European Journal of Orthodontics, 2021, 313–323
doi:10.1093/ejo/cjab005
Advance Access publication 21 April 2021

Systematic Review

Efficacy of Miniscrew-Assisted Rapid Palatal Expansion (MARPE) in late adolescents and adults: a systematic review and meta-analysis

Aldin Kapetanović[1,*], Christina I. Theodorou[2], Stefaan J. Bergé[3], Jan G.J.H. Schols[1] and Tong Xi[3]

[1]Radboud University Medical Center, Radboud Institute for Health Sciences, Department of Dentistry – Orthodontics and Craniofacial Biology, Nijmegen, The Netherlands
[2]Private orthodontic practice, Hilversum, The Netherlands
[3]Radboud University Medical Center, Radboud Institute for Health Sciences, Department of Oral and Maxillofacial Surgery, Nijmegen, The Netherlands

[*]Correspondence to: Aldin Kapetanović, Department of Dentistry – Orthodontics and Craniofacial Biology, Radboudumc, PO Box 9101, Dentistry 309, 6500 HB Nijmegen, The Netherlands. E-mail: orthodontie@radboudumc.nl

Summary

Background: Miniscrew-Assisted Rapid Palatal Expansion (MARPE) is a non-surgical treatment for transverse maxillary deficiency. However, there is limited evidence concerning its efficacy.
Objectives: This systematic review aims to evaluate the efficacy of MARPE in late adolescents and adults by assessing success rate and skeletal and dental transverse maxillary expansion, as well as treatment duration, dental and periodontal side effects and soft tissue effects.
Search methods: Seven electronic databases were searched (MEDLINE, Embase, Cochrane Library, Web of Science, Scopus, ProQuest and ClinicalTrials.gov) without limitations in November 2020.
Selection criteria: Randomized and non-randomized clinical trials and observational studies on patients from the age of 16 onwards with transverse maxillary deficiency who were treated with MARPE and which included any of the predefined outcomes.
Data collection and analysis: Inclusion eligibility screening, data extraction and risk of bias assessment were performed independently in duplicate. When possible, exploratory meta-analyses of mean differences (MDs) with their 95% confidence intervals (CIs) were conducted, followed by the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) analysis of the evidence quality.
Results: Eight articles were included: two prospective and six retrospective observational studies. One study had a moderate risk of bias, whereas seven studies had a serious risk of bias. GRADE quality of evidence was very low. MARPE showed a high success rate (mean: 92.5%; 95%CI: 88.7%–96.3%), resulting in a significant skeletal width increase (MD: 2.33 mm; 95%CI: 1.63 mm–3.03 mm) and dental intermolar width increase (MD: 6.55 mm; 95%CI: 5.50 mm–7.59 mm). A significant increase in dental tipping, a decrease in mean buccal bone thickness and buccal alveolar height, as well as nasal soft tissue change was present ($P < 0.05$). The mean duration of expansion ranged from 20 to 126 days.
Limitations: One of the main drawbacks was the lack of high-quality prospective studies in the literature.
Conclusions and implications: MARPE is a treatment modality that is associated with a high success rate in skeletal and dental maxillary expansion. MARPE can induce dental and periodontal side effects and affect peri-oral soft tissues. Given the serious risk of bias of the

included studies, careful data interpretation is necessary and future research of higher quality is strongly recommended.
Registration: PROSPERO (CRD42020176618).
Funding: No grants or any other support funding were received.

Introduction

Transverse maxillary deficiency is a relatively frequently encountered orthodontic problem, with a prevalence of approximately 10% in adults, and is often characterized by a unilateral or bilateral posterior crossbite (1, 2). The discrepancy between the maxillary and mandibular arches is associated with a deep and narrow palate, crowding, excessive vertical alveolar growth, large buccal corridors, as well as dental attrition, periodontal damage and facial muscular imbalance. To achieve a stable occlusion and avoid these detrimental effects, it is essential to establish a normal transverse skeletal relationship (3).

