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Review Article

Dentistry Section

Microimplant Assisted Rapid Palatal Expansion: A Comprehensive Review

TAMANNA HOQUE[1], DILIP SRINIVASAN[2], SANGEETHA MOREKONDA GNANESWAR[3], SUSHIL CHAKRAVARTHI[4], KRISHNARAJ RAJARAM[5]

ABSTRACT

Maxillary transverse deficiency routinely requires expansion of the palate. In prepubertal patients, Rapid Maxillary Expansion (RME) is a reliable treatment modality. However, in skeletally mature patients due to progressively interdigitated mid palatal suture, decreased elasticity of bone and increased stiffness of the osseous articulations of the maxilla with the adjoining bones, palatal expansion becomes challenging. Patients are frequently suggested to opt for more invasive procedures, like the Surgically Assisted Rapid Palatal Expansion (SARPE). The quest for minimally invasive expansion appliances with pure orthopaedic movement led researchers to incorporate mini-implants with conventional RME. Microimplant Assisted Rapid Palatal Expansion (MARPE) maximises skeletal expansion and minimises dentoalveolar undesirable effects and obviates the need for orthognathic surgery. This comprehensive review aims to discuss MARPE as an effective, non surgical, minimally invasive treatment modality for skeletally mature patients with maxillary transverse insufficiency. Furthermore, various designs of MARPE with different placement sites, lengths, and numbers of miniscrews along with the latest technological advancements to improve diagnosis and treatment planning using CBCT and intraoral scan, as well as the use of Computer-Aided Design/Computer-Aided Manufacturing (CAD-CAM) technology to custom fabricate three dimensional (3D) miniscrew insertion surgical guide, 3D laser-printed metallic mini-implant to enhance implant placement accuracy and comfort were discussed along with the clinical significance and limitations of the MARPE. Maxillary Skeletal Expander (MSE) is a unique lineage of MARPE when combined with facemask results in distraction osteogenesis like movement of midface and forms a promising basis for non surgical orthopaedic treatment modality for skeletal class III mature patients. Bone-anchored maxillary expansion appliances provide better vertical control, especially beneficial for hyperdivergent skeletal pattern patients. MARPE significantly increases transverse widths of the nasal floor, nasopharyngeal volume and significantly lowers mean nasal airway resistance thereby facilitating nasal breathing. MARPE results in greater orthopaedic expansion and safety, with fewer undesirable effects and high success rates.

Keywords: Bone-anchored maxillary expansion, Hybrid hyrax, Maxillary skeletal expander, Maxillary transverse deficiency, Mini-implant

INTRODUCTION

Maxillary transverse deficiency is one of the most pervasive problems in the craniofacial region prevalent in all age groups, from deciduous to permanent dentition. It has been reported that almost 30% of adult orthodontic patients and 9.4% of the entire population have a maxillary transverse deficiency [1-3]. However, a previous study reported that the prevalence of maxillary transverse deficiency ranges from 8% to 23% in mixed and deciduous dentitions and less than 10% in adults [4]. Maxillary transverse deficiency has multifactorial aetiology and some of the most prevalent factors are narrow palatal dimensions, inheritance, ectopic eruption, impaired maxillary transverse growth associated with a palatal cleft and breathing disorders and soft tissue imbalance like prolonged digit sucking, lower tongue position [5,6]. When the maxilla and mandible fail to properly orient in the transverse dimension, odontogenesis continues its process and teeth erupt in abnormal positions leading to malocclusion [7,8].

If maxillomandibular transverse discrepancies are not treated in an appropriate time, they can aggravate and metamorphose into more complex malocclusion, hindering facial growth and development [9]. Maxillary transverse deficiency impacts the occlusion not only in the transverse plane but also in the vertical and sagittal planes leading to intricate situations, such as posterior unilateral or bilateral crossbites, crowding, scissor bite, non carious cervical wear, adverse periodontal stress, low masticatory ability, functional shift of the mandible, faulty buccolingual tipping of posterior teeth, asymmetric mandibular position in growing patients, joint disorders and muscle function disharmony [6,10]. However, the grave consequence of maxillary transverse deficiency is the narrowing of the nasal cavity, which increases nasal air resistance and might become an aetiologic factor of Obstructive Sleep Apnea Syndrome (OSAS) [9-11]. In class III malocclusions nearly half of the patients have maxillary skeletal retrusion, which contributes to transverse discrepancies between the maxilla and mandible [12]. Dental crowding and posterior crossbite are two easily recognisable clinical features of transverse deficiency, while exaggerated buccal flaring of the maxillary dentition and deep curve of Wilson in the lower dentition can mask the maxillary transverse constriction [10].

