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Stability of skeletal, alveolar, and dental components in microimplant-supported Midfacial Skeletal Expander (MSE) expansion

A thesis submitted in partial satisfaction of the requirements for the degree Master of Science in Oral Biology

by

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ABSTRACT OF THE THESIS

Stability of skeletal, alveolar, and dental components in microimplant-supported Midfacial Skeletal Expander (MSE) expansion

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Professor Ben Wu, Chair

Maxillary transverse deficiency is one of the most common skeletal problems in the craniofacial region. Rapid palatal expansion (RPE) has been the preferred standard treatment when transverse deficit is present, especially in young patients. While the main goal of RPE is to split the midpalatal suture, the circum-maxillary sutures are also affected and alveolar bone bending, and dental tipping are common. The desire is to produce a greater skeletal effect than dentoalveolar side-effects; however, the latter are commonly expressed in substantive magnitude.

In order to assess skeletal expansion, alveolar bone bending and dental tipping after maxillary expansion, linear and angular measurements has been performed utilizing different craniofacial references. Since the expansion with Midfacial Skeletal Expander (MSE) is archial in nature, the aim of this paper is to quantify the differential components of MSE expansion using an angular measurement system described in a previous study, and assessing the stability of each component after orthodontic treatment.

Methods: A total of fourteen subjects with a mean age of 20.4 ± 3.5 years were treated with MSE. Pre-expansion (T0), post-expansion (T1), and post-treatment (T2) CBCT records were superimposed and compared. Based on methods in a previous study, the rotational fulcrum of the zygomaticomaxillary complex were identified and angular measurements were generated to assess changes of the zygomaticomaxillary complex (skeletal expansion), dentoalveolar bone (alveolar bone bending), and maxillary first molars (dental tipping). The stability of all three components after orthodontic treatment were also assessed by comparing measurements between post-expansion and post-treatment.

Results: Immediately following MSE expansion, angular measurements showed that skeletal expansion accounted for 87.50% and 88.56% of total expansion, alveolar bone bending for 7.09% and 5.23%, and dental tipping for 5.41% and 6.21% on the right and left sides, respectively. At the end of orthodontic treatment, data showed that skeletal expansion relapsed by 11.20% and 13.28% on the right and left sides, respectively. Changes in alveolar bone bending and dental tipping between post-expansion and post-treatment varied greatly due to orthodontic dental decompensation after expansion.

Conclusions: Maxillary skeletal expansion using the microimplant-supported Midfacial Skeletal Expander (MSE) produces mainly skeletal changes with insignificant dentoalveolar changes immediately after expansion. In the long term, the majority of the skeletal expansion was maintained. Long-term dentoalveolar changes were in the magnitude of 300-1500% in the opposite direction, induced by orthodontic decompensation of the pre-existing dental compensation. However, net gains in the intermolar width were maintained despite these changes due to the long-term stability of skeletal expansion.

The thesis of Catherine Tianlan Ding is approved.

Renate Lux

Sanjay Mallya

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University of California, Los Angeles

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INTRODUCTION

Maxillary transverse deficiency is one of the most common skeletal problems in the craniofacial region. It has been found that the transverse dimension of the maxillary complex is the most malleable.[1] Traditionally, rapid palatal expansion (RPE) has been the preferred standard treatment, especially for younger patients. Although the main purpose of RPE is to expand the maxilla by splitting the midpalatal suture, the surrounding circum-maxillary sutures are also affected.[2] In addition, dental tipping and alveolar bone bending are commonly observed.[3-6] Although the goal is to achieve skeletal expansion, oftentimes dental side effects are created and true skeletal expansion is not fully expressed.

RPE treatment for maxillary skeletal expansion is most effective when performed prior to the pubertal growth spurt to minimize dentoalveolar side effects.[7] As patients mature and the midpalatal suture interdigitates, maxillary skeletal transverse expansion becomes more difficult and the lateral forces from the tooth-borne RPE appliance are translated into alveolar bone bending and dental tipping; this is true in even young patients but to a lesser extent. These dentoalveolar changes can include fenestration, bone dehiscence, and decrease in alveolar bone height.[8] In order to avoid these undesired dentoalveolar side effects, a variety of bone-supported or hybrid microimplant assisted rapid palatal expanders (MARPE) have been introduced. [9-19] These MARPE appliances have grown in popularity in recent years as a potentially effective way to minimize dentoalveolar side effects in mature patients due to their ability to anchor directly into bone. However, results between different designs of MARPE appliances are varied and significant dentoalveolar changes have still been reported in many MARPE studies despite bone anchorage.[11, 14-20] One study reported negligible molar tipping,[21] while others claimed that side effects such as alveolar bone bending and dental tipping are not preventable but can be reduced compared to RPE. [9, 10]

