Three-dimensional Maxillary and Nasal Airway changes associated with Hybrid Hyrax and Maxillary Skeletal Expander (MSE)

by

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DEDICATION

This thesis is dedicated to the people who have stood next to me my whole life, and they have helped me achieve my goals and become a better man. To my mom, who is always there for me with her unconditional love. To my dad, who supports me in every step of my life and to my brother, who is my best friend. Finally, to my grandparents that are no longer with us; thank you for supporting and inspiring me before and during my journey to follow my dream and complete my Orthodontic residency in the United States.

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ABSTRACT

Introduction

This study aims to compare the skeletal, dental, and nasal airway changes in patients treated with two types of mini-implant-assisted rapid palatal expanders: the Maxillary Skeletal Expander (MSE) and the Hybrid Hyrax (HH), using three-dimensional Cone Beam Computed Tomography (CBCT) and artificial intelligence-assisted segmentation.

Methods

Thirty-four patients aged 13-33 years (mean 18 years; 74% females) treated with MSE or HH (N=17 each) at Case Western Reserve University Orthodontic Clinic retrospectively collected were analyzed. The inclusion criteria were: maxillary transverse deficiency, cervical vertebral maturation stage ≥3, permanent dentition, and successful suture opening. 3D voxel-based superimposition of pre-expansion (T1) and post-expansion (T2) CBCT scans was performed in Dolphin Imaging and nasal airway volumes were calculated. The files were segmented in the RELU software and transverse, vertical, and anteroposterior dentoskeletal measurements were made in 3D slicer.

Results

No significant skeletal, dental, or airway differences were observed between treatment effects of MSE and HH in any dimension. Both appliances were successful, increasing intermolar width by 6–7mm and intercanine width by 3mm. Nasal airway volume increased by 4180.6 ±5044.6mm³ in MSE ($p=0.003$) and 38495.5 ±5889.4mm^3 in HH ($p=0.001$), and the nasal minimum constriction area by 35 ±34.8mm² in MSE ($p<0.001$)

and 19.9 ±30.9mm^2 in HH (p=0.001). Both appliances demonstrated minor buccal tipping (2-6°) and excellent vertical control (<1mm).

Conclusion

MSE and HH are equally effective for addressing maxillary transverse deficiency. Both appliances result in significant skeletal and dental expansion and improved nasal airway dimensions.

Keywords: MSE, Hybrid Hyrax, maxillary expansion, mini screw assisted rapid palatal expander, nasal airway, CBCT, 3D superimposition

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LITERATURE REVIEW

1. Normal maxillary development in the transverse dimension

1.1 Midpalatal suture growth

Midpalatal sutural growth has been shown by Björk and Skieller to be 6.9 mm on average from four to eighteen years old [1–3]. A remaining 4 mm of midpalatal sutural growth was estimated after ten to eleven years old when the premolars erupted [1–3]. Moreover, an increase in height due to growth was correlated significantly with the midpalatal suture growth [1–3].

Additionally, Melsen performed a histological study in which the midpalatal sutures from the autopsy of individuals at different ages were excised and analyzed [3,4]. According to the analysis, the midplatal suture of children with deciduous dentition (six months to six years old) showed a Y shape (Figure 1A), while of children in mixed dentition, a wave-like shape (Figure 1B) [3,4]. Finally, a heavily interdigitated pattern was noticed in the permanent dentition (Figure 1C) [3,4].

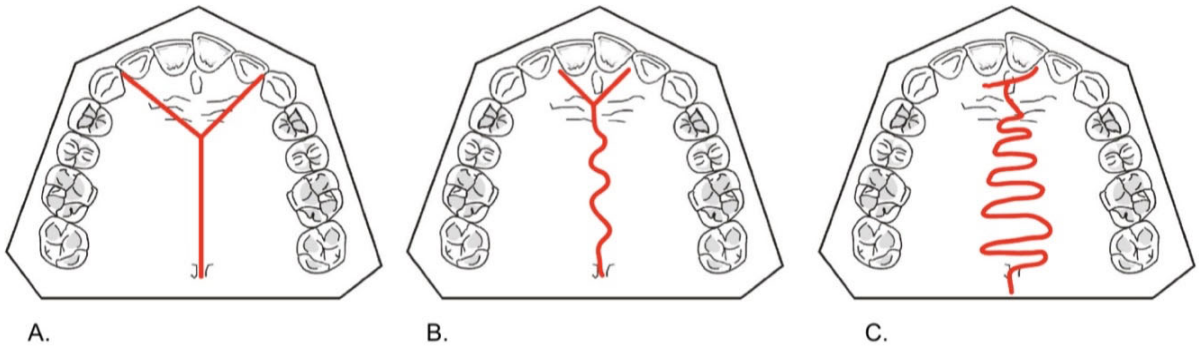


Figure 1. Midpalatal suture (adapted from Melsen [3,4]). A: deciduous dentition, B: Mixed dentition, C: permanent dentition

According to Melsen, most adult skulls had a significantly interdigitated midpalatal suture, and some showed a fused suture [3,4]. The midpalatal suture seems to be closing progressively, but this closure presents great variability according to the patient's age and gender [5]. Theoretically, as individuals age, sutural ossification should gradually happen, leading to heavy interdigitation or fusion in late adolescence or adulthood.

According to Persson and Thilander, significant midpalatal suture fusion is expected in the third decade of life but can also be observed during the juvenile period to a smaller extent [6]. Also, despite the variability in the start and the progression of the midpalatal suture closure, the closure progression was greater in the oral part of the suture (compared to the nasal part) and in the more posterior area, progressing from the palatine bone anteriorly to the maxillary bone [5–8]. Despite of finding midpalatal suture fusion in a 15-year-old female and a 21-year-old male, no fusion was observed in patients aging 27 and 32 years old [5,6]. Similarly, other studies have noticed no midplatal suture fusion in patients 54 years old [8] and 71 years old [5,9].

Therefore, a more detailed method for classifying the midpalatal suture maturation in five stages (Stage A - Stage E) using CBCT has been recently suggested [7], due to the variability of the midplatal suture fusion according to chronological age and gender. The five stages can be seen in Figure 2. In stage A the midplatal suture is an almost straight high-density line with little to no interdigitation, while in stage B is a more scalloped high density line [7]. In stage C the midpalatal suture is characterized by two parallel scalloped high density lines that are closely positioned to each other and are separated by small low-density spaces within the maxillary and palatine bones [7]. In stage D, the suture remains visible as two parallel scalloped high density lines, but there is progressing fusion of the midpalatal suture in the palatine bone with a posterior to anterior direction [7]. Finally, in stage E the fusion of the midpalatal suture is completed and the suture is not visible in the palatine bone and the maxilla [7].

According to their diagram [7]: if the suture is only visible in the maxillary bone it can be classified as stage D and if is not visible in maxillary and palatine bones it can be classified as stage E. Furthermore, if the suture is visible in the maxillary and palatine bones and it has two scalloped lines it can be classified as stage C. Finally, if the suture is visible in the maxillary and palatine bones and it has one line, then it can be classified as stage B if the line is scalloped and as stage A if it is not.

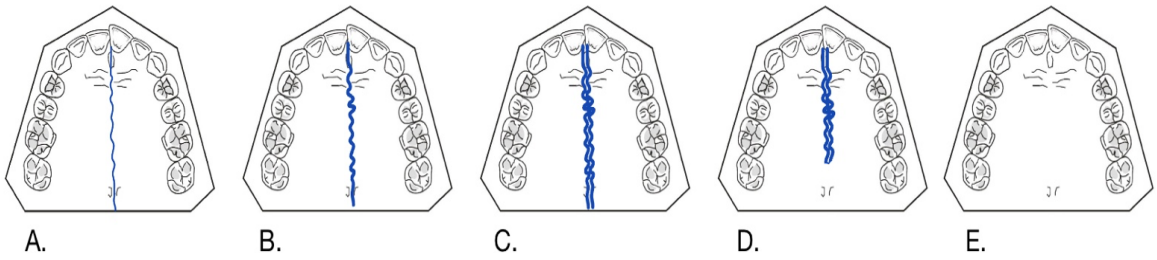


Figure 2. Midpalatal suture maturation stages (adapted from Angelieri(7)).

1.2 Maxillary arch transverse changes during growth

Björk and Skieller [1] described the development of the maxillary dental arch and noted great stability in the arch width after the age of 5 years old despite the medial eruption of the premolars [3]. Similarly, Moorrees et al [10] observed that the maxillary and mandibular arch widths showed on average minimal change at the level of the second deciduous molars in males and females between 5 to 18 years old [3]. The available maxillary space remained mainly unchanged as its expected increase due to the more labial eruption of the upper incisors (compared to the primary incisors) was mitigated by the Leeway space loss [3,10]. Crowding and spacing in children was attributed to the individual variability of each child [3,10]. More recently, a study using CBCT [11] to investigate the transverse maxillomandibular relationships in untreated children corroborated their findings. They reported greater dentoalveolar increase in the maxilla, attributed to growth in the midpalatal suture, and coordination between the maxillary first molars and mandibular first molars, despite the different amount of growth between the maxilla and

the mandible [4,11]. Therefore, the normal growth of the midpalatal suture seems to be offset by the medial eruption of the maxillary posterior teeth in order to maintain proper occlusion with the mandibular posterior teeth [3].

