The role of micro-implant-assisted rapid palatal expansion (MARPE) in clinical orthodontics – a literature review

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A maxillary transverse deficiency is a common craniofacial problem. Rapid palatal expansion (RPE) has been traditionally considered for the treatment of children and young adolescents, but this is not applicable in late adolescents or adults due to the ossification of facial sutures. A surgically assisted rapid palatal expansion (SARPE) was initially advocated for this group of patients, but the surgical procedure is associated with morbidity. As temporary anchorage devices (TADs) have been recently and popularly applied in clinical orthodontics, micro-implant-assisted rapid palatal expansion (MARPE) has been employed to facilitate maxillary expansion in skeletally mature patients. There have been various proposed MARPE designs and the outcomes appear promising. The aim of the present article is to discuss the role of MARPE in clinical orthodontics by reviewing its background, design, indications, treatment effects, stability, and limitations in the current literature. The treatment effects of two types of MARPE, bone-borne and tooth-bone-borne (hybrid), will be individually assessed.
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The treatment protocol for transverse problems has been well-developed for growing patients, but the protocol associated with skeletally mature patients has often been overlooked. As advances in cone-beam computerised tomography (CBCT) and micro-implants have occurred, a transverse discrepancy in adults has been increasingly examined and various non-surgical alternatives involving bone-anchored expanders have been proposed. The aim of this article is to review micro-implant-assisted rapid maxillary expansion (MARPE) and to assess its suitability and efficacy in modern orthodontics.

Rationale/background

A maxillary transverse deficiency is usually accompanied by an anterior and/or a posterior crossbite, a narrow nasal cavity, dental crowding, an excessive buccal corridor and non-carious cervical wear which is possibly due to increased non-axial loading and stress concentration in the cervical region.[1,2] A constricted maxilla in a growing patient is conventionally treated by rapid palatal expansion (RPE) which exerts an orthopaedic force by the use of a tooth-borne expander to open the mid-palatal suture and to widen the affected maxillary dentition.

Proffit and White[3] stated that 30% of adult patients had a transverse discrepancy. However, expansion through conventional RPE had been reported to be less effective during late adolescence and in adults due to adverse side effects and limitations including a minimal skeletal effect, undesirable tooth movement, root resorption, unfavourable periodontal

consequences, and a lack of long-term stability.[1,4,5] The fusion (or progressive ossification) of the mid-palatal suture and the increased interdigitation of craniofacial sutures are the main factors which render the maxilla more resistant to expansion.[6,7] Widening the maxilla via a segmental osteotomy has been shown to be largely unstable, and so surgical-assisted rapid maxillary expansion (SARPE) was considered to achieve a more skeletal effect during the expansion process.[8,9] Nevertheless, there are some noted complications of SARPE including a complex treatment process, significant haemorrhage, gingival recession, the possibility of root resorption, injury to the branches of the maxillary nerve, the devitalisation of teeth, infection, pain, periodontal breakdown, and sinus infection.[10,11] In addition, SARPE has resulted in mainly lateral rotations of the maxillae and only minimal horizontal translations have been maintained after retention and an accompanying large amount of relapse.[12,13] Complicated surgery is the main reason most patients are reluctant to proceed.

Recently, clinicians have initiated alternative ways to correct the transverse problem.[1,14–19] Orthodontic micro-implants have been incorporated as auxiliary anchorage to which a jackscrew may be attached in the palatal vault to achieve expansion. The mechanism exerts a mechanical force to the circum-maxillary sutures during expansion conducted on skeletally mature patients.[20] This type of design is generally called micro-implant-assisted rapid palatal expansion (MARPE), and may avoid the need for osteotomies. More skeletal effects of MARPE have been reported compared to a conventional RPE. The present article will review the designs, indications, treatment outcomes, stability, and limitations of MARPE.

Design/expansion scheme

There are a variety of recommended MARPE designs, and these can be categorised into bone-anchored or tooth-bone-anchored (hybrid) appliances. Some incorporate two mini-implants in their designs, while others recommend using four to six screws. Several clinicians have emphasised the importance of bi-cortical engagements of the mini-implants, but others have suggested the avoidance of nasal floor penetration. MARPE designs will be mainly discussed through these two groups.

Bone-anchored appliances

Winsauer et al.[21] introduced a strict bone-borne device, a MICRO ('mini-implant collar-retained orthodontic') expander, with four or six miniscrews (2–2.5 mm in diameter, 10–14 mm long) inserted exactly perpendicular to the anterior palate in the paramedian area. The MICRO-4 Hyrax, with four palatal miniscrews, was mainly used in adolescents, and the MICRO-6 Hyrax, with six miniscrews, was recommended for use in adults. After expansion, it was advocated that the MICRO-4 and the MICRO-6 Hyrax expanders remain in situ for 6 and 12 months, respectively, for retention.

Kim et al.[16] demonstrated two kinds of bone-borne appliances, with and without palatal acrylic resin coverage. Four miniscrews (1.6 mm × 10 mm in the anterior and 1.6 mm × 8 mm in the posterior regions) with stainless-steel arms extending to the lingual surfaces of the upper premolars and first molars were inserted para-medially in the premolar areas. Acrylic resin was occasionally added over the expander and secured to the palatal miniscrews. It was suggested that, in patients with extremely narrow or high-vaulted palates, the use of an acrylic RPE was beneficial because it produced less gingival impingement and inflammation compared with the wire type.

Yoon et al.[22] analysed the effects of the number, position, and length of miniscrews in a three-dimensional finite element analysis of bone-borne RPE. It was concluded that placing four minscrews antero-posteriorly was more advantageous and aided stress distribution and transverse expansion. It was further found that the length of the miniscrew or the antero-posterior position of the expander showed little effect on maxillary expansion. However, the results of Yoon et al. indicated that an anterior position of the expander seemed to encourage more extrusive displacement of the premaxilla than a posteriorly-positioned expander.