The midfacial skeletal expander (MSE) is one particular design of MARPE appliance that has been described in the literature since 2014.[12, 20-29] There have been many studies on the use and successful application of the MSE in mature patients over the recent years.[12, 21, 28] Cantarella describes a downward and outward movement of the zygomaticomaxillary complex in the coronal plane, with the fulcrum localized slightly above the frontozygomatic suture.[21]

Thus far, the amount of skeletal, alveolar and dental expansion achieved with RPE and MARPE have been measured mostly using linear measurements and angular measurements based on arbitrary points.[8-19, 30] Previous studies have shown that MARPE expansion is stable one year after expansion according to linear measurements.[31] However, it has been shown that expansion is often archial in nature.[21] This calls into question the accuracy of linear measurements in measuring expansion and stability. Furthermore, angular measurements would be more accurate if a true fulcrum were to be located. A previous study by Paredes et al. introduced a novel angular measurement system that takes into account the true fulcrum, providing a method to more accurately assess the rotational expansion created by MARPE.[32] The purpose of this study is to assess the stability of MSE expansion using this previously described angular measurement system.

Overall Objectives and Specific Aims

Objective: The long-term goal of this study is to differentially assess the stability of skeletal expansion, alveolar bone bending, and dental tipping induced by microimplant-supported Midfacial Skeletal Expander (MSE) after orthodontic treatment, utilizing angular measurements from the fulcrum described in a previous study.

Specific Aims:

The first aim of this paper is to evaluate the skeletal, alveolar and dental components induced by microimplant-supported Midfacial Skeletal Expander in the long term at the end of orthodontic treatment, utilizing an angular measurement system from the fulcrum.

The second aim of this study is to assess the stability of MSE expansion in terms of its skeletal, alveolar and dental components in the long term compared to immediately post-expansion.

DESIGN AND METHODOLOGY

This retrospective study is an extension of a previous study MSE study [32] and was performed at the University of California at Los Angeles (UCLA) with approval by the ethics committee (IRB number 17-000567).

The pre-expansion, post-expansion and post-treatment CBCT images from 14 randomly selected patients successively treated with MSE (Biomaterials Korea, Seoul, Korea) with mean age of 20.4 ± 3.5 years were obtained. All patients were diagnosed with maxillary transverse deficit and treated at the orthodontic clinic, UCLA School of Dentistry, under the supervision of one clinician. Orthodontic treatment, including bonding of brackets and other appliances, was carried out after the completion of MSE expansion and acquisition of post-expansion CBCT. At the end of orthodontic treatment, the post-treatment CBCT was obtained. The selection criteria included: (1) diagnosis of a transverse maxillary deficiency; (2) cases requiring MSE expansion as part of the overall treatment plan, (3) patient records with CBCT images obtained at 3 time points: pre-expansion (T0), within 3 weeks after active expansion (T1), and at the end of orthodontic treatment (T2); (4) absence of any craniofacial irregularity, and (5) no orthodontic treatment precedent. The average time interval was 8.1 ± 4.8 months between pre-expansion and post-expansion CBCT and 19.5 ± 7.3 months between post-expansion and post-treatment. Average total treatment time between pre-expansion and post-treatment CBCT was 27.6 ± 6.9 months.

The transverse deficiency was diagnosed using coronal cuts from each subject's initial CBCT. The maxillary bone width was determined by the distance between the right and left bony points at the level of the mesiobuccal root tips of the upper first molars. Mandibular bone width was defined as the distance between the right and left bony buccal surface at the level of the lower first molar furcation (Fig 1). If the mandibular width was greater than the maxillary width, a transverse discrepancy was diagnosed. Clinically, on the dental cast, the maxillary width is defined by the distance between the left and right most concave points along the maxillary vestibule above the mesiobuccal cusps of the first molars.[33] The mandibular width is defined as the distance between the left and right buccal surface over the lower first molar furcation. The amount of difference among these values also projects the extent of maxillary skeletal expansion required (Fig 2). Some patients with transverse deficiency, but not requiring expansion for normal function, will not be included in this study.