The RME has been used for more than a century to correct transverse maxillary deficiencies and the earliest commonly cited report was that of EC Angell published in Dental Cosmos in 1860 [13]. In prepubertal patients, RME is a reliable treatment modality [1]. The RME produces less predictable results in patients after 11 years of age due to high variability seen in the developmental stages of fusion of midpalatal suture [14]. In skeletally mature patients due to the complexity of interdigitation of midpalatal suture and decreased elasticity of bone, changes in the osseous articulations of the maxilla with the adjoining bones expansion becomes challenging [6]. RME can produce undesirable effects, including buccal tipping of posterior teeth, root resorption, alveolar bone bending, fenestration of the buccal cortex, inability to open the midpalatal suture, pain and relapse [6]. The SARPE is often suggested to correct transverse maxillary deficiencies of greater than 5 mm due to its ability to overcome the sutural resistance thereby increasing the expansion possibilities with long term stability and reduced buccal dental tipping [2,14,15]. But the procedure is invasive, expensive, associated with asymmetric or incorrect maxillary expansion, surgical morbidity, incisor discolouration, mobility, periodontal complications, and even the loss of central incisors [9,15].

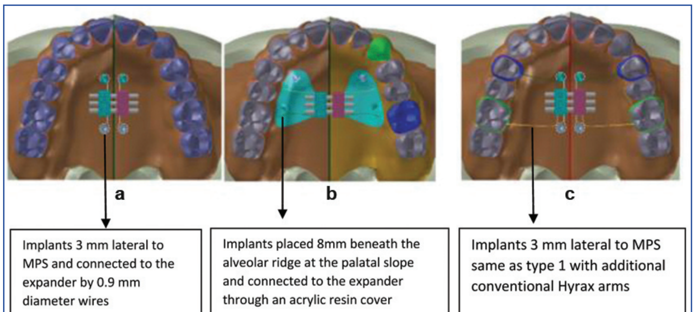
With the advent of orthodontic mini-implants, the possibilities for pure orthopaedic movement with RME were explored around the world. In the mid 2000s, MARPE soon became a generic term that transmits expansion forces to basal bones by a miniscrew anchorage system thereby maximising skeletal expansion and minimising dentoalveolar tipping. Some MARPEs are tooth-bone-anchored or hybrid and others are purely bone-borne [16,17]. Different MARPE designs with widely varying parameters like miniscrew length and anteroposterior displacement of jackscrew, different anchor locations yield varying results [16,18]. The aim of this comprehensive review was to discuss about different designs of MARPE, clinical significance, limitations, and the latest technological advancements like the use of CBCT and intraoral scan, CAD-CAM technology, 3D printed miniscrew insertion surgical guide and 3D laser-printed metallic mini-implant supported appliances.

MIDPALATAL SUTURE MATURATION WITH AGE

Midpalatal Suture (MPS) studies by Melsen B; Zimring JF and Isaacson RJ have revealed a relationship between the increased interdigitation of the MPS with the age of the subjects in hindering maxillary separation [19,20]. They also emphasised that the maximum resistance is not due to the midpalatal suture but by the surrounding maxillary articulation. Bishara SE and Staley RN suggested that the resistance to MPS opening was noticed at the sphenoid and zygomatic bones, particularly at the superior parts of the pterygoid plates of the sphenoid bone, and the anterior part of the zygomatic bone [21]. Angelieri F et al., studied the Cone Beam Computed Tomography (CBCT) images of 140 subjects and divided the MPS into five stages of maturation [14]. They concluded that chronological age cannot be directly related to developmental stages of fusion of MPS and emphasised individual assessment of suture using CBCT in young adult and adolescent. Wehrbein H and Yildizhan F emphasised that the term 'suture fusion' should be avoided in terms of radiologic terminology as they found that a radiologically invisible midpalatal suture is not the histological equivalent of a fused or closed suture after analysing the palatal suture status of young adults ranging from 18 to 38 years of age [22].

DIFFERENT DESIGNS OF EXPANDERS USING MICROIMPLANTS

The MARPE is a modification of a conventional RPE appliance that evolved as a quest for pure orthopaedic movement to maximise skeletal expansion and minimise dentoalveolar tipping. The prime difference is the incorporation of microimplants into the palatal basal bone along with the expansion screw. Following are the different designs of expander using microimplants [Table/Fig-1a-c] [2,17].



