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Los Angeles

Comparison of skeletal and dental changes with MSE (Maxillary Skeletal Expander) and
Hyrax appliance using CBCT imaging

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

by

Yiju Lin

2015

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ABSTRACT OF THE THESIS

Comparison of skeletal and dental changes with MSE (Maxillary Skeletal Expander) and Hyrax appliance using CBCT imaging

by

Yiju Lin

Master of Science in Oral Biology University of California, Los Angeles, 2015

Professor Won Moon, Chair

Introduction: The purpose of this study is to use Cone-Beam Computed Tomographic images to compare the skeletal and dental changes with MSE (Maxillary skeletal expander) and Hyrax appliance. Material and Method: 15 patients in MSE group and 8 patients in Hyrax group who met inclusion criteria were included. We used Independent-T test to compare the angulation of palatal sutures, bone bending and molar tipping between two groups. Result: In the MSE group, the angulation of palatal sutures was 0.62 degree while it was 7.50 degree in the Hyrax group. ($P < 0.01$) The bone bending was 1.39 degrees in MSE group and it was 3.77 degrees in Hyrax group. ($P < 0.01$) Molar angulation changes were 4.05 degrees in MSE group and 10.05 degrees in Hyrax group. ($P < 0.01$). Estimated molar tipping in MSE group was 2.66 degrees and 6.28 degrees in Hyrax group. Conclusion: This study showed that the MSE appliance was able to produce a more parallel palatal suture opening, less bone bending and less molar tipping than the Hyrax appliance. Cone-Beam Computed Tomography is a useful tool in quantifying the skeletal and dental changes after palatal expansion.

The thesis of Yiju Lin is approved.

Reuben Kim

Xuesong He

Won Moon, Committee Co-Chair

Robert Chiu, Committee Co-Chair

Dedication

I dedicate this to my loving family. A special feeling of gratitude to my loving parents, Yung-Su, and Tun-Hsueh, who instilled in me the desire to dream big, work hard, and always give me the very best of everything. My husband, Chun-I has always been there to support me throughout the master program. My father-in law, Chin-Ho Lu, who is a statistic professor, has selflessly contributed his professional knowledge in helping me with the data analysis. I will always appreciate their unconditional love.

I wish to thank my committee members who were more than generous with their expertise and precious time. A special thanks to Dr. Won Moon, my mentor for his countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process. His passion and willingness to provide feedback made the completion of this research an enjoyable experience. I give special thanks to Dr. Robert Chiu's for his kind support and encouragement and Dr. Reuben Kim and Dr. Xuesong He for agreeing to serve on my committee.

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Acknowledgements

I would like to give a special thank you to my colleagues and the dental student:

Dr. Mohammed for his kind and generous collaboration.

Kody Snow for his volunteering his time in assisting this research

Dr. Susan Bae, Henna Kim and Ryann Christensen for their kind assistance.

Finally, I would also like to thank my school division for allowing me to conduct my research and providing any assistance requested.

Introduction:

Maxillary transverse deficiency is common in orthodontic patients, and it can create clinical, esthetic, and functional problems that affect both the arches. Problem included crowded, impacted and protrusive teeth along with the presence of buccal corridors upon smiling. The most common finding in maxillary transverse deficiency is unilateral or bilateral crossbite.¹⁻³ According to an epidemiologic study, around 21 % of children have some form of skeleton discrepancy involving both dental arches and less than 10 % in adult orthodontic patients.^{4,5} The cause of maxillary constriction is multifactorial as it can be caused by genetic and functional factors.⁶ The correction of this problem can be associated with advantageous therapeutic effects on hearing, swallowing, and nasal breathing.⁷

Maxillary transverse deficiency can be corrected by various appliances and treatment protocols, which usually include maxillary expansion and separation of the mid-palatal suture. This includes Rapid Palatal Expansion (RPE), Slow Orthodontic Expansion (SOE), Micro-implant Assisted Rapid Palatal Expansion (MARPE), and Surgically Assisted Rapid Palatal Expansion (SARPE). All techniques share the same objective to address the skeleton disharmony.

To determine what type of expansion appliance should be used, the clinician should know the stage of suture fusion in the patient. However, the timing of palatal suture inter-digitation varies among individuals. One study found that the development of the median suture could be divided into three stages. In the first stage, the suture is short, broad, and Y-shaped. In the next stage, the suture becomes more sinuous. In the third stage, the suture's interdigitation becomes so heavy that a separation of the two

halves of the maxilla would not be possible without fracturing the interdigitated processes. The study also reported that the transverse growth of the midpalatal suture continued up to the age of 16 in girls and 18 in boys.⁷ Other studies indicated that the timing of the fusion of mid-palatal suture varied greatly with age and sex. Inter-digitation of mid-palatal suture was noted primarily from 11 to 17 years of age but occasionally found to occur at older age groups as well. Fusion of the palatine and maxillary regions of the mid-palatal suture was completed after 11 years only in girls. From 14 to 17 years, 3/13 (23%) boys showed fusion only in the palatine bone. Meanwhile some studies showed that some patients had no sign of fusion of the mid-palatal sutures at the age of 32 and 54.⁸⁻¹⁰

When maxillary expansion is needed, conventional Rapid Palatal expansion (RPE) is the treatment of choice in many cases. This can correct both dental and skeletal discrepancy by separating the mid palatal suture in the late mixed or early permanent dentition stage, when the most predictable results are typically achieved.¹¹

Rapid palatal expansion was first described in the literature by E.C. Angell in 1860. He used a reciprocal jackscrew attached to premolars as a method of expanding the upper arch.¹² A common method of RPE appliance is the tooth-bound Hyrax appliance that is widely used in the treatment of transverse maxillary deficiencies. The heavy forces generated by RPE promote the separation of the mid palatal suture that is accompanied with orthodontic movement.

However, the increased rigidity of the craniofacial bones and the existence of the synostosis bridges in the mid-palatal suture after suture closure or completion of the transverse growth in adults make conventional RPE less effective and may produce

undesired dentoalveolar changes.¹³ In order to overcome the limitation, Surgical Assisted Rapid Palatal Expansion (SARPE) has been advocated for adult patients with fused sutures. The lateral maxillary wall corticotomy is performed combined with mid palatal osteotomy. However, Surgical Assisted Rapid Palatal Expansion (SARPE) is a complex and a surgical procedure that has potential risks associated with its invasiveness.

In recent years, Micro-Implants (MI) have been widely introduced to the field of orthodontics because of their minimum invasiveness and relatively low cost when comparing to the regular dental implants. New designs of RPE have been developed with the use of micro implants as a temporary anchorage. Micro-implant Assisted Rapid Palatal Expansion (MARPE) is a simple modification of Rapid Palatal Expansion (RPE). It incorporates the micro-implants into the palatal jackscrew that facilitates the palatal expansion without utilizing the dentition as the sole anchorage. This novel concept can eliminate the unwanted results in the conventional palatal expansion and the morbidity and expense that come with surgery assisted rapid palatal expansion treatment.¹⁴ In this study, we used MSE (Maxillary Skeletal Expander), which is a type of Micro-Implant Supported Palatal Expander, to compare with the Hyrax appliance.

It is still inconclusive how the skeletal and alveolodental structures respond to expansion treatment.¹⁵ By far, only conventional RPE has been widely studied. The suture has been observed to split in a triangle (V) shaped where the base is in the anterior region between the central incisors and the apex is at the posterior part of the expansion.¹⁶⁻¹⁸ This can be clinically observed by the diastema that is created in the anterior region. However, since the conventional RPE appliances transmit the expansion forces throughout the teeth, alveolar bone bending and alveolodental tipping are

inevitable.⁸Others would therefore suggest the use of Slow Orthodontic Expansion (SOE). SOE can produce less tissue resistance and enhance bone formation to minimize the post expansion relapse. However, a recent study has showed that RPE and SOE show similar stability in the long term.¹⁹

Since the orthopedic forces of conventional RPE are transmitted to the skeletal sutures through the teeth, dental side effects are prone to occur.²⁰ Adverse effects are gingival recessions, fenestrations of the buccal cortex, buccal tipping of the teeth, alveolar bone bending, and palatal tissue necrosis.²¹ Although the orthodontic literature has studied the transverse changes with the expansion treatment, few have addressed molar tipping and alveolar bone bending that come along with expansion. According to Brett Garret's article in 2008, cone-beam tomography was used to quantitatively evaluate skeletal expansion and alveolar tipping of the maxillary teeth in the group of 30 patients with mean age of 13.8 years. After the expansion with a 4-banded or 2-banded hyrax appliance, maxilla had a triangle pattern with a wider base in the anterior region. At the molar region, the dental tipping accounted for 49% of total expansion. Bone bending was 4.75 degrees on average.²¹

In 2010, one study in which Newtom 3G volume scanner CBCT was used,²² reported that the alveolar bone tipped nearly by 5.6 degrees buccally in the treatment group of 25 patients with the average age of 12.9 years who had 4-banded Hyrax appliances. There was no statistically significant amount of relative dental tipping. Other studies reported molar tipping caused by conventional RPE appliances was from 0 to 24 degrees for both sides with an average of 3.1 degrees on one side.²³

In past RPE studies, most of the research used only dental casts, direct measurements of dental arch dimensions, or measurements on two-dimensional cephalogram. No 3D imaging was reported that the end of post-expansion orthodontic treatment. The lack of accurate images does not provide us a clear picture of the structural change after completing expansion. In the past, the skeletal transverse results of the mid palatal suture used to be evaluated by Maxillary Occlusal Radiograph but it obscured the posterior-anterior evaluation because of the superimposition of many bones in different planes of space. Since Cone Beam Computerized Tomography (CBCT) has been introduced, dental practitioners have entered a new era in radiographic imaging. With the 3-D imaging, it is now easier to evaluate the morphological changes in the dentofacial complex. It revolutionized the diagnostic and treatment methods in dentistry.^{15,18} Recently, it has also been proposed in the literature to use CBCT in treating orthodontic patients for several purposes. Cone-beam computerized tomography (CBCT) 3- dimensional imaging enables the capture and reproduction of actual maxillary sections in all 3 planes. This allows for measurements of the axial inclinations of the dentition, changes in the transverse dimensions, and the magnitude of displacement of the maxillary halves without distortion, magnification, and superimposition. Although the numbers of studies conducted on CT-Scan in evaluating the transverse changes in palatal expansion are limited, our aim in this study is to gather more information on the dental and skeletal effects of Mini implant supported palatal expansion and Hyrax.

Although a number of reports on RPE have been published, surprisingly little information exists to document about Micro-implant Assisted Rapid Palatal Expander (MARPE). The difference of treatment effect of conventional RPE and MARPE is

inquired by many orthodontists. In the past, most of the studies focused on conventional RPE, such as Hass expanders and Hyrax expanders. Few studies have been done on MARPE treatment. The difference in the skeletal and dental effects between MARPE and conventional RPE is not fully understood yet because of the lack of the studies and many different designs of MARPE or different expansion protocol were used.