Transverse maxillary deficiency is effectively treated with Rapid Palatal Expansion (RPE) in children and young adolescents (4). The RPE-hyrax device transmits bilateral forces from the expansion screw via the first upper molars and premolars to the palatal bone, indirectly leading to separation of the midpalatal suture, which is not fully fused (5).

The optimal timing for RPE is considered below the age of 15, as with older age the midpalatal suture and adjacent articulations start to fuse and become more rigid, leading to a higher resistance to expansion forces (6–8). Besides the pursued maxillary expansion, this may cause undesired effects such as buccal crown tipping, root resorption, gingival recession, alveolar bone dehiscence, reduction in buccal bone thickness, marginal bone loss, pain, limited skeletal expansion or failure and post-expansion relapse (9–11).

In late adolescents and adults, more force is required to open the midpalatal suture due to its increased degree of interdigitation. Treatment with a conventional RPE could lead to unwanted dental side effects (12). Therefore, from the age of 16 onwards, surgically-assisted RPE (SARPE) is commonly applied to overcome these limitations by surgically releasing the interdigitated suture prior to maxillary expansion with an RPE device, such as a hyrax or a Trans-Palatal Distractor (TPD) (12, 13). However, the inherent risks of a surgical operation, together with the cost, the hospitalization and attendant morbidity may pose a constraint for patients to undergo this procedure (14).

The ensuing quest for a non-surgical treatment for maxillary transverse deficiency in patients who would normally apply for a SARPE stimulated the development of Miniscrew-Assisted Rapid Palatal Expansion (MARPE) by Lee *et al.* in South Korea and by Moon *et al.* in the USA (15, 16). MARPE is either a tooth-bone-borne or a solely bone-borne RPE device with a rigid element that connects to miniscrews inserted into the palate, delivering the expansion force directly to the basal bone of the maxilla (15). It was designed to maximize skeletal effects and to minimize dentoalveolar effects of expansion, based on the findings of previous histological studies revealing that the midpalatal suture does not fully ossify in humans even at an elderly age, possibly due to the constant mechanical stress that it undergoes (17, 18). MARPE has received widespread attention in recent years and several researchers have studied the efficacy of MARPE (19, 20). However, to our knowledge, a systematic review on this topic has not yet been published.

This review aims to investigate the efficacy of MARPE by assessing two primary outcomes: the success rate and the achieved skeletal and dental expansion. Secondary outcomes related to the efficacy, such as treatment duration, dental and periodontal side effects and soft tissue effects will also be assessed.

Materials and methods

Protocol and registration

This systematic review reports in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (21). The review protocol was registered at PROSPERO under the unique number CRD42020176618. Details of the protocol can be found at https://www.crd.york.ac.uk/prospero.

Eligibility criteria

Based on the study objectives, the eligibility criteria were predefined. Studies on adults and late adolescents from the age of 16 onwards with transverse maxillary deficiency, treated with MARPE, including all types of MARPE appliance designs, whether hybrid tooth-bone-borne or only bone-borne, and all types of expansion protocols, were considered eligible if any of the main outcomes were reported: the success rate of the treatment of transverse maxillary expansion (dental or skeletal), or any of the additional outcomes: duration, side-effects (dental or periodontal) or soft tissue effects. Both randomized and non-randomized clinical trials and observational studies, either prospective or retrospective, were considered eligible.

Studies including patients under the age of 16, patients with cleft lip and palate or craniofacial anomalies, patients with a history of maxillofacial surgery, and in vitro simulations such as FEM analysis were excluded.

Information sources and search strategy

A comprehensive search strategy was developed in collaboration with an experienced health science librarian. To aid the selection of search terms, a PICOS question was formulated, including the following elements: Procedure: maxillary expansion or palatal expansion; Intervention: non-surgical techniques; while Control, Outcome and Study design were deliberately left open to produce a search that would be as broad as possible.

