alar width increased 2.96 mm from the start of expansion treatment to 6 months after SARME. Similarly, de Assis et al. (2010) observed an increase of 1.6 mm in the alar base width after SARME treatment that continued to widen after a 3-year follow-up period.[15] Lee and Perino (2017) also examined retention of an alar base width increase and reported a 1.7 mm increase in alar base width 6 months after SARME.[16] While several studies have investigated the retention of expansion in the mid-face area post-surgical maxillary expansion, less evidence exists that explores the retention of skeletal and soft tissue changes after maxillary expansion using microimplant assisted rapid palatal expansion (MARPE).

Cantarella et al. (2018) evaluated midface skeletal changes induced by MARPE treatment in late adolescent patients via CBCT imaging.[17] They identified the center of rotation for the zygomaticomaxillary complex as being slightly above the frontozygomatic suture after MARPE placement. Additionally, study results showed greater lateral displacement of the zygomatic bone post-MARPE usage versus that of tooth-borne expanders. The study did not, however, address any corresponding soft tissue changes following midface skeletal changes. In a CBCT study by Shimizu (2019), skeletal and soft tissue changes were found to exist immediately after MARPE.[18] These changes occurred in 16 out of 18 identified landmarks post MARPE treatment and there was a significant increase in the soft tissue alar base angle and alar base width. The study included both growing and non-growing patients and did not examine the retention of these changes after orthodontic treatment.

While studies exist that evaluate the hard and soft tissue of the nasal cavity via two-dimensional cephalograms, photography, direct measurements, three-dimensional photographs, laser scanning, and tomography, CBCT imaging that investigates long-term nasal hard and soft tissue changes post MARPE expansion is less common.[13,15,19-27] CBCT imaging is beneficial in that it allows examination of both hard and soft-tissue. It is a reliable method for evaluating soft-tissue facial changes as well as skeletal changes and can be used to evaluate skeletal expansion, molar tipping, and soft-tissue changes post MARPE treatment.[16]

The short- and long-term impact of skeletal expansion of the maxilla on the facial soft tissue, especially the nasal soft tissue, has not been rigorously studied. The aims of this study were to evaluate the amount of skeletal expansion and overlying soft tissue change that occurs using MARPEs at the end of orthodontic treatment in skeletally mature (CVM $\geq$ 5) patients using CBCT imaging. We hypothesized that there would be a significant increase in the width of the alar base and the alar base angle at the end of orthodontic treatment in skeletally mature patients who underwent MARPE treatment.

MATERIALS AND METHODS

In this retrospective study, patient records were drawn from the University of the Pacific School of Dentistry graduate Orthodontic clinic and from a private practice (Audrey Yoon). All patients had CBCTs as part of routine diagnostic records taken before treatment (T1), after completion of expansion with MARPE in place (T2), and at the completion of orthodontic treatment with MARPE removed (T3). The inclusion criteria were patients who were classified as skeletally mature (CVM $\geq$ 5) with less than 3.0mm of change in mandibular length between T1 and T3, had a transverse discrepancy, received a MARPE for expansion and had available pre-treatment, post-expansion, and post-orthodontic CBCTs taken between the years 2015 and 2021. The exclusion criteria were as follows: patients with craniofacial anomalies, facemask treatment followed by MARPE, unsuccessful expansion with the MARPE, orthodontics in conjunction with orthognathic surgery, or incomplete records.

A total of 19 subjects (16 female, 3 male) were included in the sample (Figure 1). The acquired CBCT scans were traced using Anatomage InVivo6® 3D Imaging Software. Three judges were calibrated and randomly assigned to trace the 14 hard tissue landmarks and 6 soft tissue landmarks for T1, T2, and T3 (Table 1). Left and right points were traced for bilateral structures. Hard tissue landmarks were found by tracing points on a rendered 3D volume or in individual coronal slices (Figure 3). The nasal cavity points were identified in 2 sagittal locations: the anterior nasal cavity (ANC) was identified as the most anterior slice where the continuous outline of the lower piriform aperture could be seen and the posterior nasal cavity (PNC) was determined to be at the level of PNS (Figure 4). Soft tissue landmarks were traced on 3D volumes on settings that displayed the soft tissue contours (Figure 5). Traced points were averaged between the 3 judges and distances were calculated between left and right points. A comparison between distances at T1, T2, and T3 was performed.