2. Maxillary Transverse Deficiency

2.1 Prevalence and clinical features

Maxillary transverse deficiency is a frequent orthodontic problem that results from insufficient transverse development of the maxillary arch. This skeletal condition often manifests clinically with signs such as unilateral or bilateral posterior crossbites, dental crowding, tapered maxillary arch, high palatal vault, dark buccal corridors, and nasal airway constriction [12–15]. The prevalence of maxillary transverse deficiency has been shown to be approximately 9.4% in the general population, increasing to nearly 10-30% among adult orthodontic patients [16,17]. Among children, the prevalence has been documented at 18% in those presenting with mixed dentition [3]. These statistics emphasize the importance of the early identification and treatment of the maxillary transverse deficiency.

A maxillary transverse deficiency with posterior crossbite can be accompanied by functional shift between Centric Relation and Centric Occlusion (CR-CO shift). If this condition is diagnosed in a growing patient, it is important to be addressed early in order

to prevent the negative impact that it can have on facial symmetry and function of the temporomandibular joint[18,19].

Additionally, a maxillary transverse deficiency may be present even without a crossbite. In such cases a combination of increased maxillary buccolingual inclination and/ or decreased mandibular molar buccal inclination (increased Curve of Wilson) might be noticed. This combination is often associated with crowding, periodontal compromise, and imbalance in facial musculature[19,20].

Furthermore, a maxillary transverse deficiency may be obscured by a discrepancy in the anteroposterior malocclusion [19]. This situation may become apparent after the anteroposterior correction of a Class II or a Class III malocclusion[21]. In the case of a Class II malocclusion, a pre-treatment crossbite may not be initially present because the maxillary teeth occlude with a narrower and more anterior part of the mandibular arch. However, a crossbite could be evident after correcting the Class II malocclusion as the maxillary teeth occlude with a broader part of the mandibular arch. Conversely, in the case of a Class III malocclusion, a pretreatment crossbite might be present due to maxillary teeth occluding with a broader and more posterior part of the mandibular arch. Following the Class III correction, the crossbite may no longer be present.

In his classic paper, Andrews [22] developed the "6 Keys to Normal Occlusion" by evaluating 120 dental models from non-orthodontic patients with normal occlusion. Among these keys, Andrews highlighted the buccolingual inclination of crowns as crucial for achieving normal occlusion. Additionally, the importance of the compatibility between the maxillary and mandibular arch widths to ensure oral and facial harmony was

emphasized by Andrews and Andrews[23,24] in their study of the "6 Keys to Orofacial Harmony". Moreover, the American Board of Orthodontics (ABO) had included the buccolingual inclination of posterior teeth as part of the cast-radiograph evaluation for assessing orthodontic treatment quality [24,25]. Furthermore, the role of a normal transverse dimension in overall smile esthetics and in reducing the dark buccal corridors was emphasized in another study by Sarver and Ackerman[26].

2.2 Etiology and Risk Factors

Maxillary transverse deficiency can be the result of a combination of genetic, environmental, and developmental factors. Environmental and developmental contributors include low tongue posture, narrow pharyngeal airway, increase nasal resistance, and mouth breathing, which can change the normal craniofacial and growth patterns[27]. More specifically, narrow airway passages that can be caused by conditions such as allergic rhinitis, nasal septum deviation, and enlarged tonsils and adenoids can cause mouth breathing. Mouth breathing can lead to low tongue posture which in turn can result in higher palatal vault and a maxillary transverse deficiency since the tongue cannot equilibrate the buccal pressure during maxillary development in its abnormal position [27,28].

Genetic predisposition seems to also play a role, with familial tendencies observed in transverse discrepancies. A recent meta-analysis calculated the heritability index of different dental arch features and occlusal factors some of which are often evaluated in diagnosing transverse maxillary deficiencies [29]. According to their meta-analysis, the

heritability index that can range from 0 to 1 (with values closer to 1 indicating greater heritability) was found to be 0.52 for the maxillary intermolar width, 0.55 for the maxillary intercanine width, 0.56 for the palatal depth, and 0.46 for the presence of crossbite[29]. These findings indicate that there is a significant genetic component in the development of features that can accompany a maxillary transverse deficiency [29].

2.3 Clinical Consequences

Maxillary transverse deficiency in growing patients can result in functional disturbances, skeletal asymmetry, and muscle imbalances if left untreated[27]. More specifically, an untreated maxillary transverse deficiency that is accompanied by a posterior crossbite and a mandibular shift can lead to differential mandibular growth due to the different position of the condyles in the glenoid fosses in the crossbite and the non-crossbite sides and thus a skeletal asymmetry[27]. Additionally, it can increase the normally absent activity of the muscles of mastication at rest and can cause differential growth of the elevator muscles (thinner masseter on the crossbite side) and altered chewing patterns to avoid occlusal interferences [27, 30].

2.4 Diagnosis

The diagnosis of maxillary transverse deficiency traditionally relied on a combination of clinical examinations, plaster model analyses, and posteroanterior cephalometric X-rays assessment. Orthodontists would evaluate the intermolar width, with normal values ranging from 36 to 39mm and values below 31mm indicating a constricted maxilla[20]. Additional assessments include the Curve of Wilson on the mandibular molars, the presence or absence of crossbites, the extent of dark buccal corridors, and posteroanterior cephalometric analyses, such as the frontal analysis introduced by Ricketts[31]. These methods highlight the lack of a standardized approach to diagnosing maxillary transverse deficiency.

However, with the recent advancements in cone-beam computed tomography (CBCT) imaging, combined with the development of ultra-low dose protocols that have comparable effective doses with panoramic radiographs[32], a more objective method for diagnosing maxillary transverse deficiency was developed at Case Western Reserve University[24]. The CWRU transverse analysis offers a reliable approach for diagnosing maxillary transverse deficiency while also enhancing orthodontic treatment planning [24]. Additionally, it delivers improved orthodontic outcomes, particularly when assessing the buccolingual inclination of the posterior teeth [24].

In this method[24], the buccolingual inclination of maxillary and mandibular molars and canines is reliably assessed aiding in the diagnosis of maxillary transverse deficiency even in the absence of crossbite (Figure 3).

If the buccolingual inclination of the maxillary teeth falls within normal limits (mean normal value ± 1 SD) and a crossbite is present, this indicates a skeletal transverse deficiency, requiring maxillary expansion for correction. Similarly, a maxillary transverse deficiency can be diagnosed in cases of increased maxillary teeth crown buccal inclination, decreased mandibular teeth crown buccal inclination, or a combination of both. Lastly, if there is a decreased maxillary molar inclination resulting in an edge-to-edge buccolingual relationship or a dental crossbite, archwire expansion or cross elastics are recommended, as the maxillary skeletal transverse dimension would be within normal limits.