[Table/Fig-1a-c]: Designs of the RME types using microimplants: (A) Type 1, (B) Type 2, (C) Type 3 [17]. MPS: Mid palatal suture.

Type 1: Bone-borne expander with microimplants placed lateral to midpalatal suture

Type 2: Bone-borne expander with microimplants placed at the palatal slope

Type 3: Miniscrews as in type 1 but with additional conventional Hyrax arms

Lee HK et al., study on Finite Element Method (FEM) showed that type 2 was the most efficient bone-anchored maxillary expander because of the widely distributed stress throughout the palate, decreased amount of stress around the microimplant and reduced buccal inclination of the dentition [17].

Lee KJ et al., modified conventional RPE by soldering four rigid connectors of stainless steel wire with helical hooks on the base of the hyrax screw body [1]. Two hooks were positioned anteriorly on the rugae region, and the other two hooks posterior on the parasagittal. Orthodontic miniscrews (Orlus, Ortholution, Seoul, Korea) seven mm length with a 1.8 mm collar diameter and were placed in the center of the helical hooks [Table/Fig-2a-c]. The activation protocol followed was one-quarter of a turn (0.2 mm) once a day, with a total activation period of six weeks resulting in an 8.3 mm increase in intermolar width. The maxillary basal bone transverse width increases were 2.4 mm and nasal width by 2.5 mm with no buccolingual molar inclination changes after expansion and alignment.

[Table/Fig-2a-c]: Fabrication and application of the MARPE: a) Fabrication on the cast with anterior and posterior hooks; b) Placement of the appliance with miniscrews; c) Expansion after six weeks [1].

Cunha AC et al., achieved complete disjunction of the midpalatal suture from the anterior nasal spine until the posterior nasal spine was classified as a type I palatal split pattern with MARPE [23]. Transverse width increased 4.9 mm anteriorly, 3.6 mm intermediately and 2.4 mm posteriorly. They concluded that the position of posterior miniscrews in MARPE may have a crucial role in providing adequate stress distribution for the parallel splitting of the palate [Table/Fig-3a,b] [23].

[Table/Fig-3a-b]: a) CBCT after MARPE, frontal and occlusal views; b) Axial slice with linear measurements of anterior, intermediate and posterior midpalatal widths [23].

Lim HM et al., used MARPE with a modified hyrax-type expander (hyrax II; Dentaurum, Ispringen, Germany), and achieved a significant increase in transverse widths of the nasal floor, and nasal cavity, alveolar bone, intercusp, interapex postexpansion [24]. Alveolar bone showed a 2.26^0 buccal tipping and the 1^{st} molar showed 2.07^0 buccal tipping, the thickness of the alveolar bone at the 1^{st} premolar and 1^{st} molar decreased on the buccal side, and increased on the palatal side. Treatment outcomes were stable after one year after expansion with 43.2% skeletal, 15.0% alveolar, and 41.8% dental expansion. However, the alveolar crest at the 1^{st} premolar was reduced by 1.54 mm. MacGinnis M et al., used FEM to compare between MARPE and conventional hyrax expansion simulation groups and demonstrated that the point of force application is closer to maxillary fulcrum of rotation as well as the center of resistance in the MARPE group, thereby the possibility of more horizontal translation of the maxilla halves increases [4]. Wilmes B et al., evaluated the time needed to achieve the intended expansion with hybrid hyrax which ranged from 4 to 14 days (mean 8.7±3.6 days) and the mean expansion was 6.3±2.9 mm and 5.0±1.5 mm in the first premolar and molar region [13]. Yoon S et al., analysed the effect of changing various parameters in the bone-borne rapid RPE using the finite element study (FEM) method and found that the miniscrew length and anteroposterior displacement of the expander did not significantly affect stress distribution and displacement changes and also found that the maxilla rotated clockwise when the miniscrews were placed in the anterior region [18].