The design of the MARPE and the expansion protocols from the two clinics were similar. A Won Moon expander type II MSE (Biomaterials, Korea) or a similar custom designed expander was used. They consisted of a jackscrew appliance that was placed on the palatal region around the maxillary first molars. The jackscrew was connected to stainless steel arms soldered to molar bands that were passively fit around the maxillary first or second molars. Four microimplants were used per MARPE with a screw diameter of 1.7 mm and length of 9 mm, 11mm, or 13mm. The length of the implant used was determined by the doctor and based on the patient's CBCT in order to achieve bicortical engagement whenever possible. All implants were placed under local anesthesia. The right and left side of the MARPE housing contained two rigid microimplant guides (one posterior and one anterior) (Figure 2). These implants were intended to deliver expansion force directly to the palate. Activation protocol varied per patient based on the doctor's discretion.

STATISTICAL ANALYSIS

All traced points were averaged to find the mean among all three judges and the distances between right and left points were averaged. Comparisons were made between the three time points (T1, T2, and T3). An intraclass correlation coefficient (ICC) was used to evaluate inter-judge reliability for all measurements. Data were analyzed using the repeated measures ANOVA test for statistical comparison across all three time points. A Tukey post hoc test was used for pairwise comparison and the significance was set to $P < 0.05$. Bonferroni correction was applied and stepwise regression was used to compare soft and hard tissue changes.

RESULTS

An ICC value of > 0.70 was used to determine good inter-rater reliability. The sample had an average age of 16.11 years at the pre-treatment T1 records with a range between 11.9 and 27.1 years of age. T2 record age was averaged at 16.79 with a range between 12.1 and 27.2 years of age. The average amount of time between T1 and T2 was 10 months. The shortest time interval before the post-expansion records was 2 months and the longest was 20 months. At T3, the average age was 18.16 years with a range between 13.0 and 28.8 years of age. The average amount of time between T2 and T3 was 17 months. The shortest time interval before the post orthodontic records was 3 months and the longest was 34 months. The average amount of time between T1 and T3 was 27 months (Figure 1).

Hard tissue results

An increase in skeletal width from the ANS down to the maxillary alveolar bone were statistically significant for several hard tissue landmarks both in the short term (T1-T2) and the long term (T1-T3) (Table 2). However, there was no significant increase in width for the nasofrontal suture points (NFS).

Within the nasal cavity, there were significant changes from expansion in the anterior region at the inferior boundary as well as in the posterior region at the inferior boundary and at the nasal floor (Table 3). The anterior nasal cavity width at inferior turbinate area increased significantly after expansion from 20.49 ± .41 mm at T1 to 23.44 ± 1.21 mm at T2 and remained at an increased width of 23.48 ± 1.54 mm at treatment completion (T3). The posterior nasal cavity at the level of the inferior turbinate also showed a persistence of increased width with values increasing from 25.26 ± 0.86 mm at T1 to 26.96 ± 0.72 mm at T2 and 27.24 ± 0.73 mm at T3 (Table 3, Figure 7).

Additionally, expansion at the maxillary level increased in the short term (T1-T2) at the level of Ju-Ju, ANS, and A point, and the amount of decrease post-expansion was not significant (T2-T3) (Figure 5). From T1 to T2, Ju-Ju increased from 66.1 ± 0.68 mm to 69.6 ± 0.65 mm and from T2-T3, Ju-Ju decreased from 69.6 ± 0.65 mm to 68.9 ± .074 mm. ANS widened to 4.82 ± 1.1 mm from T1- T2. From T2-T3, ANS decreased to 4.55 ± 1.02 mm. PNS increased 5.1 ±

0.91 mm from T1 to T2 and presented no significant change (5.70 ± 1.99 mm) from T2 at T3. A point showed a width increase of 5.08 ± 0.72 mm from T1 to T2 and decrease to 3.9 ± 0.91mm at T3.

Soft Tissue Results

Soft tissues around the nose showed changes that accompanied underlying skeletal changes. The change in width from alare to alare and alare-cheek to alare-cheek were both statistically significant (Table 4). The distance from alare to alare increased from 35.52 ± 0.49 mm at T1 to 36.21 ± 1.44 mm at T2 and remained at an increased value of 36.54 ± 0.63 mm at T3. The distance from alare-cheek to alare-cheek increased from 29.92 ± 2.21 mm at T1 to 32.56 ± 0.88 mm at T2 and remained at an increased value of 31.72 ± 2.19 mm at T3. While the angular measurements evaluated did not show any statistically significant changes, the change in angle of the alare-cheek-pronasale-alare-cheek should be noted. While the change in angle from T1 to T2 to T3 was not significant, it did show a slight increase post-expansion that remained at the end of orthodontic treatment (Table 4, Figure 8). Superimpositions on the cranial base for soft-tissue CBCT imaging give visual representation congruent with the data obtained (Figure 10). Using linear regression, no correlation was found between the hard and soft tissue measurements for any time points (Table 5).