Tooth-bone-anchored (hybrid) appliances

Lee et al.[2,15] introduced a combined Hyrax RPE with four extension arms comprising helical hooks soldered under the body of a jackscrew to accommodate the miniscrews. Lateral arms from the body of the Hyrax expander were soldered to bands on the first premolars and first molars, respectively. Two anterior hooks were positioned in the rugae area and the other two were placed posteriorly in the parasagittal area.

It was recommended that orthodontic miniscrews (1.8 mm collar diameter, 7-mm length) be placed in the centre of the helical hooks. Patients were advised to activate the expansion mechanism once a day following placement. The role of the miniscrews in the MARPE was intended to secure sufficient expansion in the dentoalveolar area with less dental tipping, and to reduce the excessive pressure on the buccal cortical plates. It was considered that the incorporation of four miniscrews provided better dissipation of the pressure along the sutures and a reduction of pressure on the buccal cortical plates.[2]

Montigny[23] proposed a Hyrax expansion device supported by two molar bands and two anterior palatal mini-implants. The mini-implants were 1.8–2.2 mm in diameter, 7–9 mm in length and inserted into the paramedian area aligned with the premolar region. According to a cartographic study of the palate, this insertion position was reported to be the most favourable because it could produce 5–6 mm of intraosseous anchorage for primary stability.[24] This was also supported by studies which located the centre of resistance of the nasomaxillary complex in the premolar region.[25–27] The anterior arms of the appliance delivered a force via the mini-implants to the anterior palate, whereas the posterior arms delivered a force via the molars to the posterior segments. It was believed that placing the anchorage directly on the palate, i.e. closer to hemi-maxillary resistance centre, would allow better skeletal maxillary expansion.

In addition, Garib et al.[17] suggested using a Hyrax expander supported by the permanent first molars and palatal implants placed bilaterally between the first and second premolars. The advice was to place the implants obliquely and lingually in order to avoid contact with important anatomical structures (nasal cavity, maxillary sinuses, dental roots), and to resist transverse expansion forces.[28,29] Palatal expansion was recommended to begin one month after the implant surgery.

Nojima et al.[30] advocated the utilisation of a CBCT scan to guide mini-implant insertion during the MARPE surgical procedure. The expansion device was similar to the design of Lee et al.[2,15] and bone thickness at the expected miniscrew insertion sites was evaluated from the coronal plane of the CBCT image. Bicortical engagement of the miniscrews was recommended for the internal cortices of the hard palate and nasal fossa, and it was believed that this was fundamental to support anchorage during expansion and to overcome the resistance of the maxillary bone. By utilising CBCT scans, safe bicortical engagements of the miniscrews were guaranteed in a consideration of palatal bone height, palatal soft tissue thickness, fixation band height, and the clearance between band and palate.

Moon et al.[31] developed a MARPE device named the Maxillary Skeletal Expander (MSE), which was deemed to simplify complicated procedures. The main body of the appliance contained an expansion screw with four parallel holes sited at the corners of the expander. Each hole was sized 1.8 mm in internal diameter and 2 mm in thickness and acted as a guide for the placement of the micro-implants. In addition, the holes prevented tipping of the implants during insertion and activation. Four lateral arms extended from the main body and were soldered to the molar bands. Moon et al. urged that force application should be delivered more posteriorly and so the expander was placed at the level of the first molar to overcome initial resistance. It was believed that, in this position, a lateral force could be exerted directly against the pterygomaxillary buttress and promote a parallel opening on the midpalatal suture.[14,20] After cementation of the MSE, micro-implants were placed through the parallel holes with a manual driver.[31] The inserted micro-implant was 1.8 mm in diameter, and either of 9 mm, 11 mm, or 13 mm in length according to the thickness of palate measured from the CBCT image. The length of the screw should provide at least 5–6 mm of bone engagement and ensure bicortical penetration.[32] In a finite element analysis, it has been shown that bicortical micro-implant anchorage could improve screw stability and decrease screw deformation and fracture during expansion.[33] The activation protocol varied according to the patient's age as recommended by Moon et al. in Table I.[20] The frequency of activation could be reduced to once a day after an inter-incisal gap appeared in the adult.

Table I. Activation protocol suggested by Moon et al.

Age range	Suggested activation protocol
Beginning of adolescent	3~4 turns/week
End of adolescent	1 turn/day
Young adults	2 turns/day
Older than 25 years old	2 turns or more/day

Indications

The use of a MARPE may be categorised by:

1. A constricted maxilla along with a unilateral or bilateral crossbite in skeletally mature patients.

   In adolescents or adults presenting with a constricted maxilla along with a unilateral or bilateral crossbite, the palatal suture is often rigid and complexly interdigitated, which may need extra consideration to separate.[14] A common method to diagnose and quantify a constricted maxilla based on Andrews' six keys of occlusion was recommended for clinical use.[34] Maxillary width was measured on a stone cast between the most concave points in the vestibule at the level of the mesiobuccal cusp of the first molars. Mandibular width was measured at the level of the mesiobuccal grooves of the first molars on the WALA ridge (the most prominent portion of the buccal alveolar bone). These two widths should be equal in a normally developing maxilla and mandible. Betts et al.[35] developed a postero-anterior cephalometric analysis to calculate the variation in maxillomandibular widths using the Ricketts Rocky Mountain analysis.[36] If the transverse discrepancy was greater than the Ricketts' norm (19.6 mm), maxillary skeletal expansion might be considered.