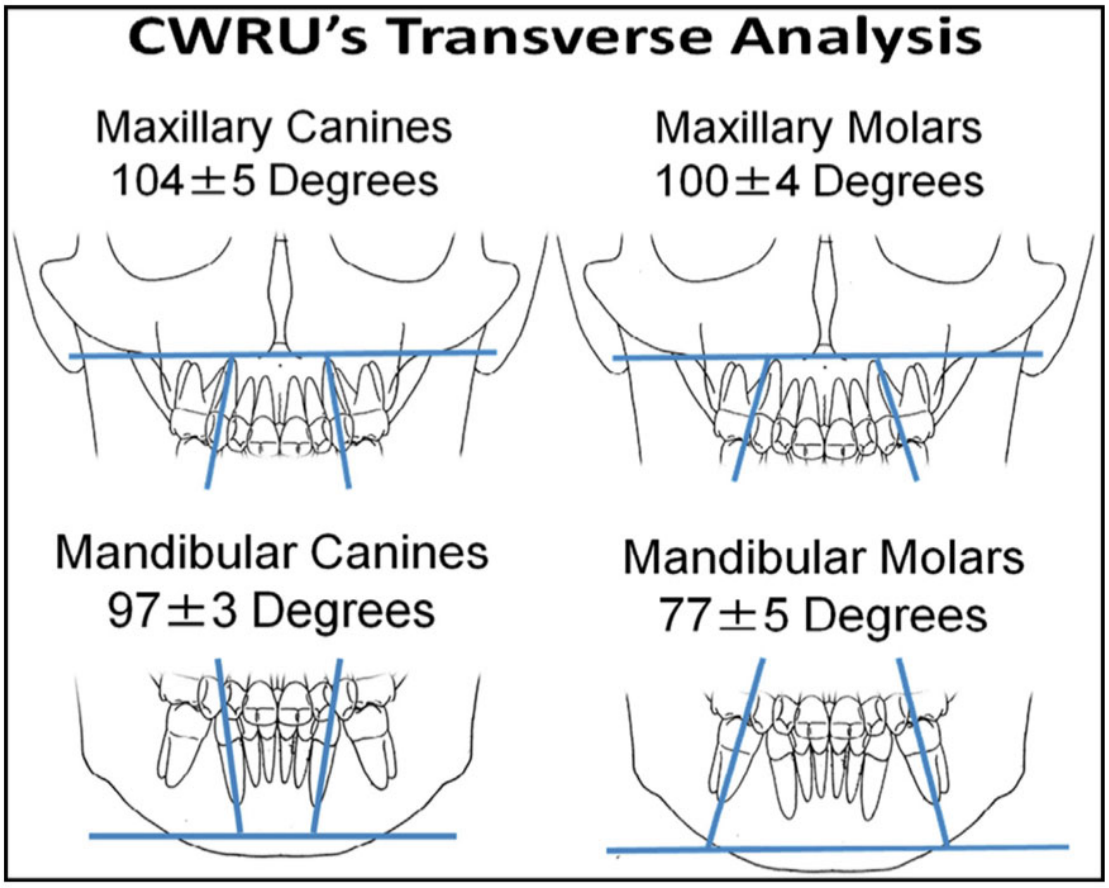


Figure 3. CWRU transverse analysis normal values (mean normal value ± SD)

3. Maxillary Expansion

3.1 Historical Development of Maxillary Expansion

Despite Codivilla[33] publishing about distraction osteogenesis for bone leghteneing in 1905 and Ilizarov popularizing this technique in the 1950s, Angell had already described maxillary expansion using a jackscrew appliance on a 14-year-old girl in 1860 in the Dental Cosmos journal [34]. They noticed sufficient opening of the midplatal suture after turning the expansion screw daily for 2 weeks. Although he noted the correction of maxillary width discrepancies, his findings were not widely accepted at the time due to the lack of radiographic evidence[14,34]. It was not until a century later, in 1961, that Haas introduced his maxillary expander, revolutionizing the treatment of transverse maxillary deficiencies[35]. He emphasized that rapid maxillary expansion was most effective during the growth spurt, particularly for deficiencies exceeding 5mm [14,35], while orthodontic approaches could camouflage smaller deficiencies[36].

3.2 Evolution of Maxillary Expansion approaches

Among the various appliances and protocols have been used to treat constricted maxillary arches, the rapid maxillary expansion performed using a tooth-anchored expander, such as the Hyrax expander, is one of the most used in children and early

adolescents [14,37]. A study that used dental models and radiographs that compared banded and bonded tooth-anchored expanders had shown that both can cause buccal tipping of posterior teeth, which is often asymmetric [14,38]. Additionally, tooth-anchored expanders may have limitations in achieving stable skeletal expansion and when used in late adolescent and adult patients they can result in undesirable tooth movements, root resorption, and tooth dehiscences and fenestrations [14,36,38] .

To overcome these limitations, surgically assisted rapid palatal expansion (SARPE [14,36] have been developed by combining the rapid palatal expansion with the surgical release of the structures that resist the expansion forces such as the midplatal and the circummaxillary sutures. More, recently a minimally invasive option using mini-implant supported rapid palatal expanders (MARPE) has been developed aiming to apply the expansion forces to the palatal bone and reduce the stress on the posterior teeth[39]. Finally, a combination of the previous two approaches led to the development of Distraction osteogenesis maxillary expansion (DOME) that combines a type of mini-implant supported rapid palatal expander (Maxillary Skeletal Expander) with the surgical releases of a surgically assisted rapid palatal expansion, with or without the separation of the pterygoid plates[39].

3.3 Rapid Palatal Expansion (RPE)

Rapid Palatal Expansion (RPE) is a widely used technique for treating maxillary transverse deficiencies in growing patients [14]. The RPE appliances are typically anchored

to the upper first permanent molars and premolars, and apply heavy intermittent, forces to the maxilla through an expansion screw [14]. These forces can separate the maxilla at the midpalatal suture, promoting skeletal expansion while minimizing tooth movement, despite some initial buccal tipping[14,40], by inducing undermining resorption in the anchor teeth. Forces typically range from 4 to 9 kilograms, with the screw transferring these forces to the cranial base through the maxillary bones[14,41]. The forces generated by RPE decrease over time, with 30–50% dissipating within 15 minutes and 50–70% within 24 hours while the remaining forces help in overcoming skeletal resistance, which affects the stability of the expansion [41].

As rapid palatal expansion causes the disjunction of the midplatal suture, the palatine bones and the pterygoid processes, also undergo separation[42]. Stress from expansion also impacts the circummaxillary structures [43], affecting mainly the anterior sutures, namely the intermaxillary, frontomaxillary, nasomaxillary, internasal, and frontonasal sutures [44].

Additionally, it causes increase in the nasal cavity width by about one-third of the screw's opening which is more pronounced near the anterior nasal spine [42]. This increase seems to have systemic benefits, such as the improvement in respiratory function and even child obstructive sleep apnea by reducing airway resistance, promoting normal breathing patterns, and increasing upper airway volume[27].

Rapid maxillary expansion is considered more effective in younger patients due to the decreased interdigitation of their sutures. Thus, more skeletal change is expected in patients from 6 to 8 years old than patients from 9 to 11 years old[19]. Therefore, it is recommended to complete rapid palatal expansion in a younger age before pubertal

growth spurt (prior to 13 to 15 years old [19]) , as the midpalatal suture becomes more interdigitated and ossified resulting in greater sutural resistance[19,45]. The physiologic process of maxillary expansion also involves alveolar bone bending with studies showing that this alveolar bone deflection accounts for almost 25% of the initial anchor teeth movement[14,46]. Interestingly, in a study that performed a finite-element analysis of stress distribution in the skull bones during expansion[47], adult cranial bases that have decreased bone elasticity, were found to be under increased stress and thus were more prone to microfractures close to the cranial foramina that contain vulnerable nervous and vascular structures[14,47]. Therefore, they recommended that they pterygomaxillary suture should be released bilaterally in all adults during surgically assisted rapid palatal expansion [47].

4. Mini-implant-Assisted Rapid Palatal Expansion (MARPE)

Mini implant-assisted rapid palatal expander (MARPE) is a transformative tooth-bone-borne or bone-borne expansion appliance designed to address maxillary transverse deficiency, especially in patients with limited growth potential. By utilizing mini-implants or temporary anchorage devices (TADs), MARPE applies mechanical forces directly to the midpalatal suture, significantly reducing stress on anchored teeth and mitigating adverse dentoalveolar effects. This innovation has enabled MARPE to surpass the efficacy of traditional tooth-borne rapid palatal expanders by achieving greater skeletal expansion with fewer complications [39,48,49].

4.1 Hybrid Hyrax and Maxillary Skeletal Expander

The concept of incorporating TADs into rapid palatal expanders (RPE) was first introduced by Wilmes et al. with the Hybrid Hyrax appliance, which used two mini-implants [50]. This was followed by Lee et al., who introduced a four-mini-implant modification, now recognized as MARPE [51]. These designs strategically place TADs in regions of optimal bone quality within the anterior palate, engaging them monocortically or bicortically to enhance stability and efficacy [19,39,52,53]. By anchoring forces directly to the palate, MARPE minimizes undesirable dental tipping and extrusion, achieving superior skeletal expansion and greater control of the vertical dimension compared to conventional RPE or surgically assisted rapid palatal expansion (SARPE) [54].

Among the various MARPE designs, the maxillary skeletal expander (MSE) is particularly notable. This device incorporates four TADs with a dead-soft connector to anchor the expander to the teeth[39]. Studies indicate that MSE achieves a skeletal-to-dental expansion ratio of 59:41 in nongrowing patients with an average age of 19.9 ± 4.4 years old and midpalatal suture maturation stages D and E [39,55,56]. In adolescents aging 13.8 ± 1.2 years old on average, bone-borne expanders like MSE have demonstrated significantly greater skeletal changes (68%) compared to traditional RPE (26%) [39,57].

Only the study of Villareal et al has compared the two appliances by performing two-dimensional measurements on pre-expansion and post-expansion CBCT images[14]. Both appliances were found to be effective achieving approximately 65% of skeletal

expansion which was noticeably parallel[14]. No intergroup differences were observed in alveolar bone bending, buccal bone thickness, palatal suture opening, maxillary and palatal width, and intermolar and interpremolar distance[14].