The MSE developed by Moon W. and his colleagues at the University of California-Los Angeles (UCLA) is a unique lineage of MARPE due to its distinctive position of miniscrew in the superior and posterior aspect of the palate with four long implants engaging the palatal bone bicortically [Table/Fig-4] [9,16,25]. The posterosuperior position gives a significant advantage in overcoming the resistance from zygomatic buttress bones and pterygopalatine sutures, possibly leading to a more parallel expansion in contrast to many other designs of MARPE. It causes expansion of the entire midface, agitating all peri-maxillary structures. In class III patients, MSE and FM (face mask) combination resulted in bone anchored expansion and protraction even in mature patients with almost negligible vertical side effects. This simulated distraction osteogenesis like movement, where not only the maxilla but the entire midface can be advanced, forms a promising basis for non surgical orthopaedic treatment modality for Class III.

[Table/Fig-4]: Maxillary Skeletal Expander (MSE), miniscrew in the superior and posterior aspect of the palate [16,25].

Carlson C et al., suggested the use of an 11 mm length of mini-implant for bicortical engagement that would adequately fit in the palatal vault, concurrently allowing close adaptation of the appliance to the tissue surface between the maxillary first molars [26]. The 11 mm length was chosen by making allowance for the 2 mm height of the insertion slots, the 1-2 mm of space between the expander and the palatal surface, the 1-2 mm of gingival thickness, and a desired 5-6 mm of bone engagement at least. This position exerts lateral forces against the pterygomaxillary buttress of the bone, which is a major resistance factor in maxillary expansion. The expansion rate was selected based on the protocol developed by Dr. Won Moon through clinical experience with the MARPE appliance [Table/Fig-5] [26].

Age of the patient	Initial expansion rate	Expansion rate after opening of the diastema
Early teens	3 turns/week	3 turns/week
Late teens	1 turn/day	1 turn/day
Adults	2 turns/day	1 turn/day
Older patients (>30 years)	>2 turns/day	1 turn/day

[Table/Fig-5]: Suggested expansion rates for different age groups [26].

Clement EA and Krishnaswamy NR concluded that MSE used in young adults produced 61% of expansion at skeletal level, 20% at alveolar, and 19% dental level [27]. Cantarella D et al., evaluated midfacial skeletal changes in the coronal plane in late adolescent patients treated with a bone-anchored maxillary expander using CBCT and found significant lateral displacement of the zygomaticomaxillary complex and outward rotation of zygomatic bone along with the maxilla with a common center of rotation located near the superior aspect of the frontozygomatic suture [28]. Cantarella D et al., obtained sagittal parallelism of midpalatal suture opening with MSE [25]. The opening of the midpalatal suture in the anterior nasal spine region was 4.8 mm and at the posterior nasal spine was about 4.3 mm. Brunetto DP et al., revealed that the greatest benefit of using MARPE was the improvement of sleep quality by facilitating nasal breathing. Postexpansion polysomnography suggested a reduction of the Apnea Hypopnea Index (AHI) from 7.9 to 1.5 using MARPE [9].

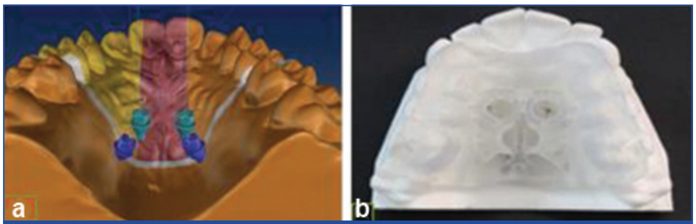
SELECTION OF MINI-IMPLANTS AND SITE OF PLACEMENT

Nojima LI et al., suggested the following steps to select the length of miniscrews for the MARPE: 1. Procurement of dental casts; 2. Selection of Digital Imaging and Communications in Medicine (DICOM) visualisation software and maxilla orientation in CBCT images; 3. Measurement of bone thickness on the coronal section of CBCT images; 4. Evaluation of expander miniscrews fixation rings; 5. Selection of miniscrew [29]. The total length of the miniscrew (MI) is represented by the variables: bone thickness (o), adding 1.0 to 2.0 mm which is necessary for the miniscrew tip to surpass the cortical plate of the nasal fossa, soft tissue thickness (m), fixation ring thickness (a), distance from the ring to the palatal surface (d). The equation employed to calculate the total miniscrew length is described, with the value in millimeters, as MI=o+m+a+d+(1 or 2). Lee RJ et al., suggested the use of bicortical (cortical bone of palate and nasal floor) mini-implant anchorage over monocortical anchorage to achieve more parallel sutural expansion with enhanced mini-implant stability and resistance against mini-implant deformation and fracture [30]. Peri-implant stress was pre-eminent in the monocortical anchorage model compared with both bicortical anchorage models. Wilmes B et al., found that the area immediately posterior to the palatal rugae, and the paramedian area referred to as the "T-Zone", is a more suitable region for insertion of palatal mini-implants due to the available bone volume and bone is much thinner in posterior and lateral areas [31]. Lombardo L et al., conducted a FEM study and demonstrated that a miniscrew of diameter two mm and length 11 mm inserted into the palate can withstand loads between 240 and 480 gf (gram force), without causing a fracture to the bone, even in the absence of osseointegration [32].