DISCUSSION

When skeletal transverse discrepancies exist between the maxilla and mandible, various modalities of maxillary expansion therapy can be used. Factors such as the patient's age, gender, skeletal structure, and dental tooth position will influence what type of appliance is chosen to yield optimal results. Utilization of micromplants in palatal expansion aims to correct transverse discrepancies between the maxilla and mandible by separating the palatal suture in a parallel manner in hopes of maximizing skeletal changes and minimizing dental side effects. In an attempt to mitigate many of the dental side effects that accompany rapid palatal expansion, microimplants are used along with palatal expanders to obtain a higher degree of pure orthopedic movement. Theoretically, the absolute skeletal anchorage provided by the MARPE can maintain full skeletal expansion and minimize relapse while bone apposition and stabilization can occur at the site of the separated suture.[12,17,13] With expansion of the maxilla, it follows logically that the overlying soft tissue can also be affected by any induced skeletal changes.

In a CBCT study by Shimizu (2019), skeletal and soft tissue changes were found to exist immediately after MARPE treatment. Results showed that post MARPE treatment, there was a significant increase in the soft tissue alar base angle and alar base width.[18] The study included both growing and non-growing patients and did not examine the retention of these changes after orthodontic treatment.

The present follow-up study aimed to evaluate the amount of skeletal expansion and overlying soft tissue change that occurred using MARPEs at the end of orthodontic treatment in skeletally mature (CVM $\geq$ 5) patients using CBCT imaging and evaluated skeletal and soft tissue relapse that occurred at the time of orthodontic treatment completion using CBCT imaging.

Similar to the original study, there was an increase in skeletal width from the ANS down to the maxillary alveolar bone at all bilateral skeletal landmarks both in the short term (T1-T2) and the long term (T1-T3) (Table 2) except for at the nasofrontal suture. One example of a superimposition of CBCT images on the cranial base shows skeletal changes and patterns that are congruent with the numerical results obtained (Figure 8). In terms of soft tissue assessment, Shimizu's study found a statistically significant increase in the width between bilateral alare-cheek structures and a statistically significant increase in angle of alare-pronasale-alare from pre-treatment (T1) to post-expansion (T2).[18] The present follow-up study also found statistically significant changes in width between bilateral alare-cheek points from pre-treatment (T1) to post-expansion (T2) and additionally, from pre-treatment (T1) to end of orthodontic treatment (T3). Due to the close proximity of the maxilla to the alare base, it follows that expansion of the maxilla would have the greatest effect on the soft tissue abutting it. While Shimizu found a statistically significant change in the alare-pronasale-alare angle from T1 to T2, the present study did not find the change in angle to be statistically significant (Figure 8). The alare-pronasale-alare angle in the present study did show an increase between T1 and T2 and a decrease between T2 and T3, although not statistically significant. Additionally, the present study found that the overall increase in width between bilateral alare points from T1 to T3 was statistically significant.

These results suggest that soft tissue changes of the nasomaxillary complex can occur alongside skeletal changes that occur with MARPE treatment. We found no correlation between hard tissue skeletal measurements and soft tissue changes in the nasal cavity region. In the mid-face area, the cartilaginous and elastic nature of nasal tissue makes it flexible and amenable to the changes happening with the underlying skeleton[28]. The statistical significance of the maintained increase in width of the nasal soft tissue at the end of orthodontic treatment proposes that nasal soft tissue widening after MARPE treatment can persist. Clinically, these findings are relevant and can be discussed with patients who need maxillary expansion and may be concerned with soft tissue widening around the nasal cavity area. Furthermore, a variety of factors such as tissue thickness, patient weight, facial expression, and patient sex can contribute to a patient's phenotype and influence soft tissue changes. While large skeletal changes associated with orthognathic surgery can lead to significantly visible soft tissue changes, it appears that the soft tissue changes associated with MARPE treatment are relatively minute and potentially unnoticeable.

The present study offers a glimpse into the potential long-term effects of MARPE treatment on soft tissue structures in the midface region but it cannot provide an absolute picture of these effects due to study limitations. The present study evaluated orthodontic records from 19 skeletally mature patients. These patients were deemed skeletally mature and non-growing based on their cervical vertebral maturation status of ≥ 5. While some studies show that CVM rating is both reproducible and accurate in congruence with hand-wrist evaluation, other studies critique their validity[29]. By using CVM score to qualify non-growing, adult patients, errors in CVM rating could have affected which patients were included in the study. If included patients were still growing, expansion and relapse values would have been confounded by facial growth. We minimized the potential error of selecting patients who still had growth by evaluating the CBCT records to make sure that less than 3mm of growth of the mandible occurred between T1 and T3. Additionally, although a sample size of 19 patients yielded some statistically significant data, a small sample size cannot represent the overall population, as the selected sample might have contained outliers. The study would have benefitted from a larger sample population from which to draw more applicable conclusions.