4.2 Timing and factors affecting success of Mini-implant-Assisted Rapid Palatal Expansion (MARPE)

Clinical research supports MARPE's effectiveness, especially in late adolescents and young adults between 16 and 26 years old, where success rates for midpalatal suture opening ranging between 84% and 88% [39,48,58–64]. However, success rates decline in older patients, particularly males over 25 years, due to advanced midpalatal suture maturation stages[39,64,65]. Factors influencing failure of correcting a transverse maxillary deficiency with a MARPE include palatal bone thickness of less than 2mm (that can reduce the primary stability of the TADs), older age over 30 years old, and advanced midpalatal suture maturation stage [39,66]. Additionally, interventions like corticopuncture were found to improve success in older patients with advanced stages of midpalatal suture maturation [39,66].

MARPE has also been proven to be effective in treating transverse deficiencies and Class III malocclusions. MARPEs can cause loosening the circumaxillary sutures and have a better vertical control due to the reduced buccal tipping of the anchor teeth compared to traditional RPEs[19]. Therefore, they have been used to support facemask protraction in skeletally mature patients[19,67].

4.4 Complications of MARPE

Despite its numerous advantages, mini-implant-assisted rapid palatal expansion is not without challenges. Common complications include inflammation, impingement on the palatal tissue, and mechanical failures such as bending of the jackscrew or breakage of the appliance[64]. Rare complications include tooth discoloration, temporary hearing loss, and sinus infections [64]. Furthermore, asymmetric expansion of the nasomaxillary complex is reported in about 30% of patients that were treated with a maxillary skeletal expander (MSE) due to irregular circummaxillary suture splits, especially the frontomaxillary suture[39,62].

4.5 Soft tissue changes after MARPE

Soft tissue changes associated with MARPE, such as lateral and forward movement of the cheeks and nasal alar curvature, are linked to skeletal modifications in the maxilla[39,68–71]. However, these changes are generally subtle and clinically negligible [39,70].

4.6 Upper Airway changes after MARPE

According to a recent systematic review and meta-analysis patient treated with MARPEs showed an average increase of 3646 mm^3 in nasal volume and 1021 mm^3 in nasopharyngeal volume after a retention period of 3 to 6 months.. However, no significant changes were noted in the volumes of the oropharynx, palatopharynx, glossopharynx, or hypopharynx after the retention period[15].

Another study [72] also showed that non-obese young adults who underwent treatment with the maxillary skeletal expansion (MSE) experienced significant improvements in daytime sleepiness and OSA-related quality of life, as measured by the Epworth Sleepiness Scale (EES) and the Quebec Sleep Questionnaire (QSQ) . Additionally, they demonstrated statistically significant enhancements in sleep test parameters, including a 65.3% reduction in the apnea/hypopnea index (AHI), improved mean oxygen saturation, reduced snoring duration, and a decrease in the bruxism-to-apnea index. Notably, about 35.7% of participants in the intervention group achieved an AHI below 5 by the end of the study. Therefore, they concluded that MSE when appropriately selected and implemented can be considered a supportive treatment option for obstructive sleep apnea in non-obese young adults with maxillary transverse deficiency [72].

Furthermore, Ngan et al. [73] examined the impact of the maxillary skeletal expansion (MSE) on airway dimensions using CBCT scans taken before and after treatment. The findings showed a significant 12% increase in nasal cavity volume, along with notable expansions in nasal width, including a 7.1% increase in the frontal dimension

and 9.4% and 3.4% increases in the anterior and posterior transverse dimensions, respectively. However, no significant changes were observed in the volumes of the nasopharynx or oropharynx. The study concluded that MARPE effectively enlarges the nasal cavity in a triangular pattern and can enhance nasal airway dimensions, offering potential benefits.

Hypothesis/Objectives:

The purpose of this study is to compare the transverse dental, skeletal, and nasal airway changes in patients treated with maxillary skeletal expanders (MSE) compared to patients treated with Hybrid Hyrax palatal expanders (HH) using Cone Beam Computer Tomography (CBCT) three-dimensional images, and a fully automated maxillary segmentation method.

Null Hypothesis: There is no difference in the three-dimensional dentoskeletal maxillary and nasal airway measurements between patients treated with the Maxillary Skeletal Expander and the Hybrid Hyrax.

Alternative Hypothesis: There are differences in the three-dimensional dentoskeletal maxillary and nasal airway measurements between patients treated with the Maxillary Skeletal Expander and the Hybrid Hyrax

Manuscript for publication

Three-dimensional Maxillary and Nasal Airway changes associated with Hybrid Hyrax and Maxillary Skeletal Expander (MSE)

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INTRODUCTION

Maxillary transverse deficiency (MTD) is considered one of the most frequent skeletal problems in orthodontics. This skeletal condition often manifests clinically with signs such as unilateral or bilateral posterior crossbites, dental crowding, tapered maxillary arch, high palatal vault, dark buccal corridors, and nasal airway constriction [12–15]. The prevalence of maxillary transverse deficiency has been shown to be approximately 9%. in the general population, increasing to nearly 10-30% among adult orthodontic patients[16,17]. Among children, the prevalence has been documented at 18% in those presenting with mixed dentition[3]. Addressing MTD is crucial, as if left untreated it can impact craniofacial growth, development, and overall health[15,74,75] and cause facial asymmetry, and compromised airway function[20].

The typical orthodontic treatment of patients with MTD includes rapid palatal expansion (RPE) of the maxilla by separating the midpalatal suture. RPE is effective in children and young adolescents while the midpalatal and the circumaxillary sutures are still pliable [35,39]. However, in late adolescents and adults the midpalatal and the circumaxillary sutures become more interdigitated, making skeletal expansion with RPE less likely and high risk for side effects, such as buccal tipping of the anchor teeth, root resorption, bone dehiscences and fenestrations [15,20,76–78]. Therefore, a mini-implant assisted rapid palatal expansion (MARPE) has been recently introduced [16,50] to achieve maxillary skeletal expansion in late adolescents and adults and to minimize the adverse

effects of rapid palatal expansion or the potential surgical complications and increased cost of surgically-assisted rapid palatal expansion (SARPE) [15,16,79,80].

Two of the most popular MARPE designs are the Maxillary Skeletal Expander (MSE) and the Hybrid Hyrax (HH) [16,50,52]. The HH uses temporary anchorage devices (TADs), in a form of two mini-implants, between the premolars combined with a Hyrax expander, while the MSE uses four TADs for enhanced skeletal support. Currently, only study has compared the two appliances by performing two-dimensional measurements on pre-expansion and post-expansion CBCT images[14]. Both appliances were found to achieve approximately 65% of skeletal expansion which was noticeably parallel[14]. No intergroup differences were observed in alveolar bone bending, buccal bone thickness, palatal suture opening, maxillary and palatal width, and intermolar and interpremolar distance[14].

The impact of MARPEs on the upper airway has gained significant attention, particularly for its potential in improving nasal breathing and improving conditions such as obstructive sleep apnea (OSA)[15,72,73]. Notably, a recent systematic review and meta-analysis investigated the effect of MARPE on the Upper Airway volume [15] including studies that used both types of appliances (MSE and HH). According to their meta-analysis, MARPE treatment led to an increase of the nasal airway volume by an average of 5804.9mm^3 and of the nasopharyngeal volume by an average of 1021.1mm^3 after a retention period of 3 to 6 months [15]. Apart from an oropharyngeal volume increase immediately after expansion, no other short-term or long-term differences were found in the volume of the oropharynx, the palatopharynx, the glossopharynx, and the hypophraynx [15]. Furthermore, another study[72] also showed that non-obese young adults

who underwent treatment with the MSE experienced significant improvements in their daytime sleepiness and OSA-related quality of life. Additional findings included a 65.3% reduction in the apnea/hypopnea index (AHI), improved mean oxygen saturation, reduced snoring duration, and a decrease in the bruxism-to-apnea index [72].

The purpose of this study is to compare the dental, skeletal, and nasal airway changes in patients treated with maxillary skeletal expanders (MSE) compared to patients treated with Hybrid Hyrax palatal expanders (HH) using Cone Beam Computer Tomography (CBCT) three-dimensional images, and an artificial intelligence assisted maxillary and teeth automatic segmentation software.

METHODS

1. Study Characteristics:

Patients who were treated with Hybrid Hyrax (n=17) or Maxillary Skeletal Expander (n=17) as part of the orthodontic treatment at the Case Western Reserve University (CWRU) orthodontic clinic were retrospectively selected for the comparison of their pre-expansion and post-expansion CBCT images.

The inclusion criteria were the following:

- Patients treated with HH or MSE at the CWRU Orthodontic Clinic
- Permanent dentition
- skeletal maturity of Cervical Vertebrae Maturation Index stage ≥ 3
- Maxillary Transverse Deficiency based on the CWRU Transverse analysis
- Successful opening of midpalatal suture

- Pre-expansion and post-expansion CBCT with diagnostic quality.