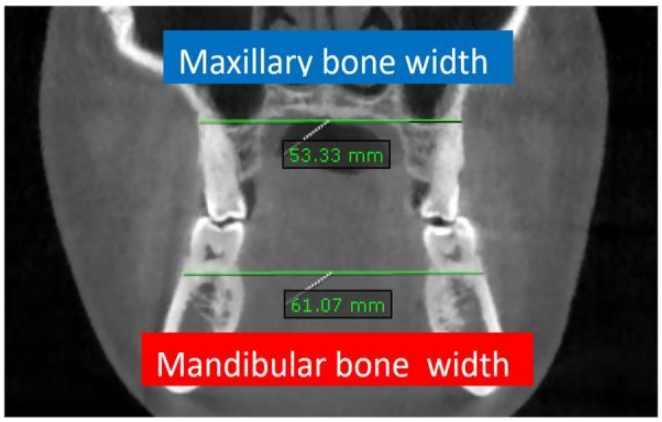
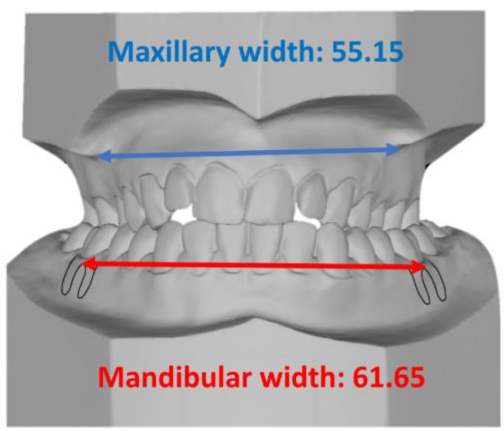


Fig. 1. Method used to diagnose transverse maxillary skeletal deficiency. Maxillary bone width is determined by the distance between the right and left bony points at the level of the mesiobuccal root tips of the first molars. Mandibular bone width is defined as the distance between right and left bony buccal surface at the level of the furcation of first molars. The maxillomandibular bone width discrepancy is obtained by subtracting mandibular bone width (61.07mm) from the maxillary bone width (53.33) = -7.74mm.

Fig 2. Method used in dental casts to project the extent of maxillary skeletal expansion required. Blue line, maxillary width and red line, mandibular width measured with a digital caliper; Mandibular width is defined as the distance between the right and left gingiva tissue projected at the level of first mandibular molar’s furcation. In this case the transverse deficiency in models accounts for 6.5 mm.



Taking measurements on study models can be done before and during the expansion in order to assess the bone relationship. The expansion was stopped once adequate expansion had been achieved and the maxillary width became wider than the mandibular width for optimal occlusion after dental decompensation. The furcation is most likely the center of rotation for mandibular molars when compensated, therefore the width between the buccal points over the furcation was used as the projected mandibular width after lower dental uprighting. The maxillary molars are generally flared buccally and decompensation by uprighting the maxillary molars will cause the maxillary dental arch to constrict. The most concave area of the maxilla is often at the apex of the maxillary molar, and controlled tipping while fulcruming at the apex is required for decompensation, unlike for the mandibular molars. Some patients with slight skeletal transverse deficiency, but not requiring expansion for normal function (due to well compensated dentition), were not included in this study.

The MSE device (Fig 3) has a jackscrew unit (16.15 mm in length, 4.5 mm in width and 14.15 mm in depth) with four parallel holes (1.8 mm in diameter) for micro-implant insertion and two soft supporting arms on each side which are soldered to the molar bands for stabilizing MSE during the expansion. The body of MSE is positioned between the zygomatic buttress bones, usually located lateral to the first molars. Four micro-implants (1.8 mm in diameter, 11 mm or 13 mm in length) were inserted through the palatal bone, bi-cortically. The posterior placement and bicortical engagements promote posterior and superior expansion of the maxillary process, which in turn produce the archial expansion described in previous study.[21] The rate of expansion was 2 activations per day (0.20 mm per turn) until a diastema appeared; then the expansion rate changed to 1 activation per day. The activation was continued until the maxillary skeletal width, was equal or greater than the mandibular width. The MSE was kept in place with no further activation for 6 months to retain the expansion during the bone formation.