Seven electronic databases were searched: MEDLINE (via PubMed), Embase (via OVID), Cochrane Library, Web of Science, Scopus, ProQuest and ClinicalTrials.gov. The search terms were developed for MEDLINE and modified accordingly for the other databases. No language or publication date restrictions were applied. All studies published until 20th November 2020 were considered. Additionally, a hand search was performed and the grey literature was searched through a Google Scholar web search. Supplementary Table 1 illustrates the details of the searches.

Study selection

Three investigators were involved in the study selection process (A.K., C.T. and J.S.). The selection process was carried out using Covidence (Veritas Health Innovation, Melbourne, Australia. Available at https://www.covidence.org), a Web-based software platform that streamlines the production of systematic reviews. After removal of duplicates, each retrieved record was assessed by two independent observers based on the predefined eligibility criteria.

All articles were screened by title and abstract first. The remaining articles were carefully evaluated and assessed based on their full texts. Furthermore, the reference lists of the selected articles were searched manually for additional relevant publications. Authors were contacted if the information was lacking or unclear. Disagreement regarding any entry was resolved by consensus by all three investigators.

Data items and collection

Data extraction was conducted independently by two researchers (A.K. and C.T.). Any differences between the two researchers were discussed and resolved by consensus. Data from one included article in Chinese were extracted by the fourth researcher (T.X.), who is proficient in Chinese. The data extraction included: study identification (authors name, publication year, setting, institution, country, e-mail, address and sponsorship source), methods (study design, data collection, measurements, number of investigators, blinding, reliability and statistical analysis), population (inclusion and exclusion criteria, sample size, sex, age range, and mean age), intervention (MARPE expansion device, miniscrews used, appliance location, and expansion protocol) and outcomes (any of the aforementioned main or additional outcomes). The extracted data were recorded in Covidence.

Transverse maxillary expansion was defined as the midpalatal suture opening in millimetres or maxillary width increase in millimetres (skeletal expansion) and intercanine, interpremolar or intermolar width in millimetres (dental expansion). Success rate of the treatment was the percentage of patients achieving the required maxillary width. Duration was expressed in days of expansion until the required width was achieved. Dental side effects were defined as post-treatment dental tipping measured in degrees, periodontal side effects were defined as post-treatment change in buccal bone thickness or buccal alveolar height measured in millimetres, and soft tissue effects were defined as post-treatment facial changes measured in millimetres.

Risk of bias assessment in individual studies

To estimate the risk of bias, two observers (A.K. and C.T.) evaluated the individual studies independently, except for one article written in Chinese, which was evaluated by T.X. and A.K. These assessments were conducted with validated instruments as described in the Cochrane Handbook for Systematic Reviews of Interventions (22), including the Revised Cochrane Risk of Bias Tool for randomized trials (23) and the Risk Of Bias in Non-randomized Studies – of Interventions (ROBINS-I) tool for observational research (24). According to the ROBINS-I tool, potential studies assessed with a critical risk of bias were excluded from further analysis and synthesis (24). Any differences between the observers were discussed and resolved by consensus.

Synthesis of results and summary measures

Mean differences (MDs) and their corresponding 95% confidence intervals (CIs) were calculated for the main outcomes: success rate, skeletal width increase and dental intermolar width increase. The heterogeneity among studies was tested using a χ^2-based Q statistic. Heterogeneity was further quantified by the τ^2 or the I^2 statistics. A random-effects model was used when homogeneity was rejected (p-value less than 0.10). The analyses were performed in R-version 3.6.3. for Windows (Available at https://www.r-project.org) (25).

Risk of bias assessment across studies

The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) assessment was performed to estimate the overall quality of evidence (26). Three observers (A.K., C.T. and T.X.) carried out this analysis and any differences between the observers were discussed and resolved by consensus.