Another study limitation was that both the treatment and CBCT timeframes were not standardized or consistent among patients. Although it would be difficult to select patients that underwent orthodontic and MARPE treatment for the same amount of time, it would provide more consistency. It is possible that the amount of time that a patient spent undergoing expansion therapy could have affected the amount of relapse, if any, that occurred both skeletally and for the overlying soft tissues. Similarly, CBCT imaging protocols differed between the two clinics that provided patients for the study. At the resident clinic, CBCT imaging was supposed to be taken at the initial records appointment, at the end of MARPE expansion, and at the end of orthodontic treatment. Due to scheduling conflicts and delays, some imaging was not taken immediately after expansion therapy or shortly after orthodontics were completed. In fact, some imaging was found to be taken several months after expansion or orthodontic therapy.

Another variable was the expansion protocol for the MARPE. While some patients were instructed to turn the appliance for rapid palatal expansion, others were instructed to approach expansion at a slower pace. The difference in expansion rate could not only affect the rate of bone formation at the mid-palatal suture, but also the amount of force directed to circummaxillary structures at any given time, thus affecting the position of the structures differently. Additionally, the total amount of MARPE activation varied per patient, thus potentially affecting the amount of change seen in the hard and soft tissues at various times.

Due to the heterogeneity of the sample, no conclusions could be drawn that were particular to a certain ethnicity. It is important to note that both the hard and soft tissues of people from different ethnic backgrounds respond differently to applied force and trends in tissue thickness and elasticity vary between sexes as well as ethnic groups[30].

As the nasal cavity expands along with maxillary expansion, so too does the airway space. Future related studies would be beneficial to examine changes related to airflow in the upper airways due to the potentially decreased nasal resistance from MARPE treatment.

CONCLUSIONS

Maxillary expansion with micromplant assisted expanders resulted in an increase in skeletal width throughout the maxilla at all designated hard tissue landmarks except for the nasofrontal sutures. The increase in skeletal width from the ANS down to the maxillary alveolar bone was statistically significant for several hard tissue landmarks both in the short term and the long term. Correspondingly, the skeletal expansion achieved also led to a significant long-term increase in nasal cavity width at the inferior turbinate area both anteriorly and posteriorly. The overlying soft tissues of the midface region were also affected by MARPE treatment. In particular, the change in width from alare-cheek to alare-cheek (alar base width) showed a significant change as well as the change in width from alare to alare. While not statistically significant, the increase in the alare base angle immediately after expansion that remained at post-treatment is a soft tissue change that could be discussed with patients. Long-term soft tissue changes associated with MARPE treatment show that a widening of the base of the nose may be expected after expansion and may persist at the end of orthodontic treatment. Microimplant assisted rapid palatal expansion provides a good treatment option for non-growing patients who need maxillary skeletal expansion and any soft tissue changes in the mid-face region after treatment may not be noticeable by the patient.

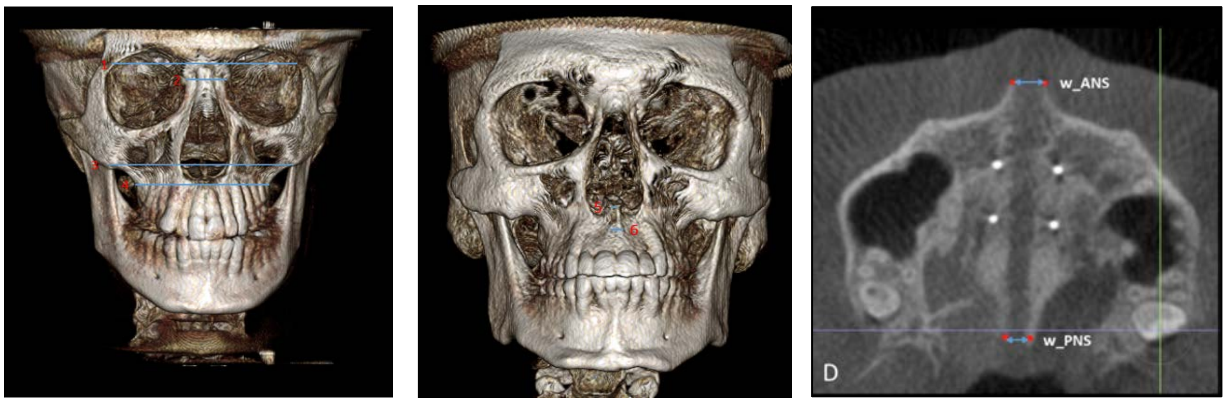
FIGURES AND TABLES

Figure 1. Demographics

CATEGORY		N	%
Sex			
	Male	7	36.84
	Female	12	63.16
CVM			
	CS 5	10	52.63
	CS 6	9	47.37
Age		Mean	
	Age at T1	16.11	
	Age at T2	16.79	
	Age at T3	18.16	