Fig. 3. Maxillary skeletal expander device

In addition to the pre-expansion CBCT scan taken before the expansion, a second CBCT scan was obtained within 3 weeks after completing the expansion. The time interval between the scans was 8.1 ± 4.8 months, and this included the time lapsed for administrative procedures, appliance fabrication, delivery and treatment. In order to assess skeletal outcomes induced purely by MSE, post-expansion scans were obtained before patients received any other orthodontic appliances. All subjects must also have a final post-treatment CBCT taken at the end of orthodontic treatment, with an average treatment time of 27.6 ± 6.9 months. The same scanner (5G; NewTom, Verona, Italy) was used for all patients, with an 18 X 16 cm field of view, 14-bit gray scale, and a standard voxel size of 0.3 mm. Configuration of the CBCT included scan time of 18 seconds (3.6 seconds emission time), with 110 kV. In order to properly adjust the milliamperes, an automated exposure control system was used to detect the patient's anatomic density. OnDemand3D (Cybermed, Daejeon, Korea) software will be used to superimpose all three CBCT images, using the anatomical structures of the entire anterior cranial base [34] by automated processing in matching the voxel gray-scale patterns.

First, the pre- and post-expansion CBCT images (T0 and T1, respectively) were superimposed and the exact fulcrum location of each patient was identified utilizing the method described by Parades, et al.[32]. According to Paredes et al., the fulcrum was located near and slightly above the external surface of the frontozygomatic suture because sutures are the weakest points of the midfacial structure during the archial movement of expansion.[21]

The true rotational fulcrum on the right and left sides (rF and lF) were found using a method previously described.[32] Utilizing the rotational fulcrum, the following angular measurements were performed to assess skeletal, alveolar and dental components of expansion: 1) the Frontozygomatic Angle (FZA) between the interfrontal line and the line extending from fulcrum to the most external point of the zygomaticomaxillary suture, 2) the Frontoalveolar Angle (FAA) between the interfrontal line and the line extending from fulcrum to the alveolar bone surface at the level of distobuccal root tip of the upper first molars, and 3) the Frontodental Angle

(FDA) between the interfrontal line and the line extending from fulcrum to the occlusal point located at the central groove of the upper first molar (Fig 4). These three angles were measured on right and left sides, and the pre-expansion value (T0) was subtracted from the post-expansion value (T1) in order to determine the treatment change for each section. The FZA changes correspond to the zygomaticomaxillary expansion, a true skeletal expansion (FZA changes); the FAA changes correspond to the sum of the skeletal expansion (FZA change) and the alveolar bone bending (FAA changes-FZA changes); and the FDA changes correspond to the sum of the skeletal expansion (FZA changes), alveolar bone bending (FAA changes-FZA changes) and the dental tipping (FDA changes-FAA changes).

In order to assess the long-term stability of MSE expansion, pre-expansion (T0) and post-treatment (T2) CBCTs were also superimposed using the method described and all angular measurements described above were repeated to compare pre-expansion (T0) and post-treatment (T2) changes.

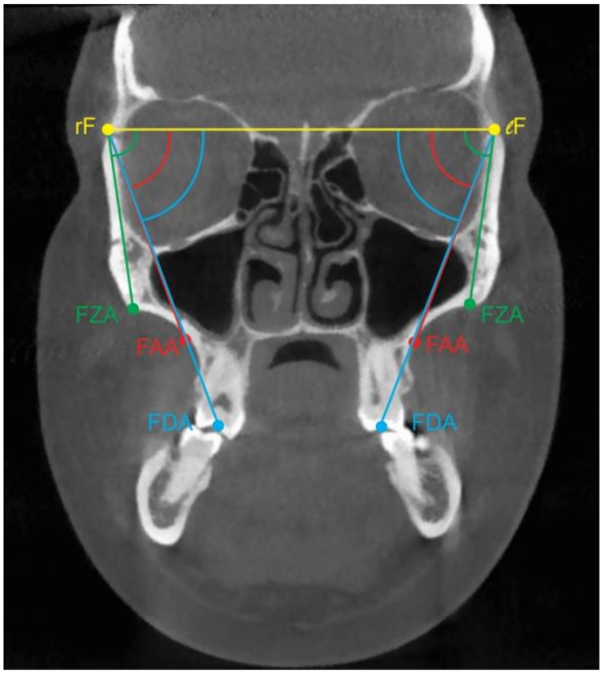


Fig 4. Angular measurement systems in the coronal zygomatic section: frontozygomatic angle (FZA), frontoalveolar angle (FAA), and frontodental angle (FDA), rF, right fulcrum, lF, left fulcrum.