   Lee et al.[2] introduced the Yonsei transverse index for the diagnosis of a transverse skeletal discrepancy using computed tomography (CT). On a CT scan, an estimated centre of resistance was used and located at the furcation level of the upper or lower first molar to represent transverse reference points. The average difference between the maxillary and mandibular transverse widths (Yonsei transverse index) at the estimated centres of resistance was reported to be −0.39 ± 1.87 mm in the Class I subjects, but −3.17 ± 3.17 mm in a Class III surgical group. The difference was statistically significant. It was believed CT could provide better insight into the transverse discrepancy than the Ricketts Rocky Mountain analysis in which landmarks were sited far from the alveolar basal bone.

2. MARPE with facemask treatment in growing and skeletally mature Class III patients.

   Moon[31] reported that it was possible to enhance the growth of the maxilla in an antero-posterior direction by applying MARPE and a facemask in growing and skeletally mature patients. It was found that the dental compensations were minimised or even reversed when the skeletal relationship improved. The unwanted dental effects related to the buccal tipping and the extrusion of the maxillary molars could also be controlled. This prevented exacerbating mandibular backward rotation while the maxilla protracted.[34] Wilmes et al.[37] reported the success of combining tooth-bone-borne RPE and facemask therapy for maxillary protraction in young patients (mean age of 11.2 years). It was suggested that this treatment alternative appeared to be effective in minimising the adverse effect of the mesial migration of the anterior teeth. Facemask protraction was reported to be much slower and required a heavier force in skeletally mature patients.[31] Moon used a 1 kg protraction force per side in a 24-year-old patient and reported a distraction-like protraction of the mid-face could be achieved. However, further clinical studies are needed to completely explain the skeletal and dental changes accompanying protraction.

3. Maxillary transverse deficiency associated with obstructive sleep apnoea (OSA) in adult patients.

   An increase in nasal cavity volume after MARPE has been described by several studies.[20,38–40] Brunetto et al.[20] reported a 22-year-oldpatient with a constricted maxilla and mild apnoea symptoms who improved following MARPE and fixed orthodontic therapy. The apnoea/hypopnoea index (AHI) reduced from 7.9 to 1.5 and the patient reported improvement in sleep quality. Storto et al.[39] assessed the changes in patients presenting with a transverse maxillary deficiency in association with respiratory muscle strength, inspiratory and expiratory peak flow, and skeletal/dental changes before and after MARPE treatment. Respiratory muscle strength was measured by maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP). MIP indicates the strength of the diaphragm and other inspiratory muscles whereas MEP reflects intercostal and abdominal muscle strength. It was concluded that MARPE, not only promoted skeletal effects around the nasomaxillary complex, but also produced a direct effect on muscle strength, which consequently improved respiratory function. Gracez et al.[40] also demonstrated an improvement in all respiratory tests in an 18-year-old swimming athlete with a narrow maxilla after MARPE treatment.

The patient's swimming ability and efficiency improved and was maintained for one year after expansion. It may be assumed that MARPE may increase nasal cavity volume and further improve OSA in the short term.

4. Maxillary transverse deficiency combined with a compromised periodontium or inadequate tooth number.

Toklu et al.[41] compared the periodontal, dentoalveolar and skeletal effects of tooth-borne and hybrid (tooth-bone-borne) expansion methods by CBCT scans. It was reported that the buccal bone thickness decreased over the premolar area in the purely tooth-borne group, whereas the buccal bone was maintained in the hybrid group. It was concluded that tooth-bone-borne expansion could be considered for patients who had a risk of periodontal destruction over the buccal areas during expansion. Wilmes[37,42] and Ludwig et al.[43] also suggested the utilisation of MARPE rather than a RPE if a patient lacked anterior dental anchorage for the expander in circumstances of missing deciduous teeth, or underdeveloped premolar roots.

Treatment effects of various MARPE designs

Bone-borne appliances

Skeletal effects

Yilmaz et al.[44] compared the short-term effects of a MARPE appliance (acrylic expansion appliance bonded to four screws placed in the palate) with two conventional rapid palatal expanders (bonded and banded types). The bone-borne expanders presented significant skeletal (5.54 mm) and dental (5.80 mm) expansions in a parallel manner, revealed by an SNA angle increase in this group. The vertical measurements showed no obvious change in the MARPE group, while a significant increase was noted in both conventional RPE groups. The authors concluded more clockwise rotation of the mandible would be observed in the conventional RPE group, and a bone-borne expander could be an acceptable alternative to avoid this effect. Lin et al.[19] also revealed a similar parallel expansion pattern.

Dentoalveolar effect

Yilmaz et al.[44] reported a large amount of buccal tipping of the upper first molars after expansion in bonded and banded RPE groups (11.75° and 10.25°,

respectively) whereas a smaller amount of palatal tipping (3.5°) was found in the bone-borne group. The authors inferred that the palatal tipping of the molars was due to a lack of tooth support associated with the bone-borne appliance. The amount of palatal tipping was small and so an overcorrection of the maxilla was unnecessary as the molars translated in a more bodily fashion. Lin et al.[19] also observed crown and apex expansions in a similar way after bone-borne expansion, and recorded ratios of dental tipping to alveolar bone bending from first premolar to first molar in the order of 0.92–1.30. It was concluded that the change of tooth axis was negligible and a bone-borne expander could produce less alveolar bending, less dental tipping and less vertical alveolar bone loss than a conventional RPE after expansion.

Ratios of skeletal to dentoalveolar effects

Lin et al.[19] also calculated the skeletal/dental expansion ratios at different coronal planes from the upper first premolars to the upper second molars. A 77.0–57.5% skeletal gain was found in total crown expansion from the anterior to posterior in the bone-borne expander group, whereas the Hyrax group only displayed 42.9–25.6% of skeletal gain. Wissheimer et al.[45] reported the immediate skeletal gain at the level of the hard palate after a conventional RME (hyrax) was approximately 54.7% of total crown expansion in the anterior region and 39.2% in the posterior region. Garrett et al.[46] showed similar results of 55% in the anterior region and 38% in the posterior region. These data implied that the bone-borne expander could produce more parallel expansion than the conventional RPE in the ratio of skeletal to dental expansion.