The exclusion criteria were the following:

- Periodontal disease
- Previous orthodontic treatment (Phase 1 or Phase 2)
- Congenital abnormalities

2. Appliances and Expansion Protocol:

The HH appliance (Thomas 2 TADs eyelet Hyrax, Dentaurum, Ispringen, Germany) includes a central jackscrew and two anterior eyelets positioned between the upper first and second premolars (Figure 4A). These eyelets, oriented perpendicular to the occlusal plane, guide the placement of the TADs. The TADs were usually 1.5–1.8 mm in diameter and 8 to 11 mm in length (Dentaurum). Additionally, the expander features two extension arms that connect to orthodontic bands on the upper first molars. These bands include 0.22 tubes, while the extension arms reach the first and second premolars, with an occlusal rest situated on the second premolars.

The MSE appliance (BioMaterials Korea, Inc, Hanam-si, Gyeonggi-do, Republic of Korea) consists of a central expansion jackscrew with four attached dead-soft arms that are soldered on maxillary first molar bands and may extend to the premolars to provide additional support (Figure 4B). The expansion screw has four welded tubes that serve as guides for the TADs placement. Therefore, depending on the screw placement, the TADs can be placed anywhere between the maxillary first premolars to the distal of the maxillary

first molars. The TADs are typically 9-13 mm long and they are inserted perpendicularly to the palatal bone to ensure biocritical engagement.

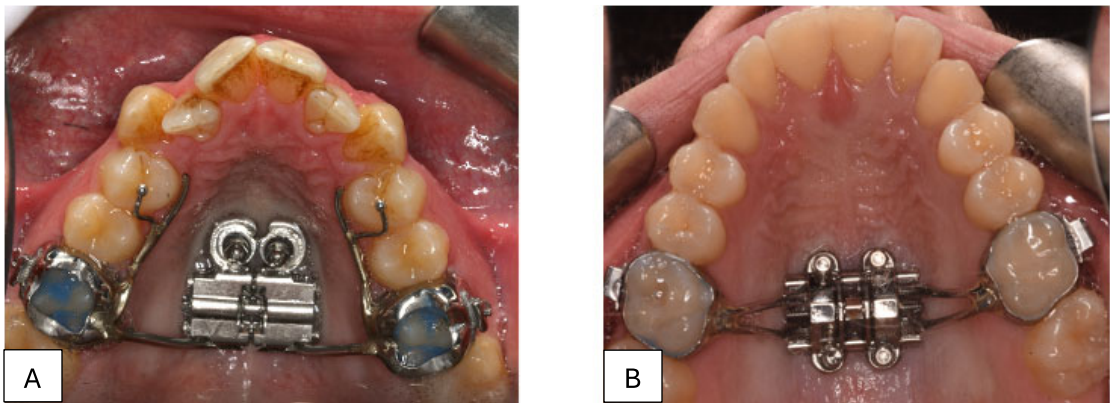


Figure 4. A. Hybrid Hyrax (HH) B. Maxillary Skeletal Expander (MSE

Treatment Protocol

After local anesthesia was administered, the HH was cemented using a light-curing glass ionomer. Then the two TADs were inserted in the anterior palate, using a contra-angle TAD driver with maximum insertion torque as guided by the anterior Thomas eyelets of the HH. The jackscrew was positioned at the anterior palate, aligned with the third rugae. The MSE protocol was similar but included the insertion of four TADs.

Rapid maxillary expansion was achieved by activating the screw four times daily, resulting in 0.8 mm daily expansion. Overexpansion (2–3 mm) was planned to account for potential relapse, with activation continuing until a diastema was visible or the posterior crossbite was corrected. The retention phase lasted 4–6 months. CBCT scans were obtained before expansion (T1) and after expansion (T2).

3. Data collection and analysis:

The i-CAT FLX (Imaging Sciences International LLC, PA, USA) was utilized to obtain CBCT images, with data extracted from pre-treatment (T1) and post-treatment (T2) DICOM files [14]. All scans were performed at the Oral Radiology Department of the CWRU School of Dental Medicine during routine records appointments, adhering to the ultra-low-dose orthodontic protocol. Scans were conducted using a 2 mA setting and the largest field of view (0.38 mm voxel size). The ultra-low-dose parameters included an exposure of 2 mA, power of 90 kVp, and a voxel size of 300 μm, with volume dimensions of 16 cm × 13 cm. All CBCT scans were acquired with the Frankfort plane aligned parallel to the floor [14].

All the selected T1 and T2 DICOM files from the CBCT were imported into the Dolphin 3D Imaging program (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, California, US) and were oriented in the three planes of space to standardize the 3D image analysis following the orientation method of Ngan et al. [81].

Initially, the total nasal airway (nasal airway and nasopharynx) along with the minimum constriction area were collected for all the T1 an T2 DICOM files following the reliable method of Tsolakis et al [82]. The nasal volume was defined as the volume of the nasal cavity and the pharynx located between the palatal plane and a parallel plane passing through the last axial slice before the nasal septum merges with the posterior pharyngeal wall[82].

Secondly, a three-dimensional superimposition of the T1 and T2 DICOM files was performed using the Dolphin three-dimensional voxel-based superimposition following

the reliable method proposed by Bazina et al [83]. Initially the T1 and T2 DICOM files were approximated using 3 landmarks (right and left frontozygomatic sutures and left mental foramen) and then they were superimposed on the cranial base.

Then, the T1 DICOM and the newly superimposed DICOM (T2 -registered DICOM) were exported and were imported into the RELU software (RELU BV, Leuven, Belgium) for Artificial Intelligence assisted maxillary and teeth segmentation. Afterward, the maxilla and the teeth (maxillary molars and canines) were separately segmented from each DICOM file. All the segmented files were exported in a stl format. Afterwards, the T1 and T2 segmented stl files were imported into 3D Slicer software (version 5.6.2) where the following landmarks (Figure 5) were identified for each image using the Q3DC add-on feature:

- OrR and OrL: lowest point in the inferior margin of the right and left orbits
- ZygR and ZygL: most inferior portion of the right and left zygomatic bones
- NCR and NCL: most lateral and external point of the right and left nasal cavity
- UR6AB and UL6AB: most palatal point of the Upper 1st molars alveolar bone
- UR3AB and UL3AB: most palatal point of The Upper canines alveolar bone
- Mesiobuccal cusp tips of Upper 1st molars
- Cusp tips of Upper canines
- Apexes of Upper 1st molars and canines
- ANS: anterior nasal spine
- PNS: posterior nasal spine
- Point A: midline point of the deepest concavity anteriorly on the maxillary alveolus

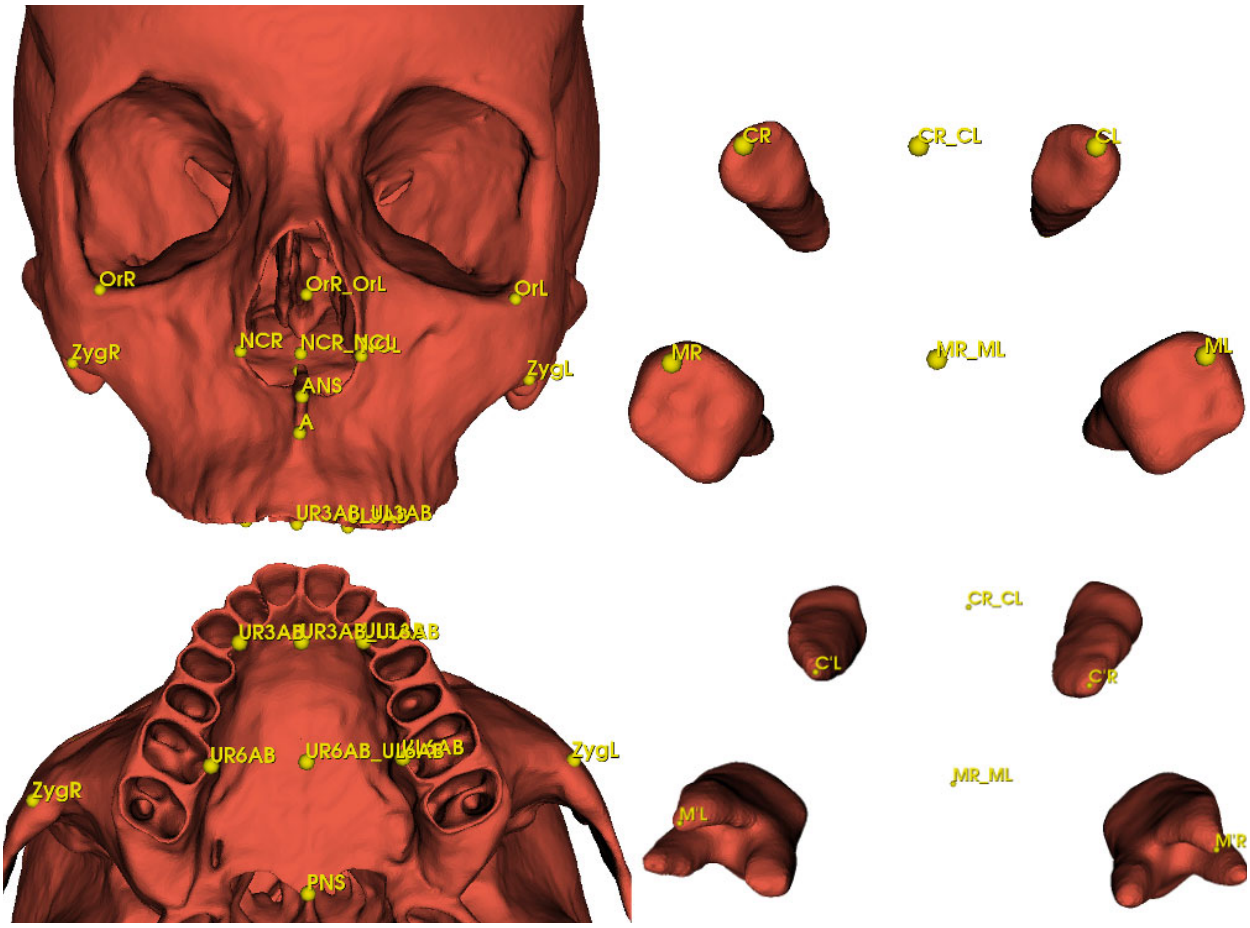


Figure 5. Landmarks Identified on a DICOM file using 3D Slicer (Q3DC add-on)