Statistical analysis

Measurements were obtained for the 18 variables (6 pre-expansion, 6 post-expansion, 6 post-treatment) on 5 randomly selected patients, by 2 raters, to assess method reliability. Measurements were then repeated after 2 weeks by the same operators. The calculated parameters were rater standard deviation, rater coefficient of variation, error standard deviation, error coefficient of variation, and intraclass correlation coefficient (ICC).

Shapiro-Wilk test was used to assess normality of the data distribution. Pre-expansion (T0), post-expansion (T1) and post-treatment (T2) variables were compared using a paired t test for the normally distributed variables, and Wilcoxon signed rank test for the nonnormally distributed variables. The significance level was set at $P < 0.05$. Statistical analysis was performed using SPSS software.

For each variable, the T0 values were subtracted from the T1 values. The percentages of skeletal expansion (a: the frontozygomatic angle changes), alveolar bone bending (b: the frontoalveolar angle change - the frontozygomatic angle change) and dental tipping (c: the frontodental angle change – the frontoalveolar angle change) were obtained. The value changes for each variable were compared to zero using a one-sample t-test ($P < 0.05$). Similarly, the T1 values were subtracted from the T2 and compared to T0-T1 results to obtain the percentages of relapse in skeletal expansion, alveolar bone bending, and dental tipping. Results were analyzed with a one-sample t-test compared to zero ($P < 0.05$).

RESULTS

The mean FZA, FAA, and FDA measurements at pre-expansion, post-expansion, and post-treatment are presented in Table 1. A significant difference was found for the mean treatment change for all variables between T0 and T1 on both right and left sides. Similarly, a significant difference was found for the mean treatment change for all variables between T0 and T2, as well as between T1 and T2 (Table 2).

Table 1. Skeletal, alveolar bone and dental measurements.

		T0		T1		T2	
	Variable	Mean	SD	Mean	SD	Mean	SD
Right	FZA (°)	85.07	3.20	85.92	3.02	87.38	2.99
	FAA (°)	70.26	2.55	73.06	2.74	72.36	3.04
	FDA (°)	69.90	1.72	72.95	1.83	72.04	1.63
Left	FZA (°)	84.16	2.92	86.87	3.83	86.51	3.55
	FAA (°)	69.91	2.12	72.78	3.08	72.06	2.98
	FDA (°)	69.87	2.00	72.94	2.63	71.49	2.96

Between T0 and T1, the total expansion consisted of 2.59 (±1.30) degrees and 2.71 (±2.08) degrees skeletal expansion, 0.21 (±0.51) degrees and 0.16 (±0.67) degrees alveolar bone bending, 0.16 (±0.39) degrees and 0.19 (±0.66) degrees dental tipping on the right and left sides respectively. These values represent 87.50% and 88.56% of skeletal expansion, 7.09% and 5.23% of alveolar bone bending, 5.41% and 6.21% of dental tipping on the right and left sides, respectively (Table 3). Skeletal expansion was significant, while alveolar bone bending and dental tipping values were not.

Between T1 and T2, the total change consisted of -0.26 (±0.34) degrees and -0.36 (±0.46) degrees skeletal change, -0.69 (±0.90) degrees and -2.51 (±1.92) degrees alveolar change, -0.91 (±1.28) degrees and -0.73 (±1.02) degrees dental change on the right and left sides, respectively. This suggests -11.20% and -13.28% skeletal relapse compared to amount of skeletal expansion gained from T0 to T1 on the right and left sides, respectively (Table 4). All changes in skeletal expansion, alveolar bone bending, and dental tipping were statistically significant.

Table 2. Comparison of the skeletal, alveolar bone and dental changes pre-expansion, post-expansion, and post-treatment using the paired *t*-test and Wilcoxon signed rank test.