LATEST TECHNOLOGICAL ADVANCEMENTS

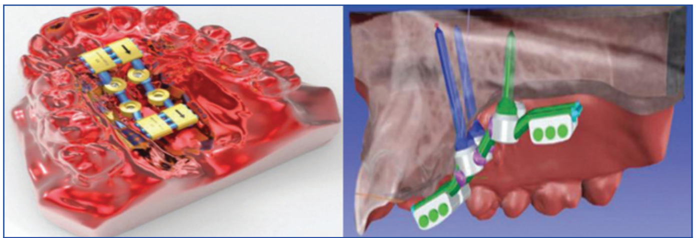
The use of neoteric technology helps us to create more effective devices and allows us to design and plan everything in a single visit with the added advantage of comfort for both the clinician and the patient [3,33]. A surgical guide is an essential tool that gives three dimensional (3D) orientation for accurately placing implants at the correct depth and proper angle of insertion in the bone. A 3D template preparation needs preoperative planning based on volumetric tomography and customised software [3]. Minervino BL et al., suggested two fundamental aspects concerning planning for the placement of MARPE [34]. Firstly, suture evaluation by CBCT to assess the possibility of expansion, cortical bone quantity, dental roots, maxillary sinuses, critical anatomical structures such as nerve or artery bundles. Secondly, virtual planning to position both expander and mini-implants.

Maino G et al., introduced a new high precision 3D miniscrew insertion guide system called Miniscrew Assisted Palatal Appliance (MAPA) system [35]. The CBCT and intraoral scan of the dental arches are an aid to MAPA guide. Standard Triangulation Language (STL) files obtained from intraoral scans of the patient were superimposed onto the Digital Imaging and Communications in Medicine (DICOM) files of the CBCT scan. The thicknesses of the palatal bone were accessed, and the ideal positions for four virtual miniscrews were identified. A 3D template was then designed and printed three dimensionally [Table/Fig-6a,b] [36].

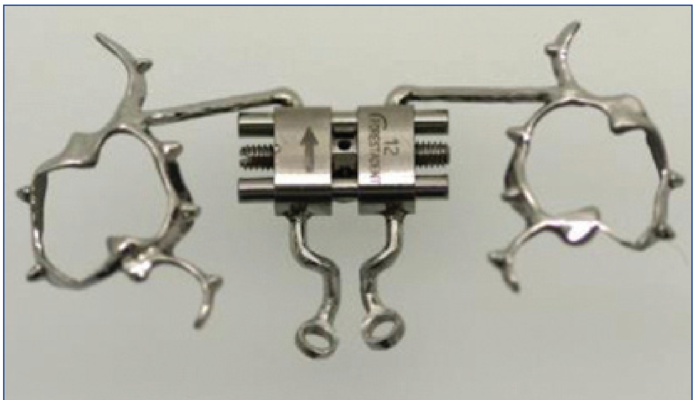


[Table/Fig-6a-b]: a: Digital Imaging and Communications in Medicine (DICOM) and Standard Triangulation Language (STL) file superimposition of intraoral patient maxilla; b: Miniscrew Assisted Palatal Appliance (MAPA) creation: three dimensional printed template for correct miniscrew placement [36].

Maino BG et al., introduced Tandem Skeletal Expander (TSE) [Table/Fig-7] which comprises two expansion screws, mounted on four 11×2 mm spider miniscrews [3,37]. A 3D surgical guide was prepared and then printed using the MAPA System. Parallel opening of the mid palatal suture was achieved when simultaneously activating both the screws due to equivalent anterior and posterior increases in the transverse dimension. The 3D technological processes assure efficient, accurate, and predictable orthodontic planning, since they standardise the technique and reduce the risks [3,35].


[Table/Fig-7]: Digital occlusal and sagittal views of Tandem Skeletal Expander and miniscrews [3].