4. Outcomes:

The following outcomes were calculated and compared using the Q3DC add-on of 3D Slicer:

A. Maxillary transverse displacements (Distance between right & left):

- Orbitale
- Nasal Cavity point
- Zygomatic point
- Upper 1st Molar points and Upper 1st Molar alveolar bone points

- Upper Canine points and Upper Canine alveolar bone points

B. Maxillary Anteroposterior & Vertical displacements (midpoints of right & left):

- Orbitale (Or_R-Or_L)
- Nasal Cavity point (NC_R-NC_L)
- Zygomatic point (Zyg_R-Zyg_L)
- Molar point (M_R-M_L)
- Canine point (C_R-C_L)
- A point
- Upper 1st Molar points and Upper 1st Molar alveolar bone points
- Upper Canine points and Upper Canine alveolar bone points

C. Maxillary angular measurements:

- Vertical Maxillary Rotation (Pitch changes in the ANS-PNS line)
- Lateral Maxillary Rotation (OrR- ZygR–OrL-ZygL)
- Upper 1st Molar and Upper Canines buccolingual inclination

D. Nasal airway measurements:

- Total nasal volume
- Minimum Constriction area

The midpoints between the right and left points of bilateral structures were marked to assess the maxillary and teeth vertical and anteroposterior displacements. Finally, all

measurements were repeated for 10 patients treated with each appliance (MSE and HH) by the same operator and another operator 2 weeks after the first measurements cases treated to test for inter-operator and intra-operator reliability.

5. Ethics

The study received approval from the Institutional Review Board (IRB) at Case Western Reserve University (Appendix A). Prior to treatment, patients or their legal guardians provided consent by signing the American Association of Orthodontists Informed Consent form, which included a section permitting the use of their records for research purposes.

6. Statistics

The sample size calculation estimated a minimum of 15 patients per group considering a significance level of 5% and a statistical power of 80%, a minimum clinical difference of 1.5mm for lateral displacement of the nasal cavity and a pooled SD of 1.4mm[84,85].

Statistical analyses were conducted in R statistical software (version 4.3.1, R Development Core Team; University of Auckland, New Zealand).

Shapiro-Wilk test was used to test normality of data distribution. Dependent t-tests was used for intra-group comparisons, and independent t-tests for inter-group comparisons,

provided the data were normally distributed. If the data were not normally distributed in at least one of the compared groups of each comparison, the equivalent non-parametric tests—Wilcoxon Signed-Rank test for intra-group comparisons and Wilcoxon-Mann-Whitney test for inter-group comparisons—were applied. All statistical tests were evaluated at a significance level of 0.05. Multivariate linear regression was used to explore predictive value of type of RME appliance in changes in nasal volume and maximal constriction when controlling for the effect of age and sex.

RESULTS

1. Baseline Characteristics

The baseline characteristics are summarized in Table 1 along with the statistical tests that were used based on the normality of the data distribution in the compared groups. Each group had 17 patients with an average age (±SD) of 19 (±5) years old for the MSE group and 18 (±5) years old for the HH group and a range from 13 to 33 years old for both groups. All patients had a maxillary transverse deficiency as verified by the CWRU transverse analysis[24], while a crossbite was present in 13 MSE patients and 11 HH patients. No differences were found in all variables except, for the average transverse Orbitale and Zygomatic distances which was found to be 3.3mm greater in the HH group.

Table 1. Baseline characteristics of the patients							
Group	**MSE (N=17)**		**HH (N=17)**		**p-value**	**significance**	**Stat. test**
	Mean	**SD**	**Mean**	**SD**			
Age (years)	19	5	18	5	0.6	ns	t-test
CVM	5	1	5	1	0.1	ns	Mann-Whitney-U
Gender (M,F)	2M, 15F		7M, 10F		0.6	ns	Fisher's exact test
T1 OrR – OrL (mm)	**78.6**	**4.3**	**81.9**	**4.6**	**0.036**	*	**t-test**
T1 ZygR – ZygL (mm)	**82.8**	**4.2**	**86.1**	**6.3**	**0.049**	*	**Mann-Whitney-U**
T1 NCR – NCL (mm)	22.1	2	22.6	1.4	0.48	ns	t-test
T1 UR6AB - UL6AB (mm)	32	3.1	28.3	7.9	0.07	ns	Mann-Whitney-U
T1 UR3AB - UL3AB (mm)	22.4	2.7	21.3	2.8	0.26	ns	t-test
T1 MR-ML (mm)	48.7	4.4	44.8	11.9	0.46	ns	Mann-Whitney-U
T1 CR-CL (mm)	32.6	5.5	31.1	6.1	0.9	ns	Mann-Whitney-U
T1 ROLL (deg.)	19.1	11.5	17.8	14.49	0.77	ns	t-test
T1 Nasal Volume (mm^3)	15658.2	5672.4	13370.6	6567.6	0.1	ns	Mann-Whitney-U
T1 Nasal MCA (mm^2)	61.2	33.2	50.7	25.7	0.3	ns	t-test

2. Changes after Expansion

A. HH

The changes that occurred in the HH are summarized in Table 2 along with the statistical tests that were used based on the normality of the data distribution in each variable in T1 and T2. Differences were found in all variables except for the transverse Orbitale distance and the lateral maxillary rotation. The rest post-expansion transverse and airway measurements were all greater as follow (mean difference ± SD): Zygomatic point: 2 ± 6.5mm, Nasal Cavity point: 2.3 ± 2.2mm, U6s Alveolar Bone Width: 5.4 ± 8.7mm, Intermolar Width: 7 ± 13mm, U3s Alveolar Bone Width: 3.6 ± 3mm, Intercanine width: 2.8 ± 6.1mm, Nasal Airway Volume: 3849.5 ± 5889.4mm^3, Nasal MCA: 19.9 ± 30.9 mm^2.

Table 2. HH: Pre-expansion and Post-expansion Maxillary Transverse Displacements

HH	T1 Mean	T1 SD	T2 Mean	T2 SD	Mean Difference	SD	P-Value	Statistical Significance	Interpretation	Test Used
Orbitale (OrR-OrL)	81.9	4.6	82.3	4.8	0.3	4.7	0.2	ns	T2 > T1	Dependent t-test
Zygomatic point (Zyg_R-Zyg_L)	86.1	6.3	88.2	6.6	**2**	6.5	0.002	*	T2 > T1	Wilcoxon Signed Rank
Nasal Cavity point (NC_R-NC_L)	22.6	1.4	24.9	2.4	**2.3**	2	0.001	*	T2 > T1	Dependent t-test
Upper 1st molar alveolar bone intermolar width (UR6AB-UL6AB)	28.3	7.9	33.8	9.4	**5.4**	8.7	<0.001	**	T2 > T1	Wilcoxon Signed Rank
Upper canine alveolar bone intercanine width (UR3AB-UL3AB)	21.3	2.8	25	3.3	**3.6**	3	<0.001	**	T2 > T1	Dependent t-test
Molar point (M_R-M_L)	44.8	11.9	51.8	14	**7**	13	<0.001	**	T2 > T1	Wilcoxon Signed Rank
Canine tip point (C_R-C_L)	31.1	6.1	33.9	6.1	**2.8**	6.1	<0.001	**	T2 > T1	Wilcoxon Signed Rank
Lateral Maxillary Rotation (OrR- ZygR–OrL-ZygL)	17.8	14.4	20.8	13.6	3	14	0.053	ns	T2 > T1	Dependent t-test
Nasal airway Volume	13370.6	6567.6	17220.1	8944.6	**3849.5**	5889.4	0.01	*	T2 > T1	Wilcoxon Signed Rank
Nasal minimum constriction area	50.7	25.7	70.6	46.7	**19.9**	30.9	0.01	*	T2 > T1	Dependent t-test

B. MSE

The changes that occurred in the MSE are summarized in Table 3 . Differences were found in all variables except for the lateral maxillary rotation. The rest post-expansion transverse and airway measurements were all greater as follow (mean difference ± SD): Orbitale: 0.91 ± 4.1mm, Zygomatic point: 3.7 ± 2.4mm, Nasal Cavity point: 2.7 ± 2.2mm, U6s Alveolar Bone Width: 5.1 ± 3.9mm, Intermolar Width: 6.1 ± 4.8mm, U3s Alveolar Bone Width: 3.4 ± 3mm, Intercanine width: 3.3 ± 5.8mm. Nasal Airway Volume: 4180.6 ± 5044.6mm^3, Nasal MCA: 35 ± 34.8 mm$^{2.}$.