		T1 - T0				T2 - T0				T2 - T1			
	Variable	Mean	SD	Z/*t*-stat	P-Value	Mean	SD	Z/*t*-stat	P-Value	Mean	SD	Z/*t*-stat	P-Value
Right	FZA (°)	2.59	1.30	Z = 3.18	0.001*	2.31	1.36	Z = 3.18	0.001*	-0.29	0.34	*t* = -3.15	0.008*
	FAA (°)	2.80	1.08	*t* = 9.69	<0.001*	2.11	1.42	*t* = 5.56	<0.001*	-0.69	0.82	*t* = -3.17	0.007*
	FDA (°)	2.96	1.23	*t* = 9.03	<0.001*	2.05	1.08	*t* = 7.13	<0.001*	-0.91	1.21	*t* = -2.80	0.015*
Left	FZA (°)	2.71	2.08	*t* = 4.88	<0.001*	2.34	1.77	*t* = 4.95	<0.001*	-0.36	0.46	*t* = -2.95	0.011*
	FAA (°)	2.87	1.93	*t* = 5.58	<0.001*	2.15	1.59	*t* = 5.05	<0.001*	-0.72	0.67	*t* = -4.03	0.001*
	FDA (°)	3.06	1.91	*t* = 6.01	<0.001*	1.61	2.00	*t* = 3.02	0.01*	-1.45	1.16	*t* = -4.69	<0.001*

**P* < 0.05

Table 3. Percentage expansion of skeletal, alveolar bone, and dental components between pre- and post-expansion (T1-T0).

		Measurements**			Skeletal expansion	Alveolar bone bending	Dental tipping
		Δa	*Δb*	*Δc*	*Δa*	*Δb-Δa*	*Δc-Δb*
Right	Mean (°)	2.59	2.80	2.96	2.59	0.21	0.16
	SD	1.30	1.08	1.23	1.30	0.51	0.39
				%	**87.50%**	**7.09%**	**5.41%**
				P-Value	**<0.001***	**0.147**	**0.149**
Left	Mean (°)	2.71	2.87	3.06	2.71	0.16	0.19
	SD	2.98	1.93	1.91	2.08	0.67	0.66
				%	**88.56%**	**5.23%**	**6.21%**
				P-Value	**<0.001***	**0.388**	**0.301**

**P* < 0.05

***Δa = change in FZA; Δb = change in FAA; Δc = change in FDA*

Table 4. Percentage change in skeletal, alveolar bone, and dental components between post-expansion and post-treatment (T2-T1).

		T1-T0**			T2-T1**		
		Δa	*Δb-Δa*	*Δc-Δb*	*Δa*	*Δb-Δa*	*Δc-Δb*
Right	**Mean (°)**	2.59	0.21	0.16	-0.29	-0.69	-0.91
	SD	1.30	0.51	0.39	0.34	0.90	1.28
				%	**-11.20%**	**-328.57%**	**-568.75%**
				P-Value	**<0.001***	**0.013***	**0.020***
Left	**Mean (°)**	2.71	0.16	0.19	-0.36	-2.51	-0.73
	SD	2.98	0.67	0.66	0.46	1.92	1.02
				%	**-13.28%**	**-1568.75%**	**-384.21%**
				P-Value	**0.012***	**<0.001***	**0.019***

**P < 0.05*

***Δa = change in FZA; Δb = change in FAA; Δc = change in FDA*

DISCUSSION

MARPE approaches are recommended to correct maxillary transverse discrepancies in adult patients to increase the skeletal effect while minimizing unwanted dentoalveolar side effects associated with traditional RPE expansion.[9] It has been found that even in growing patients, RPE expansion produces increased buccal flaring of the anchoring teeth regardless of the rate of activation [8] or the type of expander used.[3, 4, 10, 35-38] Other adverse dentoalveolar effects include fenestration, dehiscence, and gingival recession [5], which are more common and critical in non-growing patients. In addition, expansion has been found to relapse even in growing patients due to relapse of dental tipping after the expansion phase.[6, 8] The bone-borne nature of MARPE approaches is aimed to mitigate these adverse effects.