Tooth-bone-borne (Hybrid) appliances

Skeletal effects

Midpalatal suture: Cantarella et al.[34] evaluated the changes in the midpalatal suture after hybrid MARPE therapy and found the amount of separation at the PNS (4.3 mm) accounted for almost 90% of the expansion at the level of the ANS (4.8 mm). This implied that the suture expanded almost in a parallel fashion from anterior to the posterior. The proportion relative to the actual jackscrew opening (6.8 mm) at the ANS and PNS levels were 71% (4.8 mm) and

63% (4.3 mm), respectively. Zong et al.[38] also revealed similar results via a CBCT study.

Toklu et al.[41] found a triangular expansion pattern in the coronal plane and a smaller maxillary width increment compared with intermolar cuspal width. Park et al.[47] also found a similar result of a pyramidal pattern of maxillary expansion in the coronal plane after MARPE in 14 young adults (19 were recruited but 5 were excluded according to the exclusion criteria). Of the initial 19 patients treated by MARPE, only three exhibited suture-opening failure and the success rate was noted at 84.2%. Choi et al.[4] and Lim et al.[48] also demonstrated similar success rates of 86.9 and 86.8% in their studies of young adults. This indicated that MARPE was a practical procedure which achieved suture opening in adults as well as adolescents.

Pterygopalatine sutures: Cantarella et al.[34] found, of 30 pterygopalatine sutures, 16 presented displacements over the medial and lateral pterygoid plates after MARPE. The average distances of displacement were 1.4 and 2.2 mm over the right and left sides, respectively. Posterior skeletal expansion could offer advantages related to an improvement in posterior occlusion, broadening a patient's nasal airway and relieving posterior constriction. In addition, loosening of the pterygopalatine sutures could reduce posterior maxillary resistance, which is a key factor for successful protraction in mild skeletal class III treatment.

Zygomaticomaxillary complex: Cantarella et al.[49] evaluated midfacial changes in the coronal plane of CBCT images of 15 subjects with a mean age of 17.2 ± 4.2 years and found the relationship between the maxillary basal bone and the zygoma was maintained during expansion. The structures rotated together around a common centre of rotation slightly above the superior aspect of the frontozygomatic suture. It was found that each zygomaticomaxillary complex rotated 0.6° for each millimeter increase in lower inter-zygomatic distance. Furthermore, it was also found that the ethmoid and frontal bones were relatively stable and changed little after expansion.

Cantarella et al.[50] also assessed the zygomaticomaxillary changes in the axial planes after expansion using CBCT images. Revealed was a large change in anterior inter-maxillary distance (2.76 mm) and a lesser change in posterior inter-zygomatic distance (2.4 mm). The anterior inter-maxillary distance was measured between the most anterior points on the right and left maxilla, while the posterior inter-zy-gomatic distance was determined between the outermost points on the right and left zygomaticotemporal sutures. The zygomatic process angles increased 1.74° and 2.13° on the right and left sides, respectively. These changes indicated that the zygomaticomaxillary complex rotated around a centre of rotation, and the authors assumed that the location was in the proximal portion of the zygomatic process of the temporal bone in the horizontal plane. This fulcrum was positioned more posteriorly and laterally than that described for tooth-borne expanders.[1,46,51] As the zygomaticomaxillary complex rotated outwards, the maxillary halves may move laterally and anteriorly because the maxilla is located more anteriorly than the rotational fulcrum. The overall results suggested that the maxilla, zygomatic bone, and entire zygomatic arch can be displaced in a lateral direction as a result of bone bending around the zygomatic process of the temporal bone during expansion using a micro-implant supported skeletal expander.

Dentoalveolar effects

Cantarella et al.[49] found the intermolar distance increased significantly, but molar inclination relative to the maxillary bone produced no significant change. Park et al.[47] reported the expansion amounts were similar in the axial plane at the tooth crown and alveolar crest levels across the anterior and posterior regions. Buccal bone thickness reduced by 0.6–1.1 mm and the crest height decreased 1.7–2.2 mm from anterior to posterior. Greater buccal tipping was found over the first molars than the first premolars, which may be due to higher buccal bone density over the maxillary canine/premolar area.[52] The cortical bone around the premolars provided higher resistance to prevent buccal inclination during expansion.

Ratios between skeletal and dentoalveolar effects

Zong et al.[38] reported that a tooth-bone-borne appliance may deliver 59.23% of skeletal expansion and the other 40.96% of the total expansion was due to a dentoalveolar effect. Park et al.[47] reported ratios of skeletal, alveolar, and dental expansions were 37.0, 22.2, and 40.7%, respectively. When counting skeletal and alveolar effects together, the amount was similar to the results reported by Zong et al. Oh et al.[53] described almost 73% of total maxillary expansion was achieved by a skeletal effect from their tooth-bone-anchored appliance.

The hybrid MARPE presented similar expansion ratios to the bone-borne MARPE according to the current literature. However, the reported ratios varied greatly which may be attributed to the differences in measuring methods, appliance design, appliance position, sample age, and individual variability.

Impact on the Airway

Kim et al.[54] used CBCT scans to measure the changes before MARPE (T0) to immediately after expansion (T1) and subsequently at a one-year follow-up (T2). It was found that nasal cavity volume increased 9.9% from T0 to T1, and 5.5% from T1 to T2. The total expansion increment from the beginning to the one-year follow-up was 15.4%. Correspondingly, the nasopharynx increased by 6.4, 4.1, and 10.5%, from T0 to T1, T1 to T2, and T0 to T2.