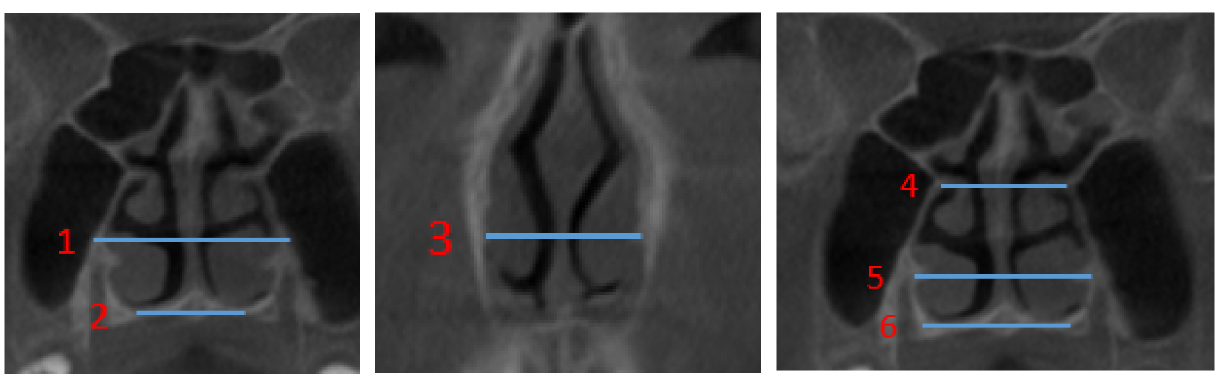
Figure 2. Won Moon expander type II MSE (Biomaterials, Korea)

Figure 3. 3D hard tissue skeletal measurements



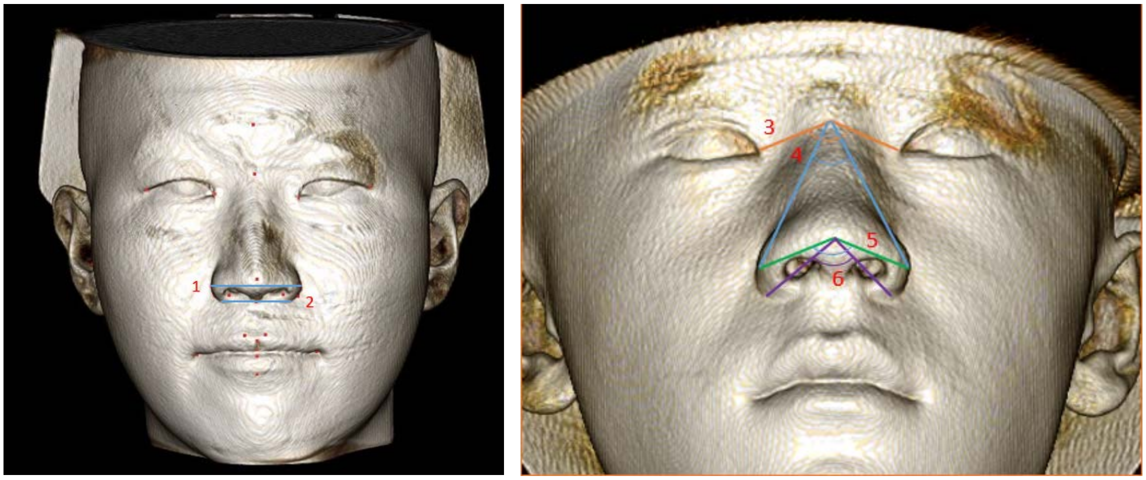
1. Fz-Fz
2. NaFrSu-NaFrSu
3. Krg- Krg
4. Ju-Ju
5. ANS- ANS
6. A-Point – A-Point

Figure 4. CBCT slice of Piriform Aperture at level of right and left Orbitale (left), Anterior Nasal Cavity (center), and Posterior Nasal Cavity (right) with associated measurements