Table 3. MSE: Pre-expansion and Post-expansion Maxillary Transverse Displacements

MSE	T1 Mean	T1 SD	T2 Mean	T2 SD	Mean Difference	SD	P-Value	Significance	Interpretation	Test
Orbitale (OrR-OrL)	78.6	4.3	79.5	3.9	**0.91**	4.1	0.018	*	T2 > T1	Dependent t-test
Zygomatic point (Zyg_R-Zyg_L)	82.8	4.2	85.3	3.7	**2.4**	4	0.046	*	T2 > T1	Dependent t-test
Nasal Cavity point (NC_R-NC_L)	22.1	2	24.8	2.4	**2.7**	2.2	<0.001	**	T2 > T1	Dependent t-test
Upper 1st molar alveolar bone intermolar width (UR6AB-UL6AB)	32	3.1	37.1	4.5	**5.1**	3.9	<0.001	**	T2 > T1	Dependent t-test
Upper canine alveolar bone intercanine width (UR3AB-UL3AB)	22.4	2.7	25.8	3.3	**3.4**	3	<0.001	**	T2 > T1	Dependent t-test
Molar point (M_R-M_L)	48.7	4.4	54.8	5.3	**6.1**	4.8	<0.001	**	T2 > T1	Dependent t-test
Canine tip point (C_R-C_L)	32.6	5.5	36	6.1	**3.3**	5.8	0.003	*	T2 > T1	Wilcoxon Signed Rank
Lateral Maxillary Rotation (OrR- ZygR–OrL-ZygL)	19.1	11.5	21.7	16.4	2.6	14.2	0.408	ns	T2 =T1	Dependent t-test
Nasal airway Volume	15658.2	5672.4	19838.9	7199.7	**4180.6**	5044.6	0.003	*	T2 > T1	Dependent t-test
Nasal minimum constriction area	61.2	33.2	96.2	42.6	**35**	34.8	<0.001	**	T2 > T1	Wilcoxon Signed Rank

3. Differences in changes between MSE and HH

The differences between the changes in the MSE and HH groups are summarized in Table 4. Independent t-test were used if the data in both groups were normally distributed, while Mann-Whitney-U tests was used if at least one was not. Statistical tests that were used based on the normality of the data distribution in each variable in T1 and T2. When comparing changes caused by the MSE with the ones caused by HH there were no significant differences in:

- transverse changes
- anteroposterior changes
- vertical changes
- Nasal airway (total nasal volume and minimum constriction area)

Additionally, the multivariate linear regression analysis did not detect significant models, pointing that changes in nasal volume and maximal constriction were not related to type of appliance, age nor sex.

Table 4. Difference in the changes caused by the MSE and HH

Group	MSE (N=17)		HH (N=17)						
	Mean	SD	Mean	SD	Mean Difference	Pooled SD	p-value	Significance	Stat. Test
DOr (mm)	0.9	1.4	0.3	1.1	0.5	1.3	0.23	ns	t-test
Dzyg (mm)	2.4	4.6	2	2.5	0.4	3.7	0.75	ns	t-test
DNc (mm)	2.7	1.9	2.3	2.2	0.3	2.09	0.37	ns	Mann-Whitney U
DU6AB (mm)	5.1	2.7	5.4	2.9	-0.3	2.8	0.74	ns	t-test
DU3AB (mm)	3.4	2.4	3.6	2.4	-0.2	2.4	0.97	ns	Mann-Whitney U
DMR-ML (mm)	6.1	3.1	7	3.8	-0.8	3.5	0.47	ns	t-test
DCR-CL (mm)	3.3	6.4	2.8	2.7	0.5	4.9	0.25	ns	Mann-Whitney U
AP Orm (mm)	0.5	0.8	0.6	0.8	-0.1	0.8	0.69	ns	t-test
APZYGm (mm)	0.6	1.3	0.2	1.3	0.4	1.3	0.33	ns	t-test
APNCm (mm)	0.2	0.9	-0.05	1.02	0.3	0.9	0.36	ns	t-test
APMOLARm (mm)	0.5	0.7	0.4	1.6	0.1	1.2	0.79	ns	t-test
APCANINEm (mm)	0.5	0.9	0.7	1.6	-0.1	1.3	0.68	ns	t-test
AAP (mm)	0.4	1.2	0.4	1.3	-0.02	1.2	0.89	ns	Mann-Whitney U
APMR-ML (mm)	1	1.4	1.4	1.8	-0.3	1.6	0.16	ns	Mann-Whitney U
APCR-CL (mm)	0.9	1.9	0.7	1.7	0.2	1.8	0.89	ns	Mann-Whitney U
VORm (mm)	-0.03	0.6	-0.2	0.7	0.1	0.7	0.49	ns	t-test
VZYGm (mm)	0.06	0.8	0.06	0.7	-0.001	0.8	0.73	ns	Mann-Whitney U
VNCm (mm)	-0.5	1	-1.2	1.4	0.7	1.2	0.1	ns	t-test
VMOLARm (mm)	-0.7	1.1	-0.6	1.3	-0.04	1.2	0.85	ns	Mann-Whitney U
VCANINEm (mm)	-1.1	1.7	-0.7	0.9	-0.4	1.3	0.38	ns	t-test
AV (mm)	-0.8	1.2	-1.4	1.9	0.6	1.6	0.44	ns	Mann-Whitney U
VMR-ML (mm)	-0.1	1.2	-0.6	1.01	0.5	1.1	0.17	ns	t-test
VCR-CL (mm)	-1.7	2.5	-0.8	0.7	-0.8	1.8	0.78	ns	Mann-Whitney U
DROLL (deg.)	2.6	12.8	3.02	5.9	-0.3	10.004	0.6	ns	Mann-Whitney U
DMR-M'R (deg.)	3.6	2.9	6.3	4.9	-2.7	4.06	0.1	ns	Mann-Whitney U
DCR-C'R (deg.)	2.8	2.7	1.9	1.4	0.9	2.2	0.24	ns	t-test
DML-M'L (deg.)	4.2	3.5	4.6	4.5	-0.4	4.07	0.97	ns	Mann-Whitney U
DCL-C'L (deg.)	3.1	2.5	2.6	1.4	0.5	2.06	0.45	ns	t-test
DNV (mm^3)	2793.2	6270.6	3375.5	6288.5	-582.3	6279.6	0.78	ns	Mann-Whitney U
DMCA (mm^3)	25	40.7	20	30.8	5	36.1	0.69	ns	t-test

4. Reliability of the measurements

Excellent intra-operator and inter-operator reliability (> 0.8) was found for all variables using the intra-class correlation coefficient.

The Intra-operator ICC was:

- OrR – OrL: 0.83
- ZygR – ZygL: 0.99
- NCR – NCL: 0.99
- UR6AB - UL6AB: 0.99
- UR3AB - UL3AB: 0.99
- MR-ML: 0.99
- CR-CL: 0.99
- Nasal Volume: 0.99
- Nasal Airway MCA: 0.99

and the Inter-operator ICC was:

- OrR – OrL: 0.88
- ZygR – ZygL: 0.99
- NCR – NCL: 0.97
- UR6AB - UL6AB: 0.99
- UR3AB - UL3AB: 0.99
- MR-ML: 0.99
- CR-CL: 0.98

- Nasal Volume: 0.97
- Nasal Airway MCA: 0.99

DISCUSSION

1. Summary of Evidence

Our study did not find any difference in the transverse, anteroposterior, and vertical dentoskeletal post-expansion changes in patients treated with the MSE or Hybrid Hyrax appliances. Additionally, there were no nasal airway post-expansion changes between the two appliances .

Finding no difference between the appliances, however, does not imply that the appliances were not effective. Both appliances caused significant changes in all variables assessed. In particular, both appliances caused an increase in intermolar width by about 6 - 7 mm on average, an increase of about 5 mm in the respective alveolar bone, and minor buccal tipping of about 2 - 6 degrees with less than 1mm in vertical movement , inidicating a great amount of skeletal expansion, minor advesre dental effects, and significant vertical control. The same trend was observed in the maxillary canines with an average increase of 3mm in the Intercanine width and the respective alveolar bone. Furthermore, the Interzygomatic and the Internasal distances were increased by 2mm on average in both groups, indicating that both type of MARPEs cause similar increase in the nasal cavity and a lateral displacement of the maxillary zygomatic process and the zygomatic bone.