SARPE studies have indicated that the nasal cavity volume increases by 17.9–23.3% when measured by acoustic rhinometry (AR).[55,56] However, only 5.1% of the increment was observed from CT studies.[57,58] The results were less than Kim's MARPE findings (15.4%). However, the increase in width of the nasopharynx after SARPE was not significant.[59,60]

Li et al.[61] used an outpatient surgical procedure termed endoscopically-assisted surgical expansion (EASE) to expand the maxilla and reported an improvement in nasal breathing and OSA by widening the nasal floor in adolescents and adults. The apnoea-hypopnoea index (AHI) and the oxygen desaturation index (ODI) improved dramatically after treatment, and the Epworth Sleepiness Scale (ESS) and Nasal Obstruction Septoplasty Effectiveness (NOSE) scale were reduced significantly. The CBCT images showed 4.9 ± 1.2 mm and 5.6 ± 1.2 mm of expansion over the anterior and posterior nasal floors, with a 2.3 ± 0.8 mm diastema created between the central incisors. Interestingly, Chang et al.[62] reported a conventional RPE can also produce a 25.9% increase in the pharyngeal volume in young adolescents, which might be due to growth and variation in the patient's age.[54]

A recent study evaluated the respiratory airflow and muscle strength before and after MARPE.[39] A significant 30.45% increase in nasal inspiratory peak flow was observed immediately after expansion, and the increment was maintained after five months of retention at a 30.28% level. Airway volume increased significantly by 26% after expansion. Respiratory muscle strength was measured by maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP). MIP showed a significant improvement of 20% after 5 months of expansion. MEP showed a significant increase of 10% immediately after expansion (T1) but no change was observed after 5 months. The authors concluded that MARPE could not only gain an increase in airway volume but also produce a significant positive improvement in respiratory function.

Hur et al.[63] used computational fluid-structure interaction analysis to investigate the influence of MARPE on airflow in the upper airway of an adult patient who suffered from obstructive sleep apnoea syndrome. Seven and nine cross-sectional planes (of 10 mm interplane distance) were set along the nasal cavity and pharynx, respectively. The change in area increments after MARPE at the set planes was significantly larger in the anterior part of the nasal cavity and the upper part of the pharynx. The increment was larger in the pharynx than for the nasal cavity despite the pharynx being positioned farther from the MARPE appliance. However, the nasal cavity exhibited a greater decrease in pressure and velocity of airflow than the pharynx. It was concluded that MARPE could expand the upper airway and decrease the total resistance significantly during the respiratory cycle.

Li et al.[64] conducted a similar study to compare the dimensions and volumes of each segment of the upper airway before and after MARPE in young adults. Twenty-two patients with the mean age of 22.6 ± 4.5 years were evaluated and it was found that the volumes of the nasal cavity and nasopharynx both increased. This finding supported the results of previous studies.[39,54,63]

In summary, airway studies demonstrated that MARPE could offer assistance in respiratory function by enlarging volume and decreasing the total resistance in the upper airway. However, the follow-up period was short in most of the studies. Further investigations assessing the long-term effects may still be needed.

Stability

The maintenance of a sutural gap during the consolidation phase would exert a favourable influence on

the resulting stability following expansion.[2] Choi et al.[4] reported the stability of the maxillary expansion using hybrid-typed MARPE in young adults was good with a 10% relapse of the intermolar width during an average 30 months retention period. The gingival recession was not noted to be significant during the observation period.[2,4] Also reported was a post-expansion change in middle alveolar width was correlated with age. The change in the inter-premolar width was positively correlated with the amount of expansion in this area, but not correlated with the amount of inter-molar expansion.

An alternative study evaluated the stability of dental, alveolar, and skeletal changes after the same hybrid-typed MARPE following a one-year review period.[48] It was shown that the expansion amounts immediately after MARPE were due to a 39.1% skeletal effect, a 7.1% alveolar effect, and a 53.8% dental effect, respectively, but the proportions changed to 43.2, 15.0, and 41.8% one year after MARPE. These changes were explained by a greater tendency for dental relapse. The skeletal measurements of nasal cavity and nasal floor decreased 0.37 ± 0.36 mm and 0.64 ± 0.73 mm after one year of follow-up, and this accounted for a 23.0 and 29.1% loss of the original expansion although the authors considered that this was clinically insignificant. Dental measurements showed a range of change, which may be a result of orthodontic treatment administered after expansion. Orthodontic treatment might have masked the dental changes produced by the MARPE.[48]

These findings suggested that the MARPE procedure could provide a clinically acceptable and stable expansion result in young adults. The skeletal effects could be maintained better than the dental effects. However, more investigations, especially in older patients, may still be needed to address the issue of long-term stability.

Limitations and side effects

The main disadvantages of MARPE are the difficulty in cleaning the expander and the invasiveness of the micro-implants.[65] No severe complication of MARPE has been reported to date. The most frequent complication is inflammation and hyperplasia of the gingiva around the micro-implants, which is usually associated with inadequate local hygiene. Brunetto et al.[20] suggested that a micro-implant should be removed if inflammation occurs. If inflammation

only affects one micro-implant, treatment may progress normally after the offending implant is removed. Hyperplasia may occur when there is not enough clearance from the expander or its wires from the palatal gingiva. Loosening of the miniscrews could also complicate MARPE therapy; however, Kim and Helmkamp[16] reported only 5.0% of the miniscrews dislodged during expansion but 13.0% showed clinical mobility. The rest remained stable during a retention period.

Asymmetric transverse expansion of the midpalatal suture has been described.[34,66] Cantarella et al. reported one half of ANS moved more than its contralateral half by 1.1 ± 1.0 mm on average. The displacement of the anterior part of the maxilla after expansion could affect soft tissue expression over the midface and lead to an aesthetic problem. Therefore, the soft tissue changes after MARPE should be managed with care.