The purpose of this retrospective study is to utilize cone beam computerized tomography to examine and compare the differences between dental and skeletal changes induced by Hyrax appliance versus MSE.

Methods and Materials

This study received approval from the Institutional Review Board of UCLA. It consisted of two groups of patients, those being treated with MSE (Maxillary Skeletal Expander) and those being treated with a Hyrax appliance. All patients received treatment at the Graduate Orthodontic Clinic of the UCLA School of Dentistry as part of their overall orthodontic treatment. The study was retrospective in design, and the data was consecutively collected on all patients that met the set inclusion criteria of 1) diagnosed with a transverse deficiency based on the transverse analysis of Andrew's elements, 2) received MSE or Hyrax as part of their treatment, 3) had CBCT imaging before expansion and right after completion of expansion, 4) had no craniofacial syndromes, and 5) received no previous orthodontic treatment.

The group treated with MSE consisted of 15 patients (mean age 20.8 years, range 14-38 years, 3 male and 12 female). The group treated with Hyrax appliances consisted of 8 patients (mean age 12 years, range 8-15 years, 5 male and 3 female).

The MSE appliance made by Biomaterials Korea Inc. Company consists of two molar bands attached to maxillary first molars and a central body containing an expansion screw with 4 welded tubes attached (Fig 1).

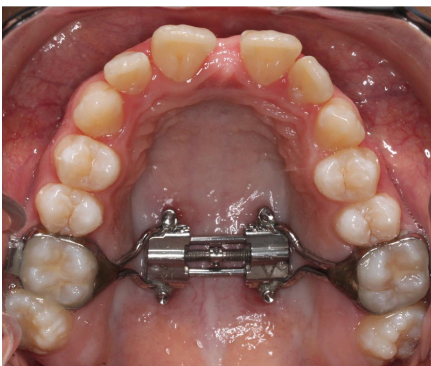


Fig 1. Image of Maxillary Skeletal Expander appliance

Each tube is 1.5mm in diameter, 2mm in length, and acts as a template for placing 4 micro-implants. Each implant is 1.5mm in diameter and 11mm in length. This diameter creates a tight fit of the micro-implants without any lateral movement during the expansion for minimizing the lateral force on the involved molars. The length of 11mm will ensure the bi-cortical engagement of the micro-implants at the palatal bone and nasal floor, which prevents unwanted tipping of the micro-implants during the expansion. (Fig 2)

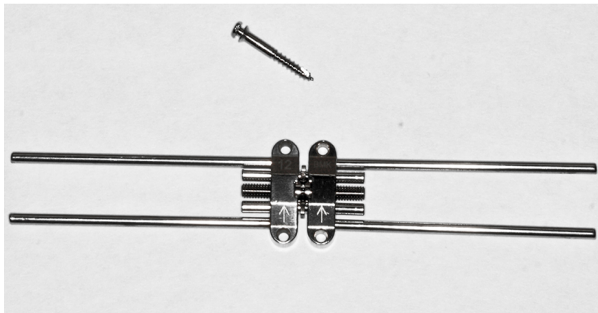


Fig 2. Image of the prefabricated MSE appliance made by Biomaterials Korea Inc. Company

Each appliance was fabricated by sizing the molar bands, taking a pick-up impression and pouring it in stone, placing the appliance 1-2mm anterior to the junction of the hard and soft palate, fitting the expander to the vault of the palate. The lateral arms were soldered to the molar bands. The central jackscrew expander was flush against to the palate and the supporting arms had 2mm clearance to the lateral wall of palate. The appliance was then cemented intra-orally, and under local anesthesia 4 micro-implants were placed. Patients were instructed to complete 2 full turns of the expansion screw each day until the desired expansion was achieved, each turn producing .25mm of expansion.

The Hyrax appliance used consisted of a central expansion screw attached to two molar bands on maxillary first molars and lingual bar extensions (Fig 3). These appliances were fabricated in a similar manner as the MSE appliances and were cemented intra-orally. Patients were instructed to complete 1 full turn of the expansion screw each day until the desired expansion was achieved, with each turn producing .25mm of expansion.



Fig 3. Image of a Hyrax appliance

CBCT scans were taken both before expansion and right after completion of expansion on all patients. All CBCT scans were taken by a NewTom 5G in an 18x16 Field of view with a 14 bit gray scale. Scan times were 18 seconds (3.6 seconds emission time), 110 kV, and utilized an automatic exposure control that adjusted the milliampere based upon the patient's anatomic density. The NewTom 5G Safebeam control reduces the radiation the patient is exposed to based on the patient's size. Data from the CBCT was reconstructed to produce .3mm slices.

Palatal suture opening pattern

Using Dolphin Imaging 11.5 Premium software, a section running through the center of the maxillary palatal bone was selected (Fig 4), generating a slice in the horizontal plane to pass the middle of the palatal bone (Fig 5), allowing for the best visualization of the opening of the mid-palatal suture. A 4-point angle measuring tool within the Dolphin 11.5 imaging software was used to measure the relative parallelism between the left and right sides of the open palatal suture (Figs 6 and 7). A suture that opened up perfectly parallel, (meaning that the amount of expansion achieved in the anterior portion of the palatal suture was the same as the amount of expansion achieved in the posterior portion of the palatal suture), would have a 0° opening. A suture that achieved more expansion in the anterior portion of the palatal suture as compared to the posterior portion would have a positive degree of opening.

All measurements were taken with the same examiner. A best-fit line was drawn along each side of the open suture from the posterior nasal spine to the anterior nasal spine. The examiner measured each patient's degree of opening at two separate occasions, and the average value was taken to reduce any measuring error. The examiner was blinded to the patient's name and treatment modality to eliminate any bias. Additionally the examiner was not aware of their initial results during their second measurements. Inter-examiner reproducibility was evaluated by a Paired T-Test. The results for patients treated with MSE were then averaged to produce an average degree of opening for MSE. The results for patients treated with Hyrax were likewise averaged. An Independent T-test was then used to compare the angulation of palatal sutures between the MSE group and the Hyrax group.

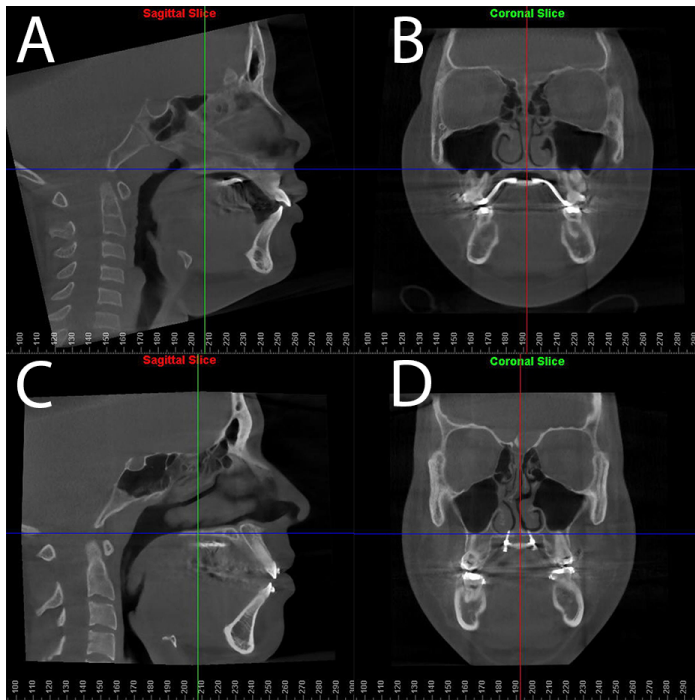


Fig 4. A and B: Sagittal and coronal views generating a horizontal slice through the palatal bone of a Hyrax patient. C and D: Sagittal and coronal views generating a horizontal slice through the palatal bone of a MSE patient

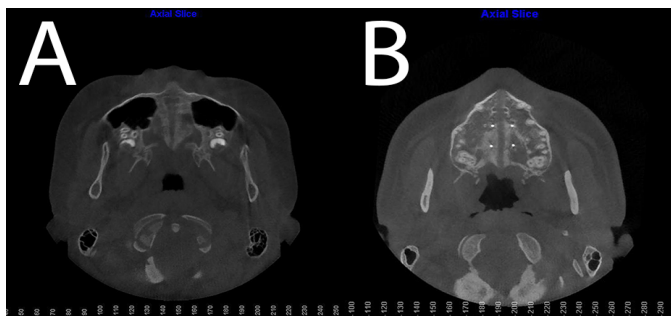


Fig 5. A: Horizontal slice through the mid palatal suture of a Hyrax patient. B: Horizontal slice through the palatal suture of a MSE patient.

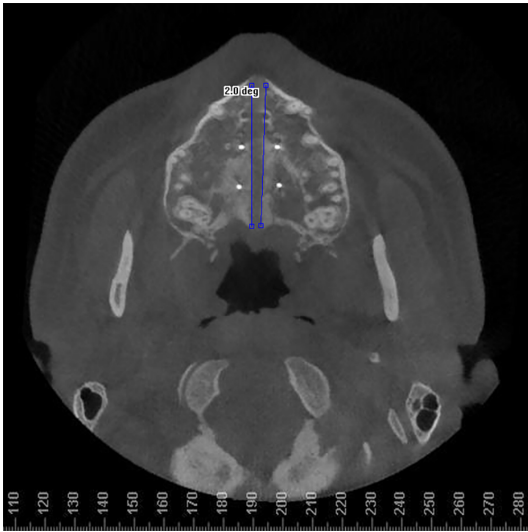


Fig 6. Measurement of the degree of opening in the mid-palatal suture of a MSE patient.

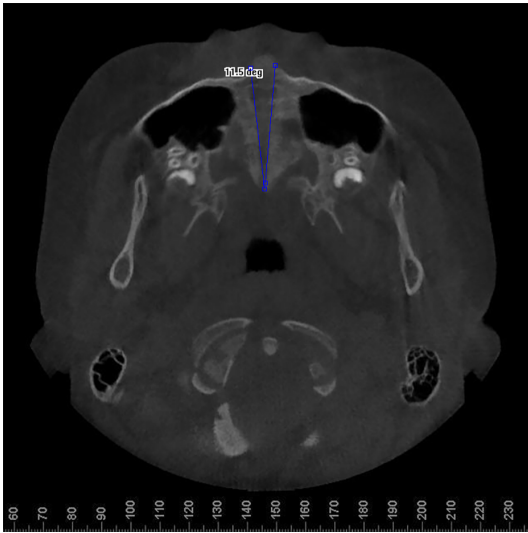


Fig 7. Measurement of the degree of opening in the mid palatal suture of a Hyrax patient.