Additionally, there were no changes in the lateral rotation of the two parts of the nasomaxillary complex as they were separated. This angle is formed between the two lines that connect the right Zygomatic point with the right Orbitale and the left Zygomatic point with the left Orbitale. When combined with the clinically insignificant increase of less than 1 mm in the interorbital distance, this finding suggests that both appliances displaced the two nasomaxillary parts in a more parallel manner.

Furthermore, both appliances, despite showing high variability, causes a significant increase in the nasal airway volume by approximately 4000 mm^3 and the nasal minimum constriction area by roughly 20 to 35 mm^2.

Regarding the anteroposterior and the vertical changes, no difference was observed between the two appliances. However, there was a trend toward a forward and downward displacement of point A by roughly 0.5-1mm, and a mesial movement of the upper molars by nearly 1 mm.

2. Strengths and Limitations of the study

To our knowledge, this is the first study to perform a three-dimensional comparison and nasal airway comparison of two of the most frequently used MARPEs. CBCT is a significant advancement over traditional two-dimensional radiography, allowing more precise superimpositions since the superimposition is performed in way more than 20 landmarks that are traditionally used in lateral cephalometric x-rays[83,86]. Additionally, we were able to show the main effects of successful expansion with two or four TADs in a more mature population that consisted mainly late adolescents and adults. Finally, our

study focused on both skeletal and nasal airway outcomes, in our attempt to provide more information about not only the traditional orthodontic effects but also about the systemic benefits of mini-implant assisted rapid palatal expansion.

This study is limited by its retrospective data collection, which introduces the potential for selection bias as the sample may not accurately represent the wider population requiring maxillary expansion . To minimize this, we used strict inclusion criteria like the more objective criteria of the CWRU transverse analysis and the inclusion of mainly post pubertal patients that shared similar baseline characteristics. However, the absence of subjective assessments, such as patient-reported breathing improvements or quality of life changes questionnaires, limits the understanding of functional outcomes. Additionally, the follow-up period was relatively short, restricting the evaluation of long-term stability. Addressing these limitations in future prospective studies with randomized controlled trials protocol, extended observation and subjective feedback would enhance the robustness of the findings.

3. Critical Appraisal of the results in the contexts of other evidence

The findings from this study align with existing evidence regarding the efficacy of maxillary skeletal expanders (MSE) and Hybrid Hyrax (HH) in achieving significant skeletal, dental, and airway changes. Both appliances effectively increased intermolar and Intercanine widths, with average gains of 6–7 mm and 3 mm, respectively. Additionally, these changes were accompanied by alveolar bone expansion of

approximately 5 mm. Despite some minor buccal tipping (2–6 degrees) and vertical displacement of less than 1 mm, these outcomes highlight both appliances' ability to achieve substantial skeletal expansion while maintaining vertical control and minimizing adverse dental effects. Similar findings have been documented in studies emphasizing the controlled nature of MARPE expansion [67,87].

Both appliances also demonstrated comparable effects on nasal structures, with increases of approximately 2 mm in interzygomatic and internasal distances. These findings suggest that MSE and HH contribute to lateral displacement of the zygomatic bone and maxillary processes, which facilitates nasal cavity widening. These results are consistent with prior evidence showing MARPE's ability to improve nasal airflow through the lateral expansion of the nasal cavity walls [15]. Furthermore, the lateral and forward movement of the cheeks and nasal alar curvature might be linked with some of the skeletal changes that we found in our study [39,68–71].

Similarly, to our study, McMullen et al. that assessed the 3D maxillary post-expansion changes produced by MSE in growing and non-growing patients showed that the Interzygomatic and internasal distances increased by an average of 2.8-3.5 mm and 1.9-3.6 mm, respectively and that he intermolar and intercanine widths increased by an average of 3.6-5.8mm and 2.7-3.6mm, respectively. Finally, minor angular movements ranging from 1.2° to 4° were observed in the U6s and U3s, demonstrating similar effective control of the vertical dimension during expansion. Additionally, Bazzani et al. (84) is showed that a tooth-bone-borne MARPE showed an interzygomatic and internasal distance increased by an average of 2.8 mm and 2.3 mm, respectively and an intermolar and intercanine width increase by an average of 4.4 mm and 2.8 mm, respectively.

Moreover, Minor angular movements ranging from 1.4° to 3.5° were observed in the U6s and U3s, demonstrating effective control of the vertical dimension during expansion.

Finally, our study revealed significant increases in nasal airway volume of about 4000 mm^3 and in minimum constriction area of about 20–35 mm^2, consistent with other studies that demonstrated the potential of MARPEs to enhance respiratory function [15,72,81]

4. Clinical Implications and Future Research

Both MSE and HH appliances were effective in correcting transverse skeletal deficiencies, giving clinicians options to choose the best device based on the patient's anatomy, cost considerations, and treatment complexity. HH might be preferred in case of a very narrow palate with high palatal vault since the TADs could be place more anteriorly in the maxilla where there is better access and more space. Conversely, having four TADs instead of two TADs ensures the adequate amount of anchorage in case of a TAD failure. Moreover, the improvements in nasal airway dimensions suggest that maxillary expansion with both appliances could help in the management of breathing issues, such as nasal obstruction and OSA [15,72,81].

However, the study has some limitations. Its retrospective data collection and its short follow up time mean that the results may not apply to all patients. Larger, prospective studies with randomized controlled trial protocols and longer follow-up periods are needed to confirm the long-term stability of our findings. Additionally, using questionnaires like Epworth Sleepiness Scale (EES) Adding to assess the subjective feedback about

breathing improvements would also help understand the broader benefits of maxillary expansion.

CONCLUSION

- MSE and HH are both equally effective in treating a maxillary transverse deficiency and increasing the intermolar and Intercanine widths. Both achieved mainly a skeletal expansion, with minor buccal tipping (2-6^{o}) and great vertical control (<1mm) of the anchor teeth.
- MSE and HH showed no difference in transverse, AP, vertical, and nasal airway post-expansion changes.
- MSE and HH seem to increase the nasal airway volume by approximately 4000 mm^3 and the nasal minimum constriction area by roughly 20 to 35 mm^2.
- MSE and HH seem to increase the Internasal and Interzygomatic distance by approximately 2mm.

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APPENDIX A

IRB Administration Offices
UH IRB Phone: 216.844.1529
CWRU IRB Phone: 216.368.6925

INITIAL APPROVAL

Principal Investigator:	Tarek ElShebiny
Title:	3D Assessment of transverse dental and skeletal changes associated with Hybrid Hyrax appliance and maxillary skeletal expander appliance, a retrospective study
Submission Number:	STUDY20221582
IRB Office:	CWRU IRB
Approval Date:	5/18/2023
Effective Date:	5/18/2023
Approval End Date	N/A
Type of Submission:	Initial Study
Type of Review:	Expedited
Documents Reviewed:	• HRP-600 - TEMPLATE - HIPAA Request for Waiver Form 12.2022.pdf, Category: IRB Protocol; • Informed Consent English2 - DIGITAL-3pg-fill-sec 5 19 20.pdf, Category: Consent Form; • Informed Consent English2 - DIGITAL-3pg-fill-sec 5 19 20.pdf, Category: IRB Protocol; • CWRU Chart Review Specimens Protocol 01.2022 for IRB clarif.pdf, Category: IRB Protocol; • IRB Villareal, Category: IRB Protocol;

The IRB has reviewed this submission.

- Per Federal regulation, changes MAY NOT be made to any element of the current research without prior IRB approval, except to eliminate an immediate and apparent hazard to subjects enrolled in the study.
- Per Federal regulation, the research may not continue beyond the Approval End date. You must submit a continuing review form 6-8 weeks before this Approval End date in order to maintain IRB approval. Failure to maintain IRB approval is human subjects non-compliance. Please note that even if your study falls into a category that does not require an Approval End date, the institution may require a yearly "check-in" to confirm the status of the study.

The UH IRB operates under HHS Federalwide Assurance (FWA) number 00003937 and IRB registration numbers 00000684, 00001691 and 00008600. The CWRU IRB operates under DHHS FWA00004428 and IRB registration number 00000683.

***Approval by the IRB does NOT mean that you have permission to start your study. Prior to starting your study, you may be required to obtain (1) a coverage analysis for studies that involve patient care, regardless of source of funding, and/or (2) a contract with the Sponsor of your study or an agreement with any third-party collaborator that may receive UH or CWRU patient information in any format. Please ensure that all required approvals are obtained before initiation of research activity. ***

The UH IRB operates under HHS Federalwide Assurance (FWA) number 00003937 and IRB registration numbers 00000684, 00001691 and 00008600. The CWRU IRB operates under DHHS FWA00004428 and IRB registration number 00000683.