A narrow and high palatal vault, which may hinder the vertical position of the device, was an additional limitation which reduced the success rate of treatment. Some clinicians proposed the replacement of the expander and the use of the same screw holes for additional expansion if the original objective had not been met.[16,18]

Investigations directed at how reduced midfacial bone elasticity, especially in the zygomatic arch, could affect the lateral movement of zygomaticomaxillary complex in older patients, are still few.[50] This could be a potential limitation when using MARPE, and so more information is needed which provides an impetus for future research.

Conclusion

Bone-borne and tooth-bone-borne types of micro-implant-assisted rapid palatal expanders (MARPE) have demonstrated promising outcomes in suture opening following application over the zygomatico-maxillary complex. The overall success rate of mid-palatal suture widening was approximately 80–90% as reported in the literature. MARPE can deliver greater skeletal effects than dental tipping following expansion in adults as well as in adolescents. This may be indicated in borderline cases presenting with a narrowed maxilla or a mild Class III skeletal pattern. Therefore, MARPE could be considered as a practical alternative if conventional rapid palatal

expansion (RPE) cannot meet a clinician's treatment expectations. Further investigations addressing the long-term stability and an improvement in the management of obstructive sleep apnoea are indicated for future studies.

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References

1. Lagravère MO, Carey J, Heo G, Toogood RW, Major PW. Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: a randomized clinical trial. Am J Orthod Dentofacial 2010;137:304.e1–12, doi: 10.1016/j.ajodo.2009.09.016.

2. Lee K-J, Choi S-H, Choi T-H, Shi K-K, Keum B-T. Maxillary transverse expansion in adults: rationale, appliance design, and treatment outcomes. Seminars in Orthodontics: Elsevier, 2018:52–65.

3. Proffit WR, White RP Jr. Who needs surgical-orthodontic treatment? Int J Adult Orthodon Orthognath Surg 1990;5:81–9.

4. Choi SH, Shi KK, Cha JY, Park YC, Lee KJ. Nonsurgical miniscrew-assisted rapid maxillary expansion results in acceptable stability in young adults. Angle Orthod 2016;86:713–20, doi: 10.2319/101415-689.1.

5. Suzuki SS, Braga LFS, Fujii DN, Moon W, Suzuki H. Corticopuncture facilitated microimplant-assisted rapid palatal expansion. Case Rep Dent 2018;2018:1392895, doi: 10.1155/2018/1392895.

6. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. Am J Orthodon 1977;72:42–52, doi: 10.1016/0002-9416(77)90123-3.

7. Melsen B, Melsen F. The postnatal development of the palato-maxillary region studied on human autopsy material. Am J Orthodon 1982;82:329–42, doi: 10.1016/0002-9416(82)90467-5.

8. Proffit WR, Turvey TA, Phillips C. The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: an update and extension. Head Face Med 2007;3:21, doi: 10.1186/1746-160x-3-21.

9. Phillips C, Medland WH, Fields HW Jr, Proffit WR, White RP Jr. Stability of surgical maxillary expansion. Int J Adult Orthod Orthogn Surg 1992;7:139–46.

10. Suri L, Taneja P. Surgically assisted rapid palatal expansion: a literature review. Am J Orthod Dentofacial 2008;133:290–302, doi: 10.1016/j.ajodo.2007.01.021.

11. Cantarella D. Skeletal Effects Induced by Maxillary Skeletal Expander (MSE) and Hyrax Appliance in the Midface. UCLA; Los Angeles, 2017.

12. Byloff FK, Mossaz CF. Skeletal and dental changes following surgically assisted rapid palatal expansion. Eur J Orthod 2004;26:403–9, doi: 10.1093/ejo/26.4.403.

13. Lee HK, Bayome M, Ahn CS, Kim SH, Kim KB, Mo SS. Stress distribution and displacement by different bone-borne palatal expanders with micro-implants: a three-dimensional finite-element analysis. Eur J Orthod 2014;36:531–40, doi: 10.1093/ejo/cjs063.

14. Carlson C, Sung J, McComb RW, Machado AW, Moon W. Microimplant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult. Am J Orthod Dentofacial Orthop 2016;149:716–28, doi: 10.1016/j.ajodo.2015.04.043.

15. Lee KJ, Park YC, Park JY, Hwang WS. Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. Am J Orthod Dentofacial Orthop 2010;137:830–9, doi: 10.1016/j.ajodo.2007.10.065.

16. Kim KB, Helmkamp ME. Miniscrew implant-supported rapid maxillary expansion. J Clin Orthod 2012;46:608–12.

17. Garib DG, Navarro R, Francischone CE, Oltramari PV. Rapid maxillary expansion using palatal implants. J Clin Orthod 2008;42:665–71.

18. Maino BG, Paoletto E, Lombardo L, Siciiani G. From planning to delivery of a bone-borne rapid maxillary expander in one visit. J Clin Orthod 2017;51:198–207.

19. Lin L, Ahn HW, Kim SJ, Moon SC, Kim SH, Nelson G. Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. Angle Orthod 2015;85:253–62, doi: 10.2319/030514-156.1.

20. Brunetto DP, Sant'Anna EF, Machado AW, Moon W. Non-surgical treatment of transverse deficiency in adults using Microimplant-assisted Rapid Palatal Expansion (MARPE). Dental Press J Orthod 2017;22:110–25, doi: 10.1590/2177-6709.22.1.110-125.sar.

21. Winsauer H, Vlachojannis J, Winsauer C, Ludwig B, Walter A. A bone-borne appliance for rapid maxillary expansion. J Clin Orthod 2013;47:375–81.

22. Yoon S, Lee DY, Jung SK. Influence of changing various parameters in miniscrew-assisted rapid palatal expansion: a three-dimensional finite element analysis. Korean J Orthod 2019;49:150–60, doi: 10.4041/kjod.2019.49.3.150.