Bone bending

The pre-expansion and post-expansion CBCT images of the same patient were oriented and standardized with Ondemand 3D software from Cybermed Inc. Company. A section running through the bifurcation of the first molars was selected to generate a slice in the coronal plane to pass through the middle of the first molars, which enables us to best see the cross-section view of bone bending of the buccal plate. We superimposed pre-expansion and post-expansion coronal section images of the same patient on the frontal bone and cranial base structures because these structures had least change during the expansion treatment. We drew a midline passing through the cribriform plate from the Crista galli on the superimposition images (C-line). A 4-point angle-measuring tool within the Ondemand 3D software was used to measure the relative angulation between the buccal plates of the first molar to the C-line. The best-fit tangent line was drawn along the buccal side of the alveolar bone with the longest contact at the level of the coronal third of the first molar's root. The examiner measured each patient's angulation of the buccal plate to the C-Line at two separate occasions, and the paired T-test was used to exam the inter-examiner's reproducibility. The results were then averaged to produce an average degree of molar tipping. An Independent T-test was then used to compare the angulation of molar tipping between the two sides (right side and left side) and two groups (MSE group and Hyrax groups). (Fig 8,9)

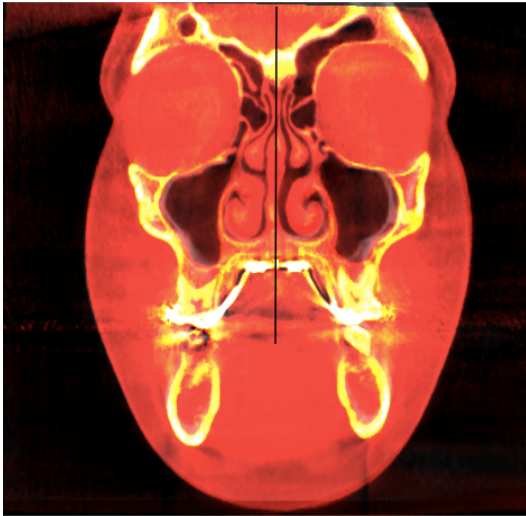


Fig 8. Example of the superimposed image of a MSE patient.

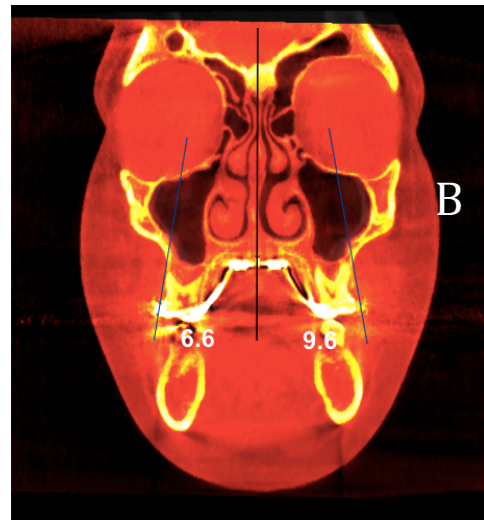
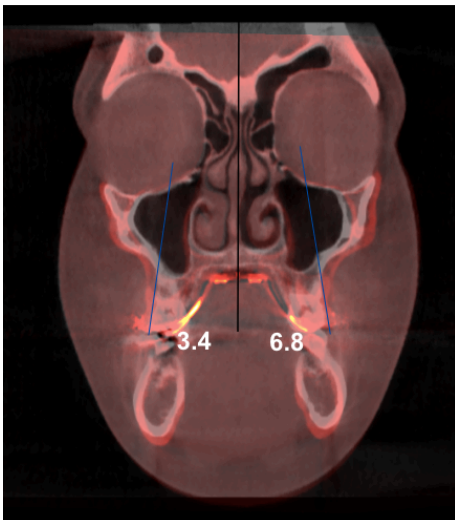


Fig 9. Image of bond bending a MSE patient. A: pre-expansion. B: post-expansion.

Molar angulation changes

The pre-expansion and post-expansion CBCT images of the same patient were oriented and standardized with Ondemand 3D software from Cybermed Inc. Company, a section running through the bifurcation of the first molars was selected to generate a slice in the coronal plane to pass the middle of the first molars which enables us to see best cross-section view of the buccally tipping of the first molar. We superimposed pre-expansion and post-expansion coronal-section images of the same patient on the frontal bone and cranial base structure, which had the least amount of change during the expansion treatment. We drew a midline passing through the cribriform plate from the crista galli on the superimposition images. (C-line) A 4-point angle-measuring tool within the Ondemand 3D software was used to measure the relative molar angulation (central pit on the occlusal surface to the center of the root bifurcation). The C-line served as a reference line to see the change of molar angulation after expansion treatment. (Fig 10,11)

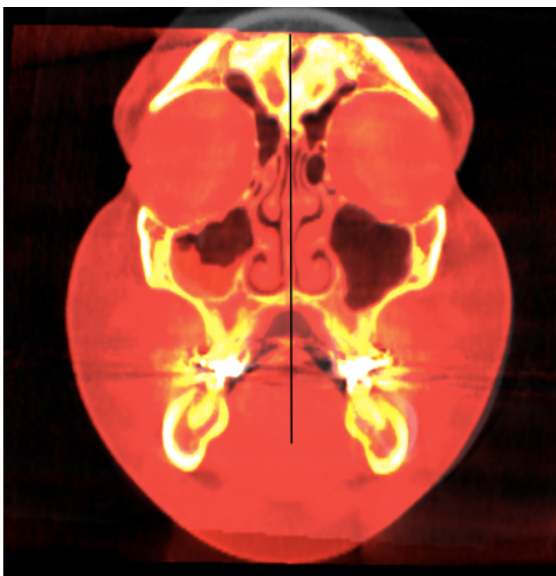


Fig10. Example of the superimposed image of a Hyrax patient.

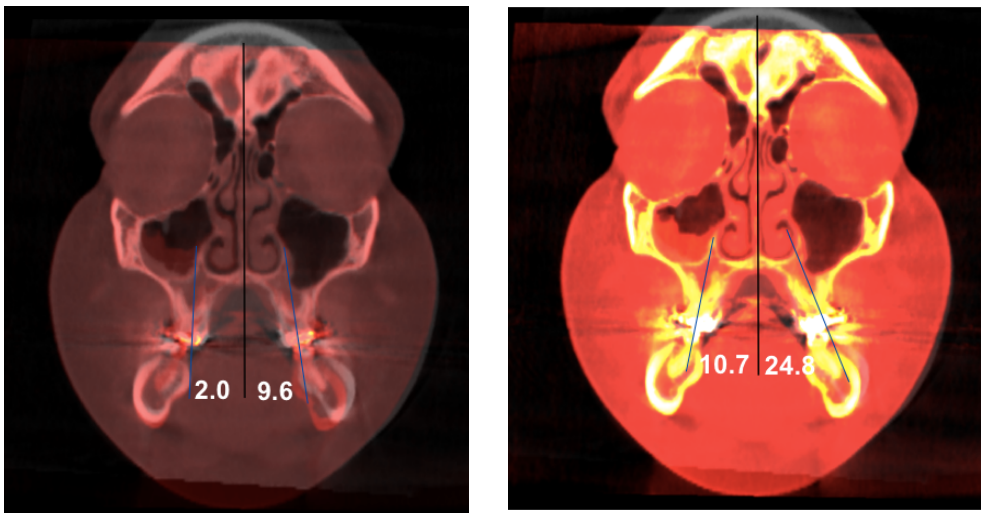


Fig11. Molar angulation changes of a Hyrax patient. A: pre-expansion. B: post-expansion.

All measurements were taken with the same examiner. The examiner measured each patient's molar angulation on each side (right and left side) independently at two separate occasions. Reproducibility was evaluated by a Paired T-Test. The results for patients treated with MSE were then averaged to produce an average degree of molar movement for MSE. The results for patients treated with Hyrax were likewise averaged. An Independent T-test was then used to compare the angulation of the molar movement between two sides (right side and left side) and two groups (MSE and Hyrax groups).

Result

1. Palatal suture opening pattern

		1 st measurement	2 nd measurement
Hyrax	1	7.2	10.6
	2	15.6	12.1
	3	13	16.3
	4	10.7	14.2
	5	1.1	6.8
	6	2.4	2.9
	7	1	1.7
	8	2	2.4
MSE	1	0.3	0.3
	2	0.1	0.2
	3	0.8	0.1
	4	0.6	0.6
	5	1.1	0.7
	6	0.7	0
	7	1	0.6
	8	0.3	0.6
	9	1.2	0.6
	10	0.4	1.6
	11	0.3	0.9
	12	0.5	1.2
	13	1.2	0
	14	1.1	1.4
	15	0.1	0.1

Table 1. Raw data of Palatal suture angulation

1a. Inter-examiner’s reproducibility was evaluated by a Paired T-test. The P Value in the Hyrax group was 0.12 and MSE group was 0.74. This showed the measurements in this study were highly reproducible and reliable (Table2 and3). Therefore we could take the average of the measurements as a mean value from two measurements to perform further statistical analysis.

		Paired difference				
		95 % Confidence Interval of the Difference				
		Lower	Upper	t	df	P value
Pair 1 MSE	First V.S. Second measurement	-0.294	0.4016	0.328	14	0.123
Pair 2 Hyrax	First V.S. Second measurement	-4.111	0.6112	-1.753	7	0.747

Table 2. Paired T-test of first and second measurement of MSE and Hyrax groups.

Pair 1: Comparison of the measurements of MSE group between first and second measurements

Pair 2: Comparison of the measurements of Hyrax group between first and second measurements

		N	Mean	Std. Deviation	Std. Error Mean
Pair 1 MSE	First measurement	15	0.647	0.398	0.103
	Second measurement	15	0.593	0.505	0.130
Pair 2 Hyrax	First measurement	8	6.625	5.849	2.068
	Second measurement	8	8.375	5.711	2.019

Table 3. Paired T-test of first and second measurements of MSE and Hyrax groups.

Pair 1: Comparison of the measurements of Hyrax group between first and second measurements

Pair 2: Comparison of the measurements of MSE group between first and second measurements

1b. An Independent T test was used to compare the angulation of palatal sutures in Hyrax group and MSE group (Table4). The mean value of Hyrax group was 7.50 degrees and MSE group was 0.62 degrees. The p value was 0.000(<0.01) indicating that there was a statistical significance between Hyrax group and MSE group. The MSE group had decreased angulation between the palatal sutures when comparing to the Hyrax group.

	N	Mean	Std. Deviation	Std. Error Mean	Mean difference	Std Error difference	P value
MSE	15	0.620	0.328	0.084	6.880	1.983	0.000
Hyrax	8	7.500	5.604	1.982			

Table 4. Independent T test of MSE and Hyrax groups

1c. We used the mean value of the two measurements to perform a bar graph. (Fig.12)
The mean value of MSE group was 0.62 degrees while it was 7.50 degrees in Hyrax group.