Results

Study selection and characteristics

The selection process is summarized in Figure 1. 1352 articles were identified through database searching (MEDLINE N = 319, Embase N = 253, Cochrane Library N = 53, Web of Science N = 263, Scopus N = 440, ProQuest N = 9, ClinicalTrials.gov N = 15) and no articles were included through the hand search. After duplicate removal, 612 studies underwent title and abstract screening and 27 studies underwent full-text screening. The reference screening of the full-text articles resulted in one additional relevant publication, while the grey literature search did not yield any new articles. Nineteen full-text articles were excluded, the vast majority of which because of the inclusion of patients under the age of 16 (see Supplementary Table 2: exclusions). One article was excluded to avoid result overestimation, as the authors failed to reply to an e-mail regarding the outcome data (27). A remaining total of nine articles (28–36), two prospective (29, 30) and seven retrospective observational studies (28, 31–36) met the inclusion criteria of this review. A Cohen's Kappa analysis was performed for assessment of inter-rater reliability, which proved to be good (κ = 0.82). The main characteristics of the included studies are shown in Table 1. There was no grouping of the results based on MARPE design as in all studies a tooth-bone-borne appliance was used.

Risk of bias within studies

The ROBINS-I tool was used for the risk of bias assessment of all the included studies, all of which were observational studies (see: Figures 2 & 3). One study (30) showed a moderate risk of bias and seven studies (28, 29, 31–35) had a serious risk of bias, mainly because of bias due to confounding, selection of participants and measurement of outcomes. One study (36) had a critical risk of bias and was thus excluded from further analysis according to the ROBINS-I tool (24), bringing the final number of included studies down to eight. Six out of eight studies (29, 30, 32–35) reported no potential conflict of interest.

Results of individual studies

The outcomes of all individual studies for the primary outcomes are summarized in Tables 2–4 and for the secondary outcomes in Supplementary Tables 3–4.

Success rate of MARPE

All eight studies (28–35) reported the success rate of the MARPE treatment, which ranged from 80.65% to 100% (see: Table 2). Three studies reported a success rate of 100% (29, 31, 33).

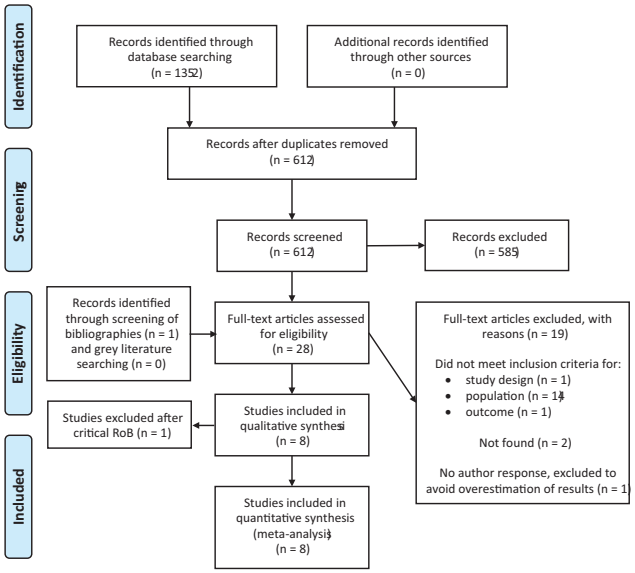

Figure 1. Literature search Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

Skeletal transverse maxillary expansion

Skeletal transverse maxillary expansion was reported in seven articles (28, 29, 31–35). A variety of different measurements was used across these studies (see: Table 3a). The mean skeletal expansion ranged from 1.11 mm to 4.5 mm and was statistically significant in all five articles (28, 29, 31, 32, 34) where the p-value was calculated. One study differentiated between a midpalatal suture separation group and a non-separation group and reported results for both groups separately and combined (35).

Additionally, the percentage of skeletal versus non-skeletal (dental, alveolar or dentoalveolar) expansion achieved by MARPE was reported in five out of eight included studies (28, 29, 32–34) and is shown in Table 3b. The skeletal component of expansion by MARPE ranged from 25% to 61% immediately post-expansion.

Dental transverse maxillary expansion

Five studies reported on dental transverse maxillary expansion (28, 29, 32–34). Table 4 gives an overview of the intermolar widths (IMW), and, when available, the intercanine (ICW) and interpremolar (IPW) widths. The mean ICW ranged from 2.86 mm to 5.83 mm, the mean IPW ranged from 5.33 mm to 6.09 mm and the mean IMW ranged from 5.4 mm to 8.32 mm. Measurements in all but one study (33) were statistically significant.