1. Lat_Pirif- Lat_Pirif
2. Inf_Pirif-Inf_Pirif
3. ANC IT-IT
4. PNC ST-ST
5. PNC IT-IT
6. PNC_NF

Figure 5. 3D volume soft tissue linear (left) and angular (right) measurements



1. al-al
2. ac-ac
3. en-Na’-en
4. al-PrN-al
5. ac-PrN-ac
6. al-Na’-al

Figure 6. Graphic representation of hard tissue measurement data for skeletal structures at pre-treatment (T1), post- expansion (T2), and end of orthodontic treatment (T3). Values are presented as a mean ± standard deviation. P < 0.05

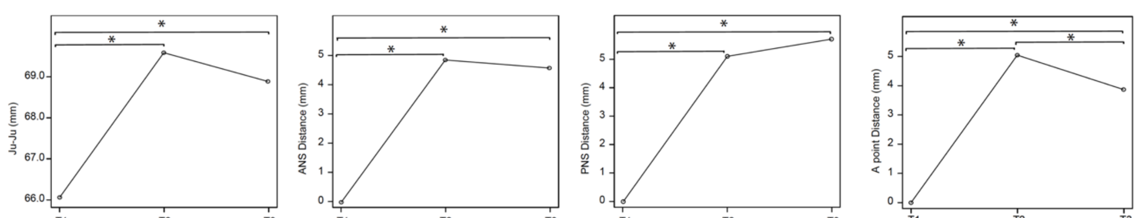


Figure 7. Graphic representation of hard tissue measurement data for the nasal cavity at pre-treatment (T1), post- expansion (T2), and end of orthodontic treatment (T3). Values are presented as a mean ± standard deviation. P < 0.05.

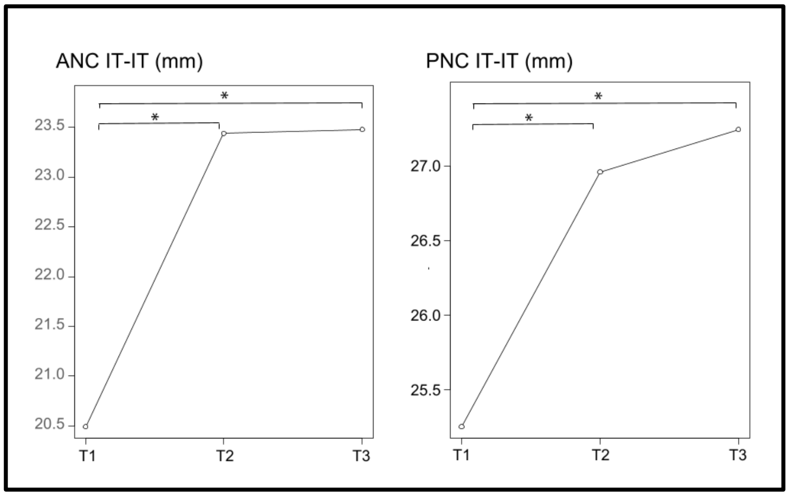


Figure 8. Graphic representation of soft tissue data at pre- treatment (T1), post- expansion (T2), and end of orthodontic treatment (T3). Values are presented as a mean ± standard deviation. P < 0.05.

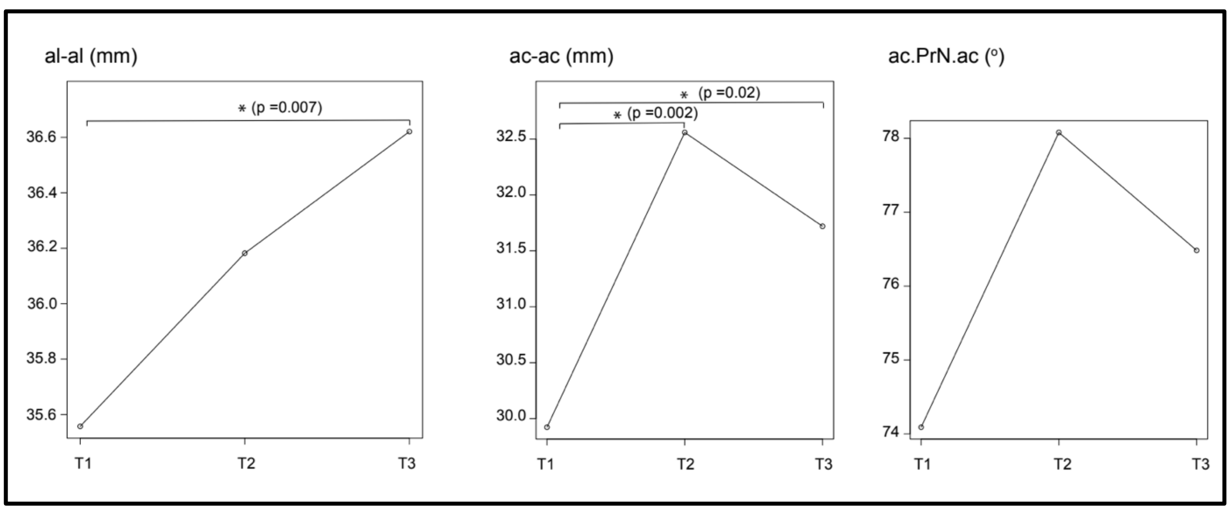


Figure 9. 3D superimpositions for hard tissue. From left to right: Pre-treatment T1 (white) and post-expansion T2(blue), post-expansion T2 (white) and end of treatment T3 (blue), pre-treatment T1 (white) and end of treatment T3 (blue).