The MSE appliance is designed to achieve skeletal expansion by direct bony anchorage with four mini-implants placed next to the midpalatal suture and in between the zygomatic buttress bones with bicortical engagement.[20] The mini-implants allow force to be applied directly against the midpalatal suture with bands on the upper maxillary molars only for stability. Bicortical engagement of the mini-implant also allows the expansion for to be applied more superiorly in the maxillary complex.[20] Paredes, et al. [32] showed that expansion achieved by the MSE appliance was significant and consisted of almost pure skeletal expansion with negligible alveolar bone bending and slight dental tipping. Our results showed that skeletal expansion accounted for 87.50% (2.59°) on the right side and 88.56% (2.71°) on the left side. These values were comparable to those previously reported by Paredes, et al. (96.58% R and 95.44% L).[32] Furthermore, only the change in FZA was statistically significant, indicating that the expansion observed was mostly skeletal with the midcranial structures rotating around the fulcrum points located near the frontozygomatic suture.[21]

To date, studies on the long-term stability of MSE expansion is limited. A previous study on MARPE expansion found stable outcomes one year after expansion according to linear measurements[31], although the specific appliance used was different and did not have bicortical engagement. Furthermore, results were measured linearly without taking into account the rotational nature of expansion. The T2 timepoint in our study reflects a mean time of 19.5 ± 7.3 months post-expansion. According to our results, there was a significant skeletal rotational expansion of 2.31° on the right and 2.34° on the left from T0 to T2, with a statistically significant relapse of 11.20% (0.29°) and 13.28% (0.36°) on the right and left, respectively, between T1 and T2. However, this relatively minimal amount of relapse is a promising clinical result especially compared to the amount of relapse noted using alternative methods such as surgically-assisted rapid palatal expansion (SARPE). Byloff et al. [39] reported in a longitudinal study of SARPE patients using a pre-fabricated Hyrax appliance that the mean skeletal expansion of 1.3mm had relapsed by 0.4mm during retention and post-retention periods, which represents 30.77% relapse. Our findings suggest that MSE expansion may produce a comparable, if not more stable result in non-growing patients compared to SARPE. Clinicians should also consider over-expansion of the MSE appliance by at least 10% in anticipation of some skeletal relapse in the long term.

The alveolar bone bending and dental tipping components varied greatly between T1 and T2, with alveolar bone measurements decreasing by 328.57% (0.69°) and 1568.75% (2.51°), and dental tipping measurements decreasing by 568.75% (0.91°) and 384.21% (0.73°) on the right and left, respectively. The significantly larger decrease in alveolar and dental components post-treatment compared to the skeletal component can be attributed to the dental decompensation of the dentition during orthodontic treatment after expansion. However, even after a relatively larger decrease in FAA and FDA angles, the change in these angles from T0 to T2 is still significant

(FAA = 2.11° R and 2.15° L, FDA = 2.05° R and 1.61° L), suggesting that true expansion was achieved.

Thus far, there has been limited data on the long term stability of MSE expansion and MARPE in general. The MSE protocol used in our study involved keeping the MSE appliance installed passively for 6 months post-expansion for retention during bone formation, similar to methods used in many previous studies.[21, 28, 29, 32] However, perhaps a longer period of retention with the mini-screws may improve expansion stability to allow more time for bone formation. Furthermore, due to the relatively new technology of MARPE, the current literature does not provide any data regarding long term stability of expansion beyond one year after MARPE expansion. Our study followed patients over a mean time period of 19 months post-expansion. Future studies should focus on stability of expansion over 5 years or longer for a more accurate assessment of long term outcomes.

In addition, our study protocol involves keeping the MSE appliance installed for 6 months post-expansion before removal to allow for sufficient bone healing. It may be of interest to explore any effects changes in the length of time the MSE appliance is left in the mouth post-expansion can have on expansion stability.

CONCLUSIONS

1. MSE expansion produced mostly skeletal rotational movement of midcranial structures with insignificant dentoalveolar changes immediately after expansion.
2. Skeletal expansion was significant both immediately post-expansion and post-orthodontic treatment.
3. The long-term loss of skeletal expansion were 11.20% (R) and 13.28% (L), and the majority of the skeletal expansion was maintained.
4. The long-term dentoalveolar changes were in the magnitude of 300-1500% in the opposite direction, induced by orthodontic decompensation of the pre-existing dental compensation; however, there were net gains in the intermolar width despite these changes due to the long-term stability of skeletal expansion.

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