Duration of expansion

Seven studies reported on the duration of expansion that was measured in months, weeks or days (28, 30–35). To compare the results, the duration was converted into days (see: Supplementary Table 3). The mean number of days of expansion ranged from 20 to 126 until the necessary amount of expansion was achieved. Different expansion protocols were used across the studies. The mean duration of expansion in those studies with a rapid expansion protocol ranged from 20 to 35 days (30, 32, 34, 35).

Dental side effects

Four studies reported on dental side effects (29, 32–34). Supplementary Table 4 gives an overview of the dental tipping of the upper first molars. All studies reported a statistically significant amount of dental tipping. There was a wide variation in the mean amount of dental tipping, ranging from −5.5° to 8.01° and the exact methods of measurements varied across the studies.

Periodontal side effects

The periodontal side effects were studied in three articles (32–34). More specifically, Supplementary Table 5 gives an overview of either buccal bone thickness at the mesiobuccal root of first upper molars (32–34) or buccal alveolar crest level/buccal alveolar height (32, 34). There was a decrease in the mean buccal bone thickness in all three studies, ranging from −0.36 mm to −0.60 mm, and a decrease in buccal alveolar height/crest level ranging from 0.74 mm to 1.7 mm. The changes were statistically significant in all studies except for mean buccal bone thickness at the left mesiobuccal first molar root in one study (33).

Soft tissue effects

One article (30) studied soft tissue effects, more specifically the short-term impact on the nasal soft tissues, the majority of which showed significant positional changes. The nose tended to widen and move forward and downward and the post-treatment nasal volume exhibited an increase relative to the initial volume (see: Supplementary Table 6).

Synthesis of the results

There were considerable differences between the studies in methodology, appliance design, expansion protocol, and other factors that could influence their results. Hence, only a meta-analysis on an exploratory basis was deemed appropriate for the main outcomes: success rate (eight contributing studies) (28–35), skeletal width increase (seven studies) (28, 29, 31–35) and dental intermolar width increase (five studies) (28, 29, 32–34). The results are shown in Figures 4 and 5. The heterogeneity of data was relatively low for success rate ($P = 0.124$), and was judged as very high regarding skeletal ($P < 0.0001$) and dental ($P < 0.0001$) width increase (see: Supplementary Table 7). The mean success rate was 92.5% (95% CI: 88.7%–96.3%), while the mean skeletal width increase was 2.33 mm (95% CI: 1.63 mm–3.03 mm) and the mean dental intermolar width increase was 6.55mm (95% CI: 5.50 mm–7.59 mm). Given that the increase in IMW represented the combined skeletal, dental and alveolar expansion, the mean skeletal component accounted for 35.6% of the total expansion (28, 29, 32–34).

Risk of bias across studies

The overall GRADE rating of the quality of evidence for the three meta-analyses was very low since observational studies start off with a GRADE rating of low and downgrading occurred for all three outcomes. The main reason for downgrading was the inclusion of studies with serious risk of bias, but inconsistency, indirectness and imprecision were also present for some outcomes (see: Supplementary Table 8).

Discussion

Summary of evidence

The aim of the present systematic review was to assess the efficacy of MARPE from the age of 16 onwards, in non-growing patients. A total of eight studies (28–35) met the eligibility criteria and were included in a qualitative analysis after the risk of bias assessment. Due to methodological differences between the articles, a meta-analysis on an exploratory basis was conducted for the main outcomes.

Table 1. Main characteristics of the included studies. Study and patient characteristics, data collection, intervention and outcomes were described for each included study.