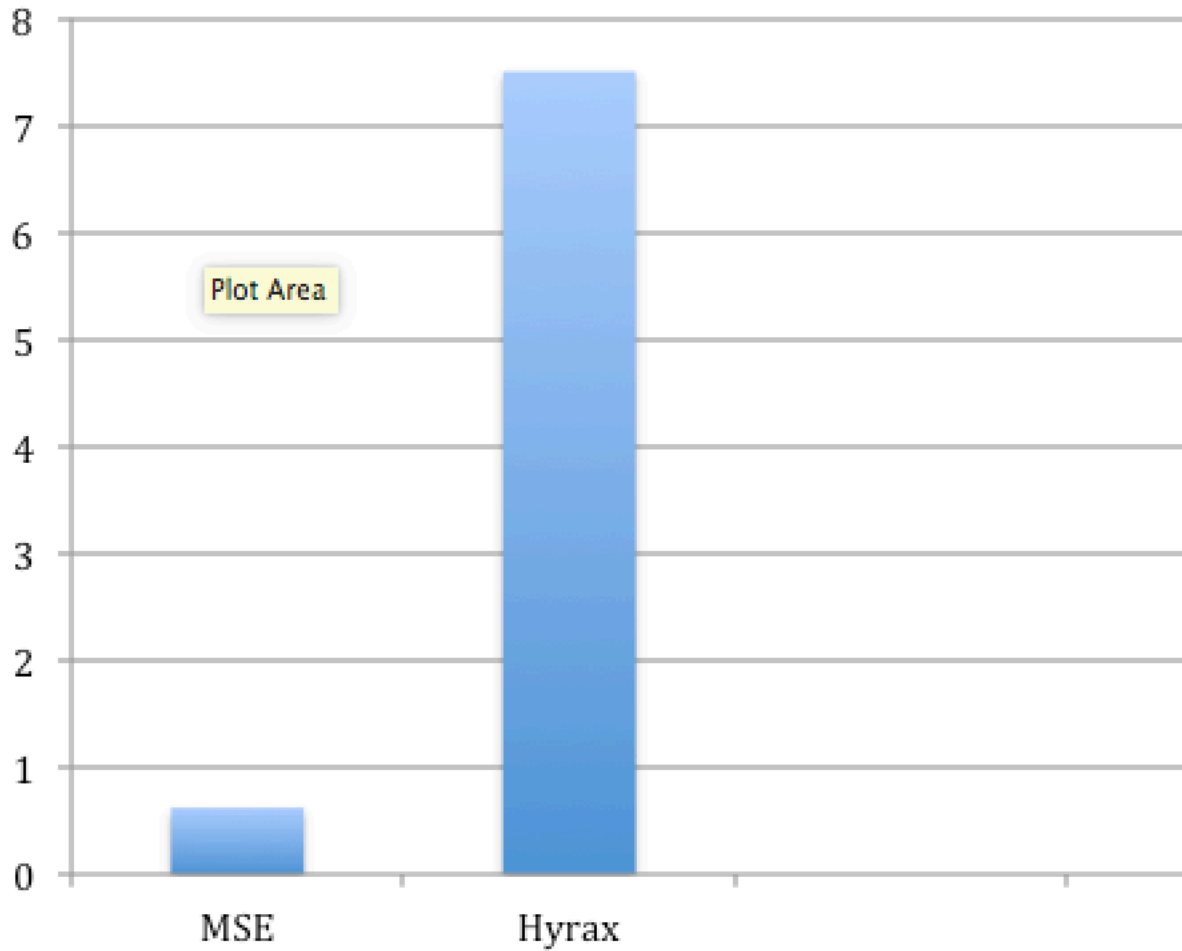


Fig12. Bar graph of palatal suture opening of MSE and Hyrax groups

X axis: MSE group and Hyrax group

Y axis: Degree of palatal suture opening

1d. We used the mean value of the two measurements to perform a Scatter plot (Fig.13). It showed Hyrax group had a greater range (1 degree to 15 degrees) than MSE group (0 degree to 2 degrees).

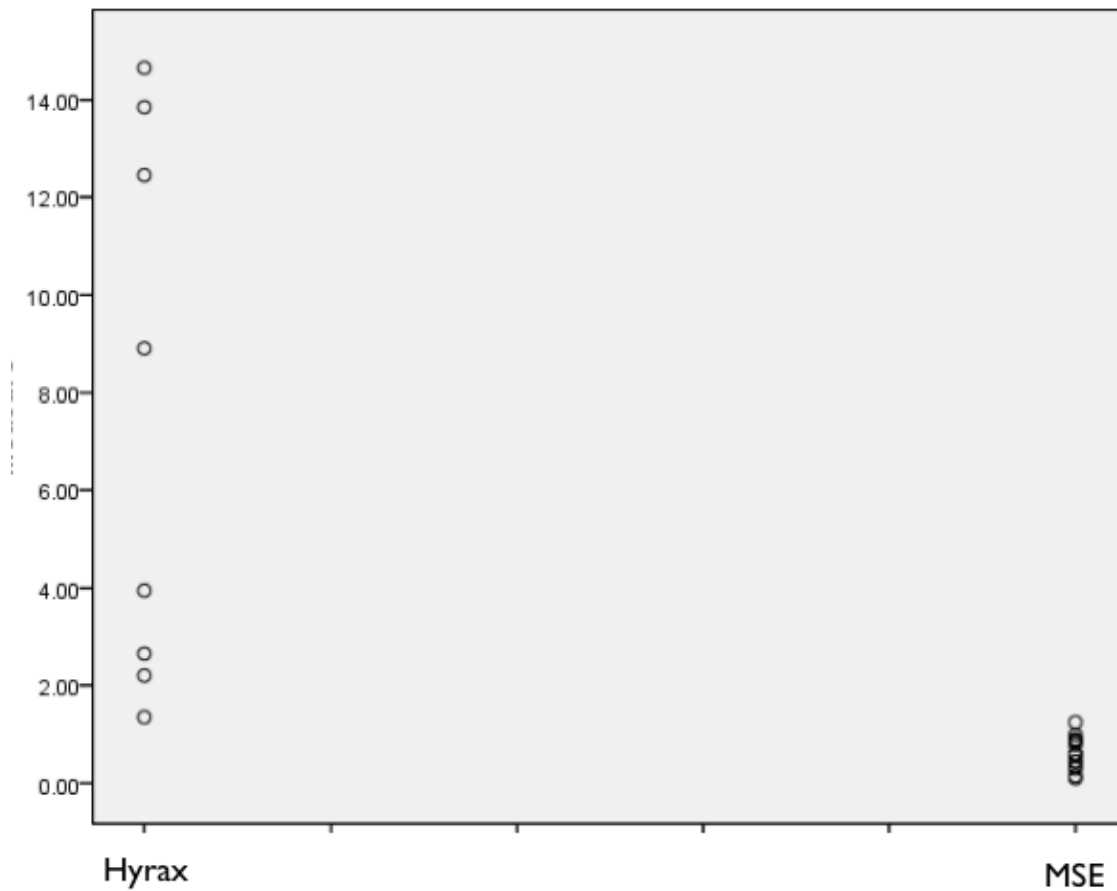


Fig13. Scatter Plot of palatal suture opening of MSE and Hyrax groups

X axis: Hyrax group and MSE groups

Y axis: Degree of palatal suture opening

2. Bone Bending Analysis

MSE	Right side Before Expansion		Left side Before Expansion		Right side After Expansion		Left side After Expansion		Right side Treatment Change		Left side Treatment Change	
	1st- A	2nd- B	1st C	2nd D	1st E	2nd F	1st G	2nd H	1st E-A	2nd F-B	1st G-C	2nd H-D
1	8.9	9	13.1	13.0	11.3	11.5	16.2	16	2.4	2.5	3.1	3.0
2	1.1	1.2	1.8	1.8	2.5	2.7	2.4	2.5	1.4	1.5	0.6	0.7
3	5.1	5.2	15.4	15.1	5.4	5.6	16.5	16.1	0.3	0.4	1.1	1.0
4	5.0	5.2	7.1	7.4	7.1	7.3	9.2	9.4	2.1	2.1	2.1	2.0
5	0.1	0.1	1.1	1.2	0.1	0.1	1.5	1.5	0	0	0.4	0.3
6	11.9	12.1	7.2	7.1	12.3	12.5	9.7	9.4	0.4	0.4	2.5	2.3
7	7.5	7.4	3.4	3.3	9.9	9.9	4.5	4.3	2.4	2.5	1.1	1.0
8	8.2	8.0	3.9	4.0	8.2	8.1	4.6	4.6	0	0.1	0.7	0.6
9	7.1	7.3	3.4	3.4	9.3	9.2	4.5	4.6	2.2	1.9	1.1	1.2
10	3.4	3.6	6.8	7.0	6.6	6.7	9.6	9.7	3.2	3.1	2.8	2.7

11	6.1	6.4	8.8	8.6	8.7	8.6	9.1	9.0	2.6	2.2	0.3	0.4
12	11.6	11.4	7.9	7.9	11.7	11.5	8.1	8.2	0.1	0.1	0.2	0.2
13	5.8	6.0	1.7	1.8	6.8	7.0	2	2.2	1.0	1.0	0.3	0.4
14	11.1	10.9	12.0	11.8	12.6	12.3	13.4	13.0	1.5	1.4	1.4	1.2
15	13.4	13.4	16.5	16.4	17.3	17.5	17.5	17.4	3.9	4.1	1.0	1.0

Table 5. Raw data of bone bending of MSE group. 1st: First measurement; 2nd: Second measurement

	Right side Before Expansion		Left side Before expansion		Right side After expansion		Left side After expansion		Right side Treatment change		Left side Treatment change	
	1 st - A	2 nd - B	1 st C	2 nd - D	1 st E	2 nd F	1 st G	2 nd H	1 st E-A	2 nd F-B	1 st G-C	2 nd H-D
1	16.0	15.7	18.8	19.1	21.6	21.5	22.5	22.7	5.6	5.8	3.7	3.6
2	5.2	5.3	7.6	7.9	11.0	11.4	13.1	13.7	5.8	6.1	5.5	5.8
3	10.1	9.9	23.1	22.9	12.4	12.1	25.1	24.9	2.3	2.2	2.0	2.0
4	5.0	5.3	8.5	8.6	10.6	10.8	12.4	12.7	5.6	5.5	3.9	3.9
5	0.0	0.0	0.5	0.6	2.2	2.3	2.9	3.1	2.2	2.3	2.4	2.5
6	2.9	3.0	1.8	2.0	5.0	5.2	4.9	5.1	2.1	2.2	3.1	3.1
7	3.2	3.1	3.5	3.4	5.3	5.2	5.6	5.5	2.1	2.1	2.1	2.1

8	3.6	3.6	4.9	4.7	9.8	9.9	10.1	9.9	6.2	6.3	5.2	5.2
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Table 6. Raw data of bone bending of Hyrax group. 1st: First measurement; 2nd: Second measurement

2a. Inter-examiner’s reproducibility was evaluated by a Paired-Test. Both the P Value in the Hyrax group and MSE groups showed the measurements in this study were highly reproducible and reliable. (Table 7-10) Therefore we could take the average of the measurements as a mean value from two measurements to perform further statistical analysis.