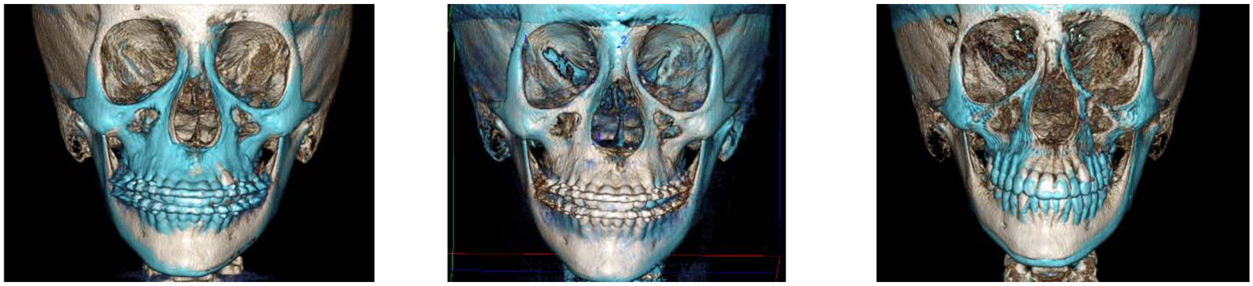


Figure 10. 3D superimpositions for soft tissue of the midface region. From left to right: Pre-treatment T1 (white) and post-expansion T2(blue), post-expansion T2 (white) and end of treatment T3 (blue), pre-treatment T1 (white) and end of treatment T3 (blue).

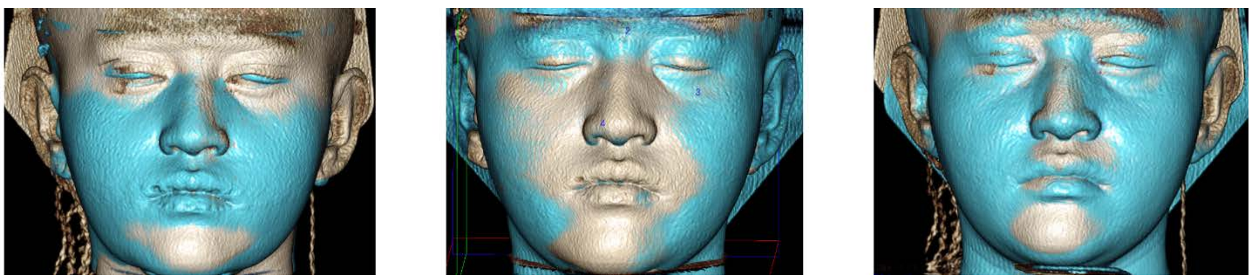


Table 1. Hard and soft tissue landmarks traced on CBCT

Hard Tissue	Soft Tissue
Porion	Endocanthion
Frontozygomatic Suture	Exocanthion
Nasofrontal Suture	Soft Tissue nasion
Key Ridge	Ala
ANC Lateral Piriform	Ala-Cheek
ANC Inferior Turbinate	Pronasale
ANC Inferior Piriform	Subnasale
PNC Superior Turbinate	Subalare
PNC Inferior Turbinate	
PNC Nasal Floor	
Jugum	
ANS	
PNS	
A Point	

Table 1A. Hard Tissue Measurements for Skeletal Structures

Landmark	Symbol	Definition
Frontozygomatic suture	Fz	the point at the intersection of the frontal and zygomatic bone on the suture on the inner rim of the orbit in the frontal plane and most anterior point of the suture from the saggital view
Nasofrontal Suture	NaFrSu	the point at the intersection of the nasal and frontal bones on the inner rim of the orbit in the frontal plane and most anterior point of the suture from the saggital view
Keyridge	KRG	Most inferior point of the zygomaticomaxillary ridge along the suture between the zygomatic bone and the maxillary bone
Jugum	Ju	Intersection of the maxillary tuberosity and the zygomatic buttress in the frontal view
Anterior Nasal Spine	ANS	Most anterior point of the premaxilla along the midline of the maxilla
Posterior Nasal Spine	PNS	Most posterior point of the palatine bone
A Point	A	The deepest point on the contour of the maxilla between the anterior nasal spline and the upper incisor