Author Year Setting & country Study design	*Study design*	Sample size, sex, age (range, mean ± SD)	Data collection	Intervention: appliance type, location, tads	Intervention: expansion protocol	Outcomes
Choi *et al.* 2016 (28) Academic, South Korea	Retrospective study	Total *N* = 69 Included *N* = 20 10 m, 10 f 18–28 years 20.9 ± 2.9 years	Dental casts and posteroanterior cephalograms at T0: before treatment T1: immediately after MARME removal T2: immediately after debonding T3: post-treatment	Modified hyrax-type MARPE appliance with rigid connectors to both P1s and M1s and helical hooks soldered on base of Hyrax screw (Dentaurum, Ispringen, Germany) Anterior position (at P1) L: 7 mm, D: 1.8 mm, *N* = 4 TADs attached to hooks with light-cured resin	1 turn (¼ of the expansion screw; 0.2 mm) every other day (slow expansion) Retention phase of 3 months before continuation of orthodontic treatment	Posteroanterior cephalogram: Nasal cavity width, maxillary width, and middle alveolus width Dental casts: ICW, IPW, IMW and average clinical crown heights at C, P1 & M1
Clement *et al.* 2017 (28) Academic, India	Prospective study	*N* = 10 5 m, 5 f 19–24 years 21.5 years	Study models, photographs & CBCT at T1: before expansion T2: after stabilization	MSE appliance (BioMaterials, Seoul, Korea) Posterior position (1–2 mm anterior to junction of hard and soft palate) *N* = 4, L: 11 mm, D: 1.8 mm	Initiated 2 days after insertion, then activated 2 turns/d Stabilization phase of 4 months after end of expansion	Transverse expansion: - skeletal: at the medial limits of L&R palatine process at maxillary I, C, P1, P2, M1. - alveolar: most coronal medial limits of Lt&Rt alveolar process at C, P1, P2, M1. - dental: ICW, IPW, IMW Dental tipping at Lt&Rt C, P1, P2, M1. Suture angulation Transverse cranial measurements: bilateral landmarks of nasal cavity, zygoma & frontonasal areas.
Lee *et al.* 2020 (30) Academic, South Korea	Prospective study	Total *N* = 46 Included *N* = 30 12 m, 18 f 17.4–42.2 years 20.46 years	3D stereo-photogrammetry at T0: pre-MARPE expansion T1: right after MARPE placing T2: post-MARPE when 7 mm of appliance expansion achieved	MSE-12 appliance (BioMaterials, Seoul, Korea) Posterior position (at M1) *N* = 4, L: 11 mm, D: 1.5 mm	1 turn/d, after 7 mm appliance expansion, evaluation of midpalatal suture separation followed by 3D scanning	Alar width, alar base width, inferior width of the nostrils, alar curvature width, pronasale, subnasale with separate (x, y, z) co-ordinate values defining each landmark in the 3D Euclidean space. Volume of the nose measured using the method of van Loon *et al.* (2010)
Li *et al.* 2020 (31) Academic, China	Retrospective study	*N* = 22 4 m, 18 f 18–35 years 22.6 ± 4.5 years	CBCT at T0: before expansion T1: after 3 months retention Lateral cephalogram before expansion	MSE type 2 appliance (BioMaterials, Seoul, Korea) Posterior position (at M1) *N* = 4, L: 11 mm, D: 1.5 mm	4 turns immediately after placing followed by 2 turns every other day (one turn = 0.13 mm) Retention phase of 3 months after end of expansion	Vertical and horizontal dimensions and volume of upper airway (nasal cavity and nasopharynx) incl. maxillary width at nasal floor and hard palate.
Lim *et al.* 2017 (32) Academic, South Korea	Retrospective study	Total *N* = 38 Included *N* = 24 8 m, 16 f 18.25–26.75 years 21.6 ± 3.1 years	CBCT images at T0: before MARPE T1: within 1 month after MARPE (mean, 9.5; range, 0–28 days) T2: 1 year after MARPE (mean, 14.17; range, 12.0–16.5 months)	Modified hyrax-type MARPE appliance with rigid connectors to both P1s and M1s and helical hooks soldered on base of Hyrax screw (Dentaurum, Ispringen, Germany) Anterior position (at P1) *N* = 4, L: 7 mm, D: 1.8 mm attached to hooks with light-cured resin	1x/d (0.2 mm per turn) Retention phase of ca. 4 months after end of expansion	Appliance expansion. Skeletal expansion: nasal cavity width, nasal floor width, alveolar width. Dental expansion: ICW, IP1W, IP2W, IMW, inter-apex width. Tooth inclination, alveolar inclination, absolute changes in tooth inclination. Interproximal & buccal alveolar crest level, buccal & palatal bone thickness.