		N	Mean	Std. Deviation	Std. Error Mean
Pair 1: Right side Before-Expansion	First measurement	15	7.0867	3.9040	1.0080
	Second Measurement	15	7.1467	3.8463	0.9931
Pair 2: Right side After-Expansion	First Measurement	15	7.3400	5.0063	1.2926
	Second Measurement	15	7.3200	4.9164	1.2693
Pair 3: Left side Before-Expansion	First measurement	15	8.6533	4.2576	1.0993
	Second Measurement	15	8.7000	4.2342	1.0932
Pair 4: Left side After-Expansion	First measurement	15	8.5867	5.3952	1.3930
	Second Measurement	15	8.5267	5.2753	1.3620

Table 7. Paired T-test of the first and second measurements of bone bending of MSE group

		Paired difference				
		95 % Confidence Interval of the Difference				
		Lower	Upper	t	df.	P value
Pair 1 Right side Before-expansion	First VS Second measurement	-.1531	.0331	.480	14	0.189
Pair 2 Right side Before expansion	First VS Second measurement	-.0692	.1092	-1.047	14	0.638
Pair 3 Left side Before expansion	First VS Second measurement	-.1424	.0489	1.146	14	0.313
Pair 4 Left side Before expansion	First VS Second measurement	-.1422	-.4894	0.323	14	0.271

Table 8: Paired T-test of the first and second measurements of bone bending of MSE group

		N	Mean	Std. Deviation	Std. Error Mean
Pair 1 Right side Before-expansion	First measurement	8	5.7500	5.0307	1.7786
	Second Measurement	8	5.7375	4.9129	1.7366
Pair 2 Right side After-expansion	First Measurement	8	8.5875	8.1665	2.8873
	Second Measurement	8	8.6500	8.1505	2.8817
Pair 3 Left side Before-expansion	First measurement	8	9.7375	5.9653	2.1091
	Second Measurement	8	9.8000	5.9078	2.0887
Pair 4 Left side After-Expansion	First measurement	8	12.0750	8.1150	2.8690
	Second Measurement	8	12.2000	8.0828	2.8580

Table 9. Paired T-test of the first and second measurements of bone bending of Hyrax group

		Paired difference				
		95 % Confidence Interval of the Difference				
		Lower	Upper	t	df	P value
Pair 1 Right side	First V.S. Second measurement	-0.1451	.1770	0.188	7	0.857
Before-expansion						
Pair 2 Right side	First V.S. Second measurement	-0.2352	0.1102	-0.856	7	0.420
Before expansion						
Pair 3 Left side	First V.S. Second measurement	-0.2462	0.1214	-0.804	7	0.448
Before expansion						
Pair 4 Left side	First V.S. Second measurement	-0.3561	-0.1214	-0.1279	7	0.242
Before expansion						

Table 10. Paired T-test of the first and second measurements of bone bending of Hyrax group

2b. We used a Paired Sample T test to compare the bone bending on the right side and left side in both groups (Table 11). It showed that in MSE and Hyrax group, there was no difference between the right side and left side. This meant both MSE and Hyrax induced similar amount of bone bending on the right side and left side.

		N	Mean	Std. Deviation	Std. Error Mean	P Value
Pair 1 MSE	Right side	15	1.5600	1.2333	0.3184	0.309
	Left side	15	1.2600	0.9160	0.2365	
Pair 2 Hyrax	Right side	8	4.0250	1.9752	0.6982	0.188
	Left side	8	3.5180	1.3706	2.8817	

Table 11. Comparison of bone bending on the right side and left side in MSE and Hyrax groups

2c. We used the mean value of the two measurements to compare the bone bending in MSE and Hyrax group. An Independent T test was used (Table 12). The mean value of MSE group was 1.39 degrees and Hyrax group was 3.77 degrees. The p value was 0.004(< 0.01) indicating that there was a statistical significance between MSE group and Hyrax group. The MSE group had less bone bending than Hyrax group.

	N	Mean	Std. Deviation	Std. Error Mean	Mean difference	Std. Error difference	P value
MSE	15	1.3933	0.8982	0.2319	-2.3785	0.6211	0.004
Hyrax	8	3.7719	1.6298	0.5762			

Table 12: Independent T-test of bone bending in MSE and Hyrax group. P value=0.004< 0.01

2d. A bar graph was used to illustrate the mean value of MSE and Hyrax Group. The mean value of MSE group was 1.39 degrees and Hyrax group was 3.77 degrees. The mean value of MSE group was smaller than Hyrax group. (Fig14)

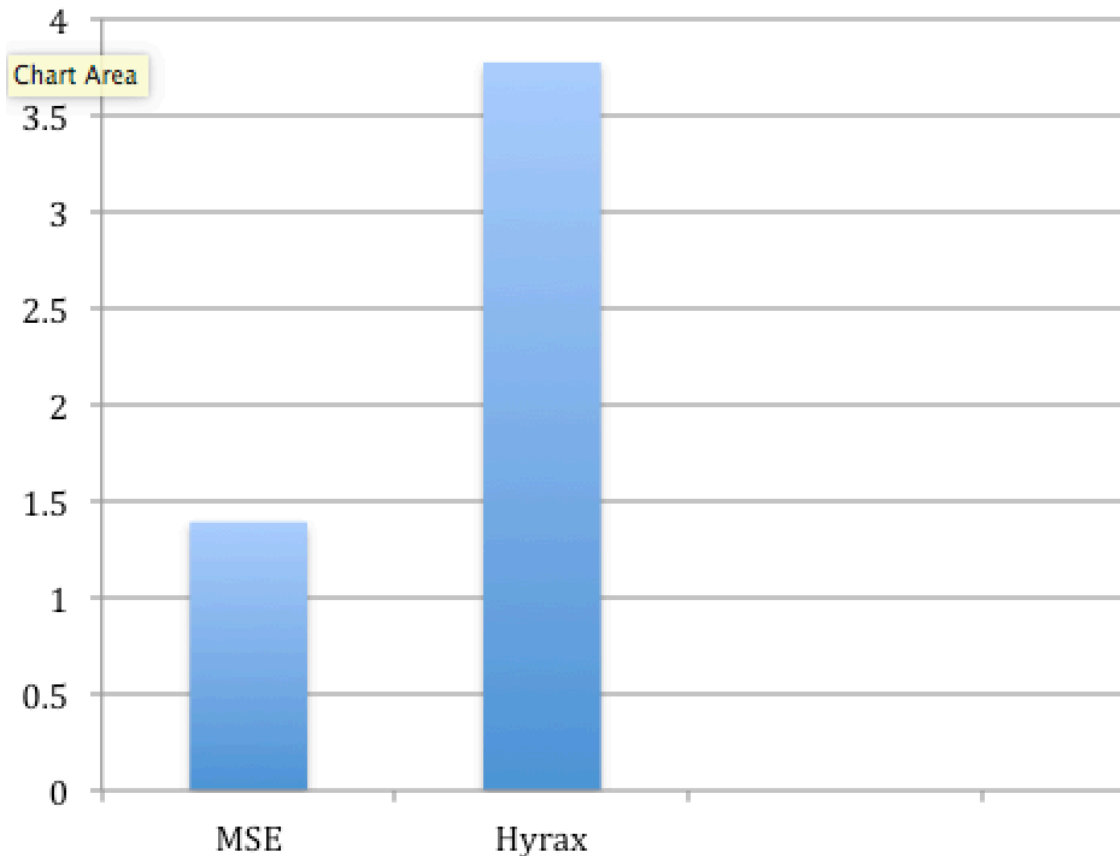


Fig14. Bar graph of bone bending of MSE and Hyrax group

X axis: MSE group and Hyrax group

Y axis: Degree of bone bending

2e. Scatter plot was used to see the distribution of the data of the bone bending of MSE and Hyrax Group. It showed Hyrax group had a slightly greater range of variation than MSE group, but there was no statistically difference. (Fig15).

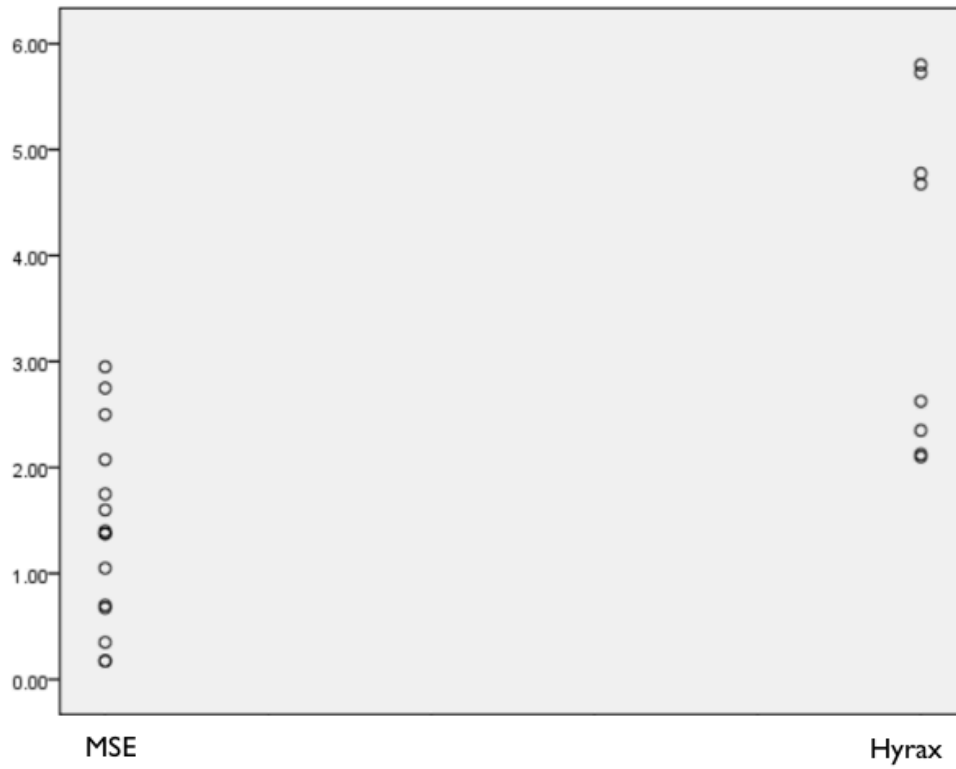


Fig15. Scatter Plot of bone bending of MSE and Hyrax groups

X axis: MSE group and Hyrax group

Y axis: Degree of bone bending

3. Molar Angulation Analysis

MSE	Right side Before Expansion		Left side Before Expansion		Right side After Expansion		Left side After Expansion		Right side Treatment change		Left side Treatment change	
	1 st A	2 nd B	1 st C	2 nd D	1 st E	2 nd F	1 st G	2 nd H	1 st E-A	2 nd F-B	1 st G-C	2 nd H-D
1	13.2	13.0	16.8	17.0	19.1	19.3	23.2	23.5	6.1	6.2	6.4	6.5
2	0.1	0.1	7.6	7.5	3.7	3.6	10.4	10.2	3.6	3.5	2.8	2.7
3	4.6	4.5	10.4	10.0	6.0	6.0	12.2	12.5	1.4	1.5	1.8	1.5
4	6.4	6.2	8.7	8.5	11.3	11.3	14.6	15.0	4.9	5.1	5.9	6.5
5	10.1	10.3	18.8	18.7	11.4	11.4	19.9	19.6	1.3	1.1	1.1	0.9
6	7.6	8.1	3.1	3.3	12.1	12.2	7.5	7.1	4.5	4.1	4.4	3.8
7	13.6	13.5	10.7	10.8	16.7	16.6	15.8	16.4	3.1	3.1	5.1	5.6
8	5.3	5.5	4.1	4.0	8.5	8.7	5.2	5.5	3.2	3.2	1.1	1.5
9	14.0	13.8	11.3	11.5	18.2	18.3	16.2	16.4	4.2	4.5	4.9	4.9
10	3.9	3.6	10.2	10.2	9.4	9.5	13.3	13.3	5.5	5.9	3.1	3.1
11	10.3	10.1	10.2	10.0	15.0	15.6	15.1	15.2	4.7	5.1	4.9	5.2
12	0.3	0.3	3.4	3.1	3.5	3.8	7.5	7.1	3.2	3.5	4.0	4.0