Graf S et al., used CAD-CAM technology to custom fabricate metallic mini-implant supported appliances with direct 3D metal printing via laser melting and laser welding of the hybrid hyrax [Table/Fig-8] [37]. Sanchez-Riofrio D et al., described a titanium grade V maxillary expander supported by two miniscrews, along with a 3D printed polyamide surgical guide in a 13-year-old female with the aid of CAD-CAM [33].


[Table/Fig-8]: Laser printed hybrid hyrax expander [37].

CLINICAL SIGNIFICANCE OF MARPE

The MARPE appliances transmit expansion force into the palatine basal bone and produced a more parallel type and more consistent suture opening upon maxillary expansion. Widening of surrounding craniofacial structures including the zygoma and the nasal bone [4,25]. Larger transverse skeletal expansion while lessening dental side effects such as dental tipping, vertical alveolar bone loss, and alveolar bending [2-4]. Bone-borne appliances lead to lesser dentoalveolar tipping and lower posterior mandibular rotation thereby allowing better vertical control and therefore beneficial in young dolichofacial patients [4,27]. The MARPE surpasses conventional RME by a significantly decreasing excessive load on the buccal periodontal ligament of teeth to which they are anchored [2]. It also propagates less stress to the buttresses and adjacent locations in the maxillary complex compared to the conventional RPE [4]. Tooth-Bone-Borne (TBB) RME induces significantly higher nasal mean flow and lower nasal mean airway resistance after maxillary expansion compared with patients with Tooth-Borne (TB) RME in with dental stage in the early or late mixed dentition patients [11]. The MARPE led to a significant long term increase in nasopharyngeal volume when compared to RPE [38]. BAME (Bone Anchored Maxillary Expansion) allows full bonded orthodontic therapy at the same time as the expansion, this could shorten the overall treatment time [39,40]. A combination of MSE and Face mask can be a successful non surgical orthopaedic treatment modality for Class III adult patients as MSE disarticulates premaxillary sutures and aid in protraction of maxilla [16,25]. The MARPE results in greater stability, reduced relapse [34]. Choi SH et al., and Park JJ et al., reported a success rate for MARPE as 86.96% and 84.2%, respectively [41,42]. A recent systematic review demonstrated the mean success rate of MARPE as 92.5% with mean transverse skeletal expansion of 2.33 mm and dental expansion of 6.55 mm. These results are clinically comparable to the expansion achieved by SARPE [43].

Limitation(s)

The most frequent complication is the inflammation and hyperplasia of the mucosa around the mini-implant due to difficulty in cleaning the area, the invasiveness of the microimplants, and the increased possibility of infection when compared to conventional RPE [4,9]. A significant decrease in mean buccal bone thickness and buccal alveolar height and increase in dental tipping, as well as nasal soft tissue change were also reported [43]. Alveolar thickness decreased on the buccal side therefore increased the possibility of buccal alveolar bone dehiscence [24]. Unilateral posterior expansion is not feasible in basic MARPE design, modifications of design are required like U-MARPE [44]. Reduced or absent bone thickness, contraindicates MARPE placement [34]. Appliances present restricted to use with extreme maxillary atresia or palatal asymmetry [29]. Systemic conditions like type II diabetes and habits like smoking should be carefully assessed and might contraindicate the therapy [9].

CONCLUSION(S)

The MARPE represents a valid minimally invasive non surgical treatment modality for transverse maxillary deficiency in skeletally mature patients. It facilitates complete disjunction of the midpalatal suture by transmitting forces into the palatine basal bone with the help of mini-implants. Mini-implant anchorage not only allows more parallel sutural expansion but also significantly increases transverse widths of the nasal floor and nasopharyngeal volume as well as significantly decreases mean nasal airway resistance. In skeletally mature class III patients with transverse maxillary deficiency combination of MSE and FM (face mask) results in distraction osteogenesis-like movement of midface and aid in protraction of maxilla. MARPE appliances significantly decreasing the excessive load on the buccal periodontal ligament of teeth to which they are anchored and minimise dental tipping and extrusion thereby allowing better vertical control, especially in dolichofacial patients. Thus, MARPE has broadened the treatment envelop to treat skeletally mature patients with greater orthopaedic expansion, safety, and fewer undesirable effects with high success rates.

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PARTICULARS OF CONTRIBUTORS:

1. Postgraduate Student, Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.
2. Professor, Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.
3. Senior Lecturer, Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.
4. Reader, Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.
5. Professor, Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Tamanna Hoque,
2nd Floor, Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.
E-mail: tamannadenthealth@gmail.com

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