Table 1B. Hard Tissue Measurements for Nasal Cavity

Landmark	Symbol	Definition
Lateral Piriform	Lat_Pirif	Lateral border of nasal cavity- the point on the surface of the pirifom aperture and at the level of the right/left orbitale
Inferior Piriform	Inf_ Pirif	Inferior lateral border of nasal cavity; the deepest point along the curvature in the frontal view
Anterior Nasal Cavity Inferior Turbinate	ANC IT	Inferior turbinate attachment of anterior limit of nasal cavity
Posterior Nasal Cavity Inferior Turbinate	PNC IT	Inferior turbinate attachment of posterior limit of nasal cavity
Posterior Nasal Cavity Superior Turbinate	PNC ST	Superior turbinate attachment of posterior limit of nasal cavity
Posterior Nasal Cavity Nasal Floor	PNC NF	Nasal floor of posterior limit of nasal cavity

Table 1C. Soft Tissue Measurements

Landmark	Symbol	Definition
Endocanthion	en	The point at the inner commisure of the right/left eye fissure
Alare	al	The outermost point on the alar contour
Ala-Cheek	ac	The crease between the outer alare and cheek (R/L)
Pronasale	PrN	The most protruded point of the nose
Soft tissue Nasion	Na'	The deepest midline point of the nasofrontal angle

Table 2. Hard tissue measurement data for skeletal structures at pre-treatment (T1), post-expansion (T2), and end of orthodontic treatment (T3). Values are presented as a mean ± standard deviation. $P < 0.05$

	T1	T2	T3	p-value
Fz-Fz	93.80±0.68	94.37±0.39	94.96±1.03	0.008
NaFrSu-NaFrSu	10.18±0.9	10.44±0.99	11.08±1.92	0.583
KRG-KRG	88.25±2.32	91.33±2.34	92.4±2.72	<.0001
Ju-Ju	66.07±0.68	69.6±0.65	68.9±0.74	<.0001
ANS_Di	0	4.82±1.1	4.55±1.02	<.0001
PNS_Di	0	5.1±0.91	5.7±1.99	<.0001
A point	0	5.08±0.72	3.9±0.91	<.0001

Table 3. Hard tissue measurement data for the nasal cavity at pre- treatment (T1), post-expansion (T2), and end of orthodontic treatment (T3). Values are presented as a mean ± standard deviation. $P < 0.05$.

	T1	T2	T3	p-value
Lat_Pirif-Lat_Pirif	19.04±0.68	21.36±1.1	21.19±0.55	<.0001
Inf_Pirif-Inf_Pirif	12.61±1.14	15.44±1.31	16.03±1.68	<.0001
ANC IT-IT	20.49±0.41	23.44±1.21	23.48±1.54	<.0001
PNC IT-IT	25.26±0.86	26.96±0.72	27.24±0.73	<.0001
PNC ST-ST	21.86±1.69	21.96±1.61	22.21±1.31	0.808
PNC NF-NF	25.42±1.24	27.83±0.98	27.3±1.25	0.0001

Table 4. Soft tissue measurement data at pre-treatment (T1), post- expansion (T2), and end of orthodontic treatment (T3). Values are presented as a mean ± standard deviation. $P < 0.05$.

	T1	T2	T3	p-value
en-Na'-en	128.98±6.77	120±7.5	123.74±11.48	0.066
al-al	35.52±0.49	36.21±1.44	36.54±0.63	0.009
ac-ac	29.92±2.21	32.56±0.88	31.72±2.19	0.002
al-PrN-al	98.15±4.36	99.3±6.63	100.27±2.32	0.403
ac-PrN-ac	74.09±8.85	78.08±1.87	76.48±5.22	0.141
al-Na'-al	44.56±1.48	46±8.16	43.8±1.29	0.279

Table 5. Pearson correlation coefficients between hard tissue and soft tissue changes (T1-T3)

	ANS Di		PNS Di		A point	
	r	*P*	r	*P*	r	*P*
al-al	-0.04	0.878	-0.07	0.779	-0.06	0.818
ac-ac	0.19	0.428	0.38	0.109	-0.22	0.374
al-PrN-al	0.34	0.159	0.13	0.602	-0.24	0.318
ac-PrN-ac	0.36	0.134	0.23	0.346	-0.36	0.125
al-Na-al	0.39	0.099	0.00	0.999	-0.04	0.884
ac-Na-ac	0.29	0.227	0.39	0.095	-0.26	0.292

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