13	5.6	5.5	3.7	3.4	11.6	11.4	11.1	11.9	6.0	5.9	7.4	8.5
14	6.6	6.4	10.7	10.2	10.2	10.3	12.1	11.6	3.6	3.9	1.4	1.5
15	4.9	5.0	4.6	4.3	10.1	10.4	9.1	8.7	5.2	5.4	4.5	4.4

Table 13. Raw data of molar angulation of MSE group. 1st: First measurement; 2nd: Second measurement

Hyrax	Right side Before Expansion		Left side Before Expansion		Right side After Expansion		Left side After Expansion		Right side Treatment Change		Left side Treatment Change	
	1 st - A	2 nd B	1 st C	2 nd D	1 st E	2 nd F	1 st G	2 nd H	1 st E-A	2 nd F-B	1 st G-C	2 nd H-D
1	10.7	11.1	5.7	5.8	20.0	20.4	14.8	15.1	9.3	9.3	9.1	9.3
2	8.1	8.2	10.1	9.8	20.2	20.5	21.0	21.1	12.1	12.3	10.9	11.3
3	0.8	0.9	9.2	9.0	8.9	9.3	18.9	18.4	8.1	8.3	9.7	9.4
4	4.7	4.6	4.5	4.6	16.0	15.6	15.8	16.0	11.3	11.0	11.3	11.4
5	0.3	0.3	7.1	7.3	9.6	9.8	11.1	11.4	9.3	9.5	4.0	4.1
6	2.1	2.0	10	9.6	11.1	10.7	25.5	24.8	9.0	8.7	15.5	15.2
7	1.2	1.3	4.8	5.0	13.0	13.0	15.2	15.4	11.8	11.7	10.4	10.4
8	1.9	2.0	7.1	7.3	13.8	14.0	14.2	14.4	11.9	12.0	7.1	7.1

Table 14. Raw data of molar angulation of Hyrax group. 1st: First measurement; 2nd: Second measurement

3b. Inter-examiner’s reproducibility was evaluated by Paired-Test. Both the P Value in the Hyrax group and MSE group showed the measurements in this study were highly reproducible and reliable. (Table 15-18). Therefore we could take the average of the measurements as a mean value from two measurements to perform further statistical analysis.

		N	Mean	Std. Deviation	Std. Error Mean
Pair 1: Right side Before-Expansion	First measurement	15	7.1000	4.3863	1.1325
	Second Measurement	15	7.0600	4.3585	1.1253
Pair 2: Left side Before-Expansion	First Measurement	15	8.9533	4.7240	1.2197
	Second Measurement	15	8.8333	4.7831	1.2349
Pair 3: Right side After-Expansion	First measurement	15	11.120	4.7233	1.2195
	Second Measurement	15	11.226	4.7492	1.2263
Pair 4: Left side After-Expansion	First measurement	15	12.8800	4.8177	1.2439
	Second Measurement	15	12.9333	4.9382	1.2705

Table 15: Paired T-test of the first and second measurements of molar angulation of MSE group

		Paired difference				
		95 % Confidence Interval of the Difference				
		Lower	Upper	t	df.	P value
Pair 1	First V.S Second measurement	--0.0780	0.1580	0.727	14	0.470
Right side						
Before-Expansion						
Pair 2	First V.S. Second measurement	-0.0041	0.2441	2.073	14	0.057
Left side						
Before Expansion						
Pair 3	First V.S. Second measurement	-0.2163	0.0030	-2.086	14	0.056
Right side						
Before Expansion						
Pair 4	First VS Second measurement	-0.2776	0.1709	-0.510	14	0.618
Left side						
Before Expansion						

Table 16: Paired T-test of the first and second measurements of molar angulation of MSE group

		N	Mean	Std. Deviation	Std. Error Mean
Pair 1: Right side Before Expansion	First measurement	8	3.7520	3.8055	1.3454
	Second Measurement	8	3.8000	39038	1.3802
Pair 2: Left side Before Expansion	First Measurement	8	7.3125	2.2509	0.7958
	Second Measurement	8	7.3000	2.0445	0.7228
Pair 3: Right side After Expansion	First measurement	8	14.075	4.3624	1.5423
	Second Measurement	8	14.162	4.4268	1.5651
Pair 4: Left side After Expansion	First measurement	8	17.062	4.5355	1.6035
	Second Measurement	8	17.075	4.2233	1.4931

Table 17: Paired T-test of the first and second measurements of molar angulation of Hyrax group

		Paired difference				
		95 % Confidence Interval of the Difference				
		Lower	Upper	t	df	P value
Pair 1 Right side Before-Expansion	First V.S. Second measurement	-0.2071	0.5718	-1.342	7	0.222
Pair 2 Left side Before Expansion	First V.S. Second measurement	-0.1944	0.2194	0.143	7	0.890
Pair 3 Right side Before Expansion	First V.S. Second measurement	-0.3609	0.1859	-0.757	7	0.474
Pair 4 Left side Before Expansion	First VS Second measurement	-0.3369	0.3111	-0.091	7	0.930

Table 18. Paired T-test of the first and second measurements of molar angulation of Hyrax group

3b. We used Paired Sample Test to compare the molar angulation changes on the right side and left side in both groups. (Table 19) It showed that in MSE and Hyrax group,

there were no difference between the right side and left side. Both MSE and Hyrax induced similar amount of molar angulation changes on the right side and left side.

		N	Mean	Std. Deviation	Std. Error Mean	P Value
Pair 1 MSE	Right side	15	4.0933	1.5015	0.3877	0.833
	Left side	15	4.0133	2.0569	0.5311	
Pair 2 Hyrax	Right side	8	10.3562	1.5695	0.5550	0.664
	Left side	8	9.7625	3.2954	1.1651	

Table 19. Paired T-test of molar angulation changes on the right side and left side in MSE and Hyrax groups.

3c. We used the mean value of the two measurements to compare the molar angulation changes in MSE and Hyrax group. Independent T test was used (Table 20). The mean value of MSE group was 4.05 degrees and Hyrax group was 10.05 degrees. The p value was 0.000(< 0.01) indicating that there was a statistically significance between MSE group and Hyrax group. The MSE group had less molar angulation change than hyrax group.

	N	Mean	Std. Deviation	Std. Error Mean	Mean difference	Std Error difference	P value
MSE	15	4.0533	1.6499	0.4260	-6.0060	0.7642	0.000
Hyrax	8	10.0544	1.79468	0.6345			

Table 20. Paired T-test of molar angulation changes of MSE and Hyrax groups.

3d. A bar graph was used to see the mean value of the molar angulation changes in MSE and Hyrax Group. The mean value of MSE group was 4.05 degrees and Hyrax group was 10.05 degrees. The mean vale of MSE group was less than Hyrax group with statistically difference. (Fig 16)

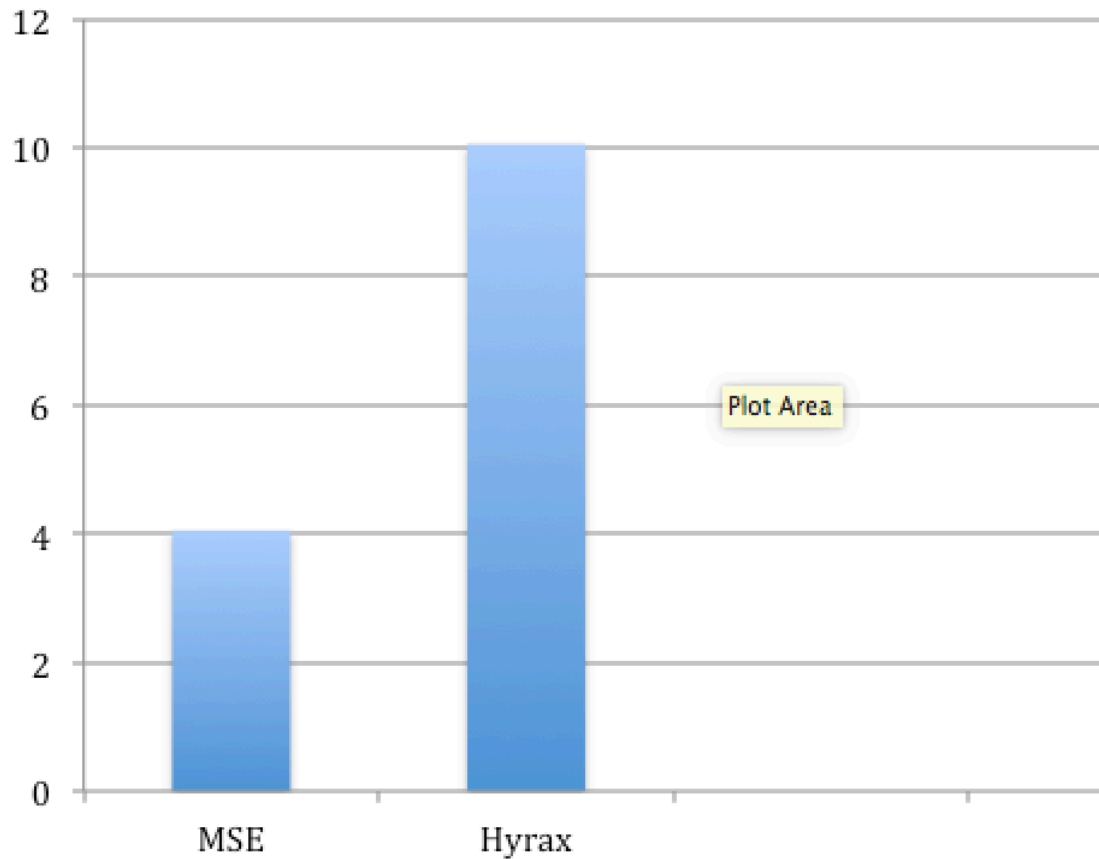


Fig16. Bar graph of molar angulation changes of MSE and Hyrax groups

X axis: MSE group and Hyrax group

Y axis: Degree of molar angulation changes

3e. Scatter plot was used to see the distribution of the data of the molar angulation of MSE and Hyrax Group. Two Groups had similar variation. There was no significant difference between the variations of the distribution of the data between two groups.