23. Montigny M. Mini-implant assisted rapid palatal expansion: new perspectives. J Dentofacial Anom Orthod 2017;20:405.

24. Boes M, Darque F. Memory CECSMO: cartography of the palate – clinical applications in orthodontic mini-implantology, 2010.

25. Lee H, Ting K, Nelson M, Sun N, Sung SJ. Maxillary expansion in customized finite element method models. Am J Orthod Dentofacial Orthop 2009;136:367–74, doi: 10.1016/j.ajodo.2008.08.023.

26. Ludwig B, Baumgaertel S, Zorkun B, Bonitz L, Glasl B, Wilmes B. Application of a new viscoelastic finite element method model and analysis of miniscrew-supported hybrid hyrax treatment. Am J Orthod Dentofacial Orthop 2013;143:426–35, doi: 10.1016/j.ajodo.2012.07.019.

27. Tanne K, Matsubara S, Sakuda M. Location of the centre of resistance for the nasomaxillary complex studied in a three-dimensional finite element model. Br J Orthod 1995;22:227–32, doi: 10.1179/bjo.22.3.227.

28. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Sur 1981;10:387–416, doi: 10.1016/s0300-9785(81)80077-4.

29. Brånemark P-I, Zarb GA, Albrektsson T. Tissue-integrated prostheses: osseointegration in clinical dentistry. Quintessence, Chicago, 1985.

30. Nojima LI, Nojima M, Cunha ACD, Guss NO, Sant'Anna EF. Mini-implant selection protocol applied to MARPE. Dental Press J Orthod 2018;23:93–101, doi: 10.1590/2177-6709.23.5.093-101.sar.

31. Moon W. Class III treatment by combining facemask (FM) and maxillary skeletal expander (MSE). Semin Orthod 2018;24:95–107. Available at: https://doi.org/10.1053/j.sodo.2018.01.009.

32. Lin Y. Comparison of Skeletal and Dental Changes with MSE (Maxillary Skeletal Expander) and Hyrax Appliance using CBCT Imaging. UCLA; Los Angeles, 2015.

33. Lee RJ, Moon W, Hong C. Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. Am J Orthod Dentofacial Orthop 2017;151:887–97, doi: 10.1016/j.ajodo.2016.10.025.

34. Cantarella D, Dominguez-Mompell R, Mallya SM, Moschik C, Pan HC, Miller J. Changes in the midpalatal and pterygopalatine sutures induced by micro-implant-supported skeletal expander, analyzed with a novel 3D method based on CBCT imaging. Prog Orthod 2017;18:34, doi: 10.1186/s40510-017-0188-7.

35. Betts NJ, Vanarsdall RL, Barber HD, Higgins-Barber K, Fonseca RJ. Diagnosis and treatment of transverse maxillary deficiency. Int J Adult Orthod Orthogn Surg 1995;10:75–96.

36. Ricketts RM. Orthodontic diagnosis and planning: their roles in preventive and rehabilitative dentistry. Rocky Mountain/Orthodontics, 1982.

37. Wilmes B, Nienkemper M, Drescher D. Application and effectiveness of a mini-implant- and tooth-borne rapid palatal expansion device: the hybrid hyrax. World J Orthod 2010;11:323–30.

38. Zong C, Tang B, Hua F, He H, Ngan P. Skeletal and dentoalveolar changes in the transverse dimension using microimplant-assisted rapid palatal expansion (MARPE) appliances. Semin Orthod 2019;25:46–59, doi: 10.1053/j.sodo.2019.02.006.

39. Storto CJ, Garcez AS, Suzuki H, Cusmanich KG, Elkenawy I, Moon W. Assessment of respiratory muscle strength and airflow before and after microimplant-assisted rapid palatal expansion. Angle Orthod 2019;89:713–20, doi: 10.2319/070518-504.1.

40. Garcez AS, Suzuki SS, Storto CJ, Cusmanich KG, Elkenawy I, Moon W. Effects of maxillary skeletal expansion on respiratory function and sport performance in a para-athlete – a case report. Phys Ther 2019;36:70–7, doi: 10.1016/j.ptsp.2019.01.005.

41. Gunyuz Toklu M, Germec-Cakan D, Tozlu M. Periodontal, dentoalveolar, and skeletal effects of tooth-borne and tooth-bone-borne expansion appliances. Am J Orthod Dentofacial Orthop 2015;148:97–109, doi: 10.1016/j.ajodo.2015.02.022.

42. Wilmes B, Drescher D, Nienkemper M. A miniplate system for improved stability of skeletal anchorage. J Clin Orthod 2009;43:494–501.

43. Ludwig B, Glas B, Bowman SJ, Drescher D, Wilmes B. Miniscrew-supported Class III treatment with the Hybrid RPE Advancer. J Clin Orthod 2010;44:533–9.

44. Yılmaz A, Arman-Özçırpıcı A, Erken S, Polat-Özsoy Ö. Comparison of short-term effects of mini-implant-supported maxillary expansion appliance with two conventional expansion protocols. Eur J Orthod 2015;37:556–64, doi: 10.1093/ejo/cju094.

45. Weissheimer A, de Menezes LM, Mezomo M, Dias DM, de Lima EM, Rizzatto SM. Immediate effects of rapid maxillary expansion with Haas-type and hyrax-type expanders: a randomized clinical trial. Am J Orthod Dentofacial Orthop 2011;140:366–76, doi: 10.1016/j.ajodo.2010.07.025.

46. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2008;134:8–9, doi: 10.1016/j.ajodo.2008.06.004.