(Fig 17)

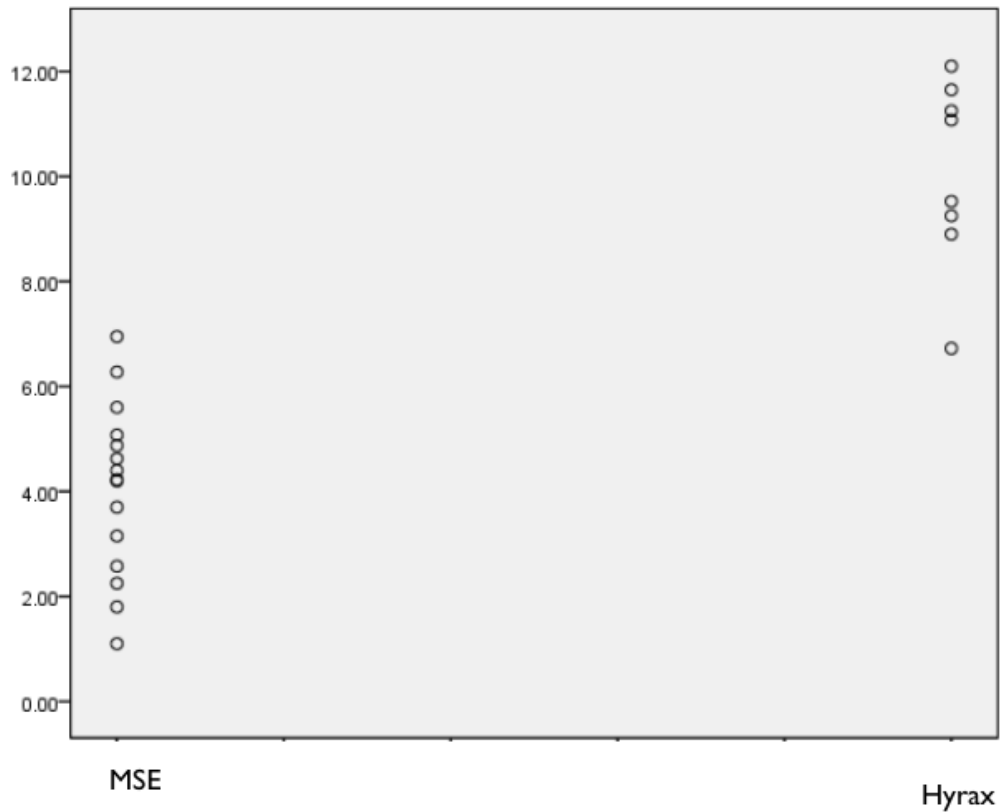


Fig17. Scatter Plot of molar angulation changes of MSE and Hyrax groups

X axis: MSE group and Hyrax group

Y axis: Degree of molar angulation changes

5. Molar tipping: Molar angulation change-Bone bending

We used the mean value of the bone bending and molar angulation changes in MSE and Hyrax group to estimate the molar tipping in MSE and Hyrax group. The estimated molar tipping in MSE group was less than Hyrax group. The estimated value of MSE group was 2.66 degrees and Hyrax group was 6.28 degrees. The equation was performed as: Estimated molar tipping= Angulation changes of the molar - bone bending

	Mean value of Molar angulation change	Mean value of bone bending	Estimated value of molar tipping
MSE	4.05	1.39	2.66
Hyrax	10.05	3.77	6.28

Table 21. Estimated molar tipping in MSE and Hyrax groups

Summary of the result:

1. MSE group produced a more parallel opening of the palatal sutures than Hyrax group. (MSE=0.62degrees, Hyrax=7.50 degrees. P=0.000)
2. MSE group had less bone bending than Hyrax group. (MSE=1.39 degrees, Hyrax=3.77 degrees. P=0.004)
3. MSE and Hyrax had similar amount of bone bending on the right and left side.
4. MSE group had less molar angulation changes than Hyrax group. (MSE=4.05degrees. Hyrax=10.05 degrees, P=0.000)
5. MSE group had less estimated molar tipping than Hyrax group. (MSE=2.66 degrees, Hyrax=6.28 degrees)

Discussion

Throughout the past decades, many studies on RPE have been published. Much of the research used dried skulls, or Rhesus monkeys, or FEM models to explore the behavior of the maxillary complex under expansion treatment with RPE. However, each type of studies had their inherent weakness. In the FEM study, the soft tissues, such as all the circum-maxillary sutures and the periodontal ligaments are difficult to be completely incorporated into the FEM model and expressed in the computer program. In the dried skull studies, the lack of gingiva, mucosa, and periodontal tissue can hamper the effect of RPE. In the Rhesus monkey studies, the result cannot represent the treatment effects on humans due to the fact that the monkey has significantly different maxillary anatomy than humans.²⁴

The effects of RPE on the maxillofacial complex have been studied with dental casts, lateral cephalograms, or posterior-anterior cephalograms. Inherent limitations of the two dimensional radiography are magnification, distortion, and difficult landmark identification. Because a three dimensional structure is presented on one plane of space, many structures overlap on the same image, which explain why most of the previous studies were done on dental plaster models. However, plaster model provides limited information about the skeletal changes in the maxillary structure.²⁵

Cone beam computed radiography is a groundbreaking diagnostic method in dentistry as it provides high dimensional accuracy of the facial structures and reliable method for quantifying the structural changes in all three planes of space. It is now possible to visualize the structural changes and acquire accurate radiographic images that allow clinicians and researchers to quantitatively evaluate skeletal and dental

changes with minimum distortion and lower radiation.⁸ In fact, CBCT allows the reproduction of the maxillofacial complex in the three planes of space, which make possible the investigation of skeletal and dental change. Advances in 3 dimensional imaging computer program, such as Dolphin and Ondemand 3D software, not only permit the acquisition of an overlay-free image, but also the construction and superimposition of 3D cone beam computed tomography.

With the increasing use of micro-implants in orthodontic field, CBCT has attracted great attention in the orthodontic community. Although the orthodontic literature has many reports on conventional RPE, very few have studied Micro-implant assisted RPE. The lack of knowledge and data regarding Micro-implant assisted RPE motivated us to conduct a study on the comparison of the dental and skeletal effect of MSE and Hyrax appliance with the use of cone beam computed radiography.

In this study, we used Maxillary Skeletal Expander (MSE) appliance, a particular type of Micro-Implant Assisted Palatal Expander (MARPE), designed by Dr. Won Moon at the UCLA School of Dentistry. It is a modification of the conventional RPE appliance. It incorporates micro-implants into the palatal jackscrew to ensure expansion of the underlying palatal bone. The overarching goal of this project was to examine and to compare the skeletal and dental effect of MSE and Hyrax appliances. This was accomplished by the utilization of CBCT imaging both before expansion and immediately after completion of expansion. The analysis of the second set of CBCT images allowed for the change in pure skeletal expansion to be detected. This made detailed measurements of the skeletal and dental change possible. Dolphin Imaging 11. 5

premium software and Ondemand 3D software were used to generate the cross-section view and to construct the superimposition of pre-expansion and post expansion.

This study found that both MSE and Hyrax successfully opened the palatal suture and corrected transverse discrepancies efficiently. It also found that MSE provided more parallel opening of the suture and induced less bone bending and less estimated molar tipping as compared to Hyrax appliances.

When the CBCT images of those treated with Hyrax were analyzed, we found that on average the suture split with a divergence of 7.50 degrees from the posterior portion of the suture and with a range of 1-15 degrees. This led to a V or triangular shaped pattern of suture opening with a wider opening in the anterior region. Studies by Garrett et al., Pangrazio-Kulbersh et al., and Kanomi et al. have shown that expansion using RPE produces similar patterns of opening.^{8,26,27} While these and other studies have looked at expansion with traditional methods of RPE, there is a lack of studies that analyzed the effects micro-implant assisted RPE have upon suture opening and other aspects of expansion. This study found that MSE provided a significantly different pattern of suture opening. On average we found that the suture diverged only 0.62 degrees from the posterior to anterior region of the suture after expansion and with a range of 0-2 degrees. This led to more uniform and equal opening along the length of the suture. A significantly greater range of opening was noted in the Hyrax group. Hyrax produces a V shape opening of the palatal suture perhaps because the interlocking palatine bone and immovable medial and lateral pterygoid plates of the sphenoid bone give more resistance during expansion.⁸ The other possible reason is that the zygomatic buttress bone is located distally to the position of the palatal expander and it

also gives more resistance to the expansion force. In other words, when the posterior part of maxilla articulates with the sphenoid bone and zygomatic buttress bone, it has more resistance when the maxilla is expanded. However, the resistance has individual variation. Therefore in hyrax group, we saw a greater range of angulation of suture opening from 1-15 degrees while the MSE group had a very consistent pattern of suture opening (0-2 degrees). This can be explained by the micro-implants that were inserted inside the palatal bone in a parallel pattern and also more distally than conventional RPE, hence, when the suture opened, it opened along with the force transmitted by the micro-implants in a parallel pattern. The force was directed more distally as well.

The ability to achieve parallel expansion could have important clinical ramifications. As the amount of expansion achieved in the region of the incisors is more equal to the amount achieved in the region of the molars, better arch coordination can be obtained. The ability of MSE to produce more parallel expansion than Hyrax is due to proper utilization of implants in the design of the appliance. Traditional RPE appliances, such as Hyrax, have relied on tooth borne anchorage to achieve expansion. Hyrax appliances have shown to be effective at producing palatal expansion especially in younger patients, whose palates have yet to interlock, or are in the early stages of interlocking. As the palate continues to interlock in an anterior direction, studies have shown that Hyrax becomes less efficient at orthopedic expansion, instead producing more orthodontic and alveolar tipping movements in the posterior region. Hyrax is unable to direct the higher forces required to open an interlocked suture of the palatal bones; instead, those forces are transferred to the dentition and alveolar process and produces unwanted side effects.

The use of 11mm micro-implants in the MSE allowed for greater bony anchorage for increased stability during expansion. It should be noted that there are multiple designs for RPE that utilize implants. MSE differs from other MARPE appliances in the length of the implants used. Previous MARPE appliances utilized shorter implants, which ended within the cancellous bone of the palate. This cancellous bone is less dense than cortical bone and doesn't provide the same degree of bony support that the bi-cortical engagement of MSE does. By utilizing longer implants, not only did the cortical bone lining the oral cavity engage the implant, but the cortical layer lining the nasal cavity also engaged. As the expansion screw was activated, the force was stabilized by the bony anchorage and prevented it from being distributed to the teeth and alveolar process. This led to more parallel opening of the suture and likely less dental and alveolar tipping.

In this study we found that the MSE group produced less bone bending than the Hyrax group. (MSE=1.4 degrees, Hyrax=3.8 degrees, $P<0.01$). In both groups, there was no statistically significant difference between the right and left side on the same patient. Limited studies have reported data on the bone bending on the clinical palatal expansion treatment so far. In Macginnis et al study in 2014, the FEM model was used to see the maxillofacial complex in reaction to MSE. The stress distributed from expansion force was mainly along the trajectories of the maxillary buttresses. The MSE model showed less rotation and tipping of the maxillary complex compared to the hyrax model.²⁸ One clinical study in 2010 used CBCT to examine the alveolar bone tipping and reported the alveolar bone of the first molar tipped buccally by nearly 5.6 degrees when using a hyrax appliance.⁹

The result showed that MSE produced less molar angulation changes than Hyrax appliance (MSE= 4.1 degrees, Hyrax=10.1 degrees, $P < 0.01$) when there was no difference between the right and left side. Many studies have reported the result of molar tipping when using conventional RPE appliances ranges from 0 to 24 degrees for both sides with an average 0-12 degrees for 1 side.^{1,9,29-32} Most of the studies used two-dimensional radiographs or dental casts to measure the molar tipping after expansion. One study used CBCT to evaluate the molar angulation changes and the data showed an average of 3 degrees on each side with the Hyrax appliance.

The molar angulation changes we measured in the studies came from the sum of bone bending and molar tipping. Since the teeth are surrounded by the alveolar bone, the teeth move with the bone. It is very difficult to differentiate and visualize true dental tipping from bone bending. The method used in this research provided us a way to see the amount of pure molar tipping under expansion force. A simple and reasonable equation was formed to best describe the relationship between bone bending, pure dental tipping, and the angulation changes of the molars .

Estimated molar tipping= Angulation changes of the molar - bone bending

For instance, when the angulation change of molar is 3 degrees, and there is 1 degree of bone bending, we thus know that the estimated molar tipping is 2 degrees. In this study, we found that MSE induced less molar tipping than Hyrax group. (MSE=2.66 degrees, Hyrax=6.28 degrees). It is mainly because MSE had skeletal anchorage while hyrax appliance applied all the expansion force on the molars during the expansion. The molar tipping is an unstable outcome of the expansion treatment and often results in the relapse from the palatal expansion. Therefore molar tipping is considered to be an

undesired side effect of palatal expansion treatment. Currently, very limited studies have reported the data on the comparison of the molar tipping with MSE and Hyrax appliance.

Our research data was performed with the same examiner to reduce the measurement error. In order to obtain the most reliable and reproducible data, the examiner had to measure each image two times. Paired T-test was used to check the reproducibility before the average of two measurements could be taken to perform further analysis.

All of the second CBCT scans were taken shortly after the completion of expansion treatment. This eliminated most of the remodeling and growth, as well as relapse from the expansion treatment. It enabled us to see the direct change of the maxillofacial complex after maxillary expansion.

The small sample size was a limitation to this study. The strict inclusion criteria eliminated many patients. The largest barrier was that patients not having pre-expansion and post-expansion CBCT imaging, due to reasons such as financial and insurance limitations. For example, Medi-Cal does not cover CBCT. Future development of this study will include an increase in the sample size. Furthermore, the long-term stability of MSE and traditional RPE should be evaluated. However, obstacles such as the cost of additional CBCT imaging and exposing patients to additional radiation will be faced.

Conclusion:

- (1) Three-dimensional radiography is a better and a more reliable diagnostic tool than two dimensional radiography and dental casts. This study utilized CBCT to construct the cross-section in 3 planes of space to best exam the skeletal and dental changes after completing maxillary expansion. Dolphin Premium 11.5 software and Ondemand 3D software enabled us to construct the superimposition images of the pre and post-expansion view to quantify the bone bending and molar tipping accurately.
- (2) In this study, the second CBCT images were taken shortly after maxillary expansion. This gave us a privilege to see the direct skeletal and dental changes of maxillofacial complex in reaction to expansion force without other affecting factors such as bone remodeling, growth, and treatment effect from orthodontic brackets and wires.
- (3) In comparison to Hyrax appliance, MSE appliances transmitted the expansion force into palatine bone and produced a more parallel-type and more consistent suture opening upon maxillary expansion. This was accompanied by less bone bending and less molar tipping during the expansion treatment. These characteristics of MSE appliance offered better arch coordination and more predictable results after maxillary expansion. The ratio of bone bending to molar tipping was reported to be same with Hyrax appliance.
- (4) Further studies could be designed to examine the long-term stability of the MSE expansion.

Reference:

1. Adkins MD., Nanda RS., et al., *Arch perimeter changes on rapid palatal expansion*. American Journal of Orthodontics and Dentofacial Orthopedics. 1990 Mar; 97(3):194-9. 2178393.
2. Sari E, Uçar C., Ceylanoglu C.. *Transpalatal distraction in a patient with a narrow maxilla*. Angle Orthod. 2007 Nov; 77(6):1126-31.
3. Kutin G., Hawes RR., *Posterior cross-bites in the deciduous and mixed dentitions*. American Journal of Orthodontics and Dentofacial Orthopedics. 1969 Nov; 56(5):491-504.
4. Da Silva Filho OG., et al., *Epidemiology of posterior crossbite in the primary dentition*. J Clin Pediatr Dent. 2007 Fall; 32(1):73-8.
- 5: Brunelle JA., Bhat M., et al., *Prevalence and distribution of selected occlusal characteristics in the US population, 1988-1991*. J Dent Res. 1996 Feb; 75 Spec No:706-13.
6. Proffit, WR. Contemporary orthodontics. 5th ed. St. Louis: Mosby Elsevier; 2012.
7. Melsen B., et al., *Palatal growth studied on human autopsy material: a histologic microradiographic study*. American Journal of Orthodontics and Dentofacial Orthopedics, 1975;68:42-54.
8. Garrett BJ., et al., *Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography*. American Journal of Orthodontics and Dentofacial Orthopedics, 2008. 134(1): p. 8-9.
9. Kartalian A., Gohl E., et al., *Cone Beam computerized tomography evaluation of the maxillary dentalskeletal complex after rapid palatal expansion*. American Journal of Orthodontics and Dentofacial Orthopedics, 2010:138; 486-92
10. Korbmacher H., Schilling A., et al., *Age-dependent three-dimensional micro-computed tomography analysis of the human midpalatal suture*. J Orofac Orthop 2007; 68:364-76.
11. Baccetti T., et al., *Treatment timing for rapid maxillary expansion*. Angle Orthod. 2001 Oct; 71(5): 343-50.
12. Angell E.H., *Treatment of irregularities of the permanent or Adult Teeth*, Dental Cosmos 1:1860.
13. Williams BJD., et al., *Complications Following Surgically Assisted Rapid Palatal Expansion: A Retrospective Cohort Study*. Journal of Maxillofacial Surgery, 2012. 70: p. 2394-2402.

14. Lagravere MO., et al., *Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: A randomized clinical trial*. American Journal of Orthodontics and Dentofacial Orthopedics, 2013. 137(3).
15. Aps JK. *Rapid maxillary expansion: effects on palatal area investigated by computed tomography in growing subjects*. Eur J Paediatr Dent. 2012 Dec;13(4):352; author reply 353.
16. Wertz R A, et al. *Skeletal and dental changes accompanying rapid midpalatal suture opening*. American Journal of Orthodontics 1970;58: 41 – 66
17. Timms D J, et al., *A study of basal movements with rapid maxillary expansion*. American Journal of Orthodontics,1980, 77: 500 – 507
18. Ribeiro GL U., Locks JP., et al, *Analysis of rapid maxillary expansion using Cone-Beam Computed Tomography*. Dental Press J Orthod. 2010 Nov 15(6): 10712
19. Pinheiro FH., Garib DG., et al., *Longitudinal stability of rapid and slow maxillary expansion*. Dental Press J Orthod. 2014 Dec;19(6):70-7. doi: 10.1590/2176-9451.19.6.070-077.oar. Epub 2014 Dec 1.
20. Lagravere M.O., Carey, J., et al., *Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: A randomized clinical trial*. American Journal of Orthodontics and Dentofacial Orthopedics, 2010. 137: p. 304.e1-304.e12.
21. Persson M., Thilander B., et al., *Palatal suture closure in man from 15 to 35 years of age*. American Journal of Orthodontics and Dentofacial Orthopedics,1977;72:42-52.
22. Knaup B, et al., *Age-related changes in the midpalatal suture*. J Orofac Orthop 2004;65:467-74.
23. Lagravere MO., et al., *Meta-analysis of immediate changes with rapid maxillary expansion treatment*. J Am Dent Assoc 2006;137:44-53
24. Woller JL., Kim KB., et al., *An assessment of the maxilla after rapid maxillary expansion using cone beam computed tomography in growing children*. Dental Press J Orthod. 2014 Jan- Feb;19(1):26-35.
25. Nada RM., Fuadelej PS., et al., *Three-dimensional prospective evaluation of tooth-borne and bone-borne surgically assisted rapid maxillary expansion*. Journal of cranio-maxillo-facial surgery 40 (2012)757-762

26. Pangrazio-Kulbersh V., Eine P., Pajtas B et al., *Cone beam computed tomography evaluation of change in the naso-maxillary complex associated with two types of maxillary expanders*. Angle Orthod.2012;82:448-457
27. Kanomi R., Deguchi T., et al., *CBCCT of skeletal changes followinf rapid mexillary expansion to increase arch-length withh a development-dependednt bonded or banded ppliance*. Angle Orthod. 2013;83:851-857
28. Macginnis M., Moon W. et al., *The effect of MARPE on the nasomaxillary complex - a FEM analysis*. Prog Orthod, 2014, Aug 29;15-5228.
29. Handelman CS., Wang L., et al., *Nonsurgicalrapid maxillary expansion in adults: report on 47 cases using the Haas expander*. Angle Orthod 2000;70:129-44.
30. McNamara JA Jr., Baccetti T.,et al.,- *Maxillary expansion followed by fixed appliances: a long-term evaluation of changes in arch dimensions*. Angle Orthod 2003;73:344-53.
31. Garib DG., Henriques JF., et al.,*Rapid maxillary expansion—tooth tissue-borne versus tooth- borne expanders: a computed tomography evaluation of dentoske- letal effects*. Angle Orthod 2005;75:548-57.
32. Hicks EP., et al., *Slow maxillary expansion. A clinical study of the skel- etal versus dental response to low-magnitude force*. Am J Orthod 1978;73:121-41.