47. Park JJ, Park YC, Lee KJ, Cha JY, Tahk JH, Choi YJ. Skeletal and dentoalveolar changes after miniscrew-assisted rapid palatal expansion in young adults: a cone-beam computed tomography study. Korean J Orthod 2017;47:77–86, doi: 10.4041/kjod.2017.47.2.77.

48. Lim HM, Park YC, Lee KJ, Kim KH, Choi YJ. Stability of dental, alveolar, and skeletal changes after miniscrew-assisted rapid palatal expansion. Korean J Orthod 2017;47:313–22, doi: 10.4041/kjod.2017.47.5.313.

49. Cantarella D, Dominguez-Mompell R, Moschik C, Mallya SM, Pan HC, Alkahtani MR. Midfacial changes in the coronal plane induced by microimplant-supported skeletal expander, studied with cone-beam computed tomography images. Am J Orthod Dentofacial Orthop 2018;154:337–45, doi: 10.1016/j.ajodo.2017.11.033.

50. Cantarella D, Dominguez-Mompell R, Moschik C, Sfogliano L, Elkenawy I, Pan HC. Zygomaticomaxillary modifications in the horizontal plane induced by micro-implant-supported skeletal expander, analyzed with CBCT images. Prog Orthod 2018;19:41, doi: 10.1186/s40510-018-0240-2.

51. Lione R, Ballanti F, Franchi L, Baccetti T, Cozza P. Treatment and posttreatment skeletal effects of rapid maxillary expansion studied with low-dose computed tomography in growing subjects. Am J Orthod Dentofacial Orthop 2008;134:389–92, doi: 10.1016/j.ajodo.2008.05.011.

52. Park HS, Lee YJ, Jeong SH, Kwon TG. Density of the alveolar and basal bones of the maxilla and the mandible. Am J Orthod Dentofacial Orthop 2008;133:30–7, doi: 10.1016/j.ajodo.2006.01.044.

53. Oh H, Park J, Lagravere-Vich MO. Comparison of traditional RPE with two types of micro-implant assisted RPE: CBCT study, Seminars in Orthodontics: Elsevier, 2019:60–68.

54. Kim SY, Park YC, Lee KJ, Lintermann A, Han SS, Yu HS. Assessment of changes in the nasal airway after nonsurgical miniscrew-assisted rapid maxillary expansion in young adults. Angle Orthod 2018;88:435–41, doi: 10.2319/092917-656.1.

55. Wriedt S, Kunkel M, Zentner A, Wahlmann UW. Surgically assisted rapid palatal expansion. An acoustic rhinometric, morphometric and sonographic investigation. J Orofacial Orthop 2001;62:107–15, doi: 10.1007/pl00001921.

56. Kunkel M, Hochban W. Acoustic rhinometry: a new diagnostic procedure–experimental and clinical experience. Int J Oral Maxillofacial Surg 1994;23(6 Pt 2):409–12, doi: 10.1016/s0901-5027(05)80032-3.

57. Deeb W, Hansen L, Hotan T, Hietschold V, Harzer W, Tausche E. Changes in nasal volume after surgically assisted bone-borne rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2010;137:782–9, doi: 10.1016/j.ajodo.2009.03.042.

58. Babacan H, Sokucu O, Doruk C, Ay S. Rapid maxillary expansion and surgically assisted rapid maxillary expansion effects on nasal volume. Angle Orthod 2006;76:66–71, doi: 10.1043/0003-3219(2006)076[0066:rmeasa]2.0.co;2.

59. Pereira-Filho VA, Monnazzi MS, Gabrielli MA, Spin-Neto R, Watanabe ER, Gimenez CM. Volumetric upper airway assessment in patients with transverse maxillary deficiency after surgically assisted rapid maxillary expansion. Int J Oral Maxillofacial Surg 2014;43:581–6, doi: 10.1016/j.ijom.2013.11.002.

60. Seeberger R, Kater W, Davids R, Thiele OC. Long term effects of surgically assisted rapid maxillary expansion without performing osteotomy of the pterygoid plates. J Cranio-maxillo-fac Surg 2010;38:175–8, doi: 10.1016/j.jcms.2009.07.003.

61. Li K, Quo S, Guilleminault C. Endoscopically-assisted surgical expansion (EASE) for the treatment of obstructive sleep apnea. Sleep Med 2019;60:53–9, doi: 10.1016/j.sleep.2018.09.008.

62. Chang Y, Koenig LJ, Pruszynski JE, Bradley TG, Bosio JA, Liu D. Dimensional changes of upper airway after rapid maxillary expansion: a prospective cone-beam computed tomography study. Am J Orthod Dentofacial Orthop 2013;143:462–70, doi: 10.1016/j.ajodo.2012.11.019.

63. Hur JS, Kim HH, Choi JY, Suh SH, Baek SH. Investigation of the effects of miniscrew-assisted rapid palatal expansion on airflow in the upper airway of an adult patient with obstructive sleep apnea syndrome using computational fluid-structure interaction analysis. Korean J Orthod 2017;47:353–64, doi: 10.4041/kjod.2017.47.6.353.

64. Li Q, Tang H, Liu X, Luo Q, Jiang Z, Martin D. Comparison of dimensions and volume of upper airway before and after mini-implant assisted rapid maxillary expansion. Angle Orthod 2020;90(3):432–441, doi: 10.2319/080919-522.1.

65. MacGinnis M, Chu H, Youssef G, Wu KW, Machado AW, Moon W. The effects of micro-implant assisted rapid palatal expansion (MARPE) on the nasomaxillary complex – a finite element method (FEM) analysis. Prog Orthod 2014;15:52, doi: 10.1186/s40510-014-0052-y.

66. Song KT, Park JH, Moon W, Chae JM, Kang KH. Three-dimensional changes of the zygomaticomaxillary complex after mini-implant assisted rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2019;156:653–62, doi: 10.1016/j.ajodo.2018.11.019.