Table 1. Continued

Author Year Setting & country Study design	*Study design*	Sample size, sex, age (range, mean ± SD)	Data collection	Intervention: appliance type, location, tads	Intervention: expansion protocol	Outcomes
Ngan *et al.* 2018 (33) Academic, USA	Retrospective study	*N* = 8 2 m, 6 f Age range: n.m. 21.9 ± 1.5 years	CBCT images at T1: Pretreatment T2: immediately postexpansion	MSE appliance (BioMaterials, Seoul, Korea), but modified with number of teeth for appliance anchorage ranging from 2 to 4 (mean: 3.63) Anterior position (at P1) *N* = 4 Middle position (at P2) *N* = 4 *N* = 4 in 7 patients, *N* = 2 in 1 patient, L: 11 mm, D: 1.8 mm	Number of turns per day varied with severity of transverse discrepancy	Total expansion Skeletal: Midpalatal suture maturation assessment by Angelieri *et al.* (20), midpalatal suture expansion at middle of the palate, C, P1, P2, M1 (coronal view) and at nasal and palatal floor (axial view) Dentoalveolar: IMW, Dental tipping angle, Palatal maxillary width, Palatal alveolar angle, Buccal bone thickness Craniofacial expansion assessment at the zygomatic and infrazygomatic areas illustrated on superimposed 3D skeletal color maps
Park *et al.* 2017 (34) Academic, South Korea	Retrospective study	Total *N* = 19 Included N = 14 9 m, 5 f 16–26 years 20.1 ± 2.4 years	CBCT images at T1: before expansion T2: after expansion (mean, 10.7 d; range, 1–35 d)	Modified hyrax-type MARPE appliance with rigid connectors to both P1s and M1s and helical hooks soldered on base of Hyrax screw (Dentaurum, Ispringen, Germany) Anterior position (at P1) *N* = 4, L: 7 mm, D: 1.8 mm attached to hooks with light-cured resin	Start 1 day after insertion at 1 turn/d (0.2 mm/turn)	Skeletal expansion: bilateral nasal, zygomatic maxillary and alveolar landmarks on posteroanterior cephalograms constructed out of CBCT Nasal cavity width and basal bone width on coronal CBCT slices. Dentoalveolar expansion: IPW, IMW, interdental angle, buccal bone thickness, buccal alveolar height on coronal slices. Displacement in the maxilla, assessed in the transverse (*x*), sagittal (*y*), and vertical (*z*) planes by superimposition of 3D CBCT volumetric images at T1 and T2.
Shin *et al.* 2019 (35) Academic, South Korea	Retrospective study	*N* = 31 10 m, 21 f 18–36 years 22.52 ± 5.11 years	Lateral cephalograms, CBCTs, and maxillary anterior periapical radiographs at T0: before T2: after MARPE Periapicals taken at 2- to 4-week intervals after start expansion to confirm midpalatal suture opening. T1 = time when suture opening was first found in a periapical	Updated modified hyrax-type MARPE appliance with rigid connectors to both P1s and M1s and precise TAD insertion openings (instead of helical hooks) soldered on base of Hyrax screw (Dentaurum, Ispringen, Germany) Middle position (at P2) *N* = 4, L: 7 mm, D: 1.8 mm (no resin needed)	1 turn/day (0.2 mm/turn) until midpalatal suture opening verified in a periapical (Separation group). If no opening was found in a periapical, 1 turn/2 days to obtain camouflage dental effect (non-separation group)	Midpalatal suture opening width and ratio Midpalatal suture maturation stage and density ratio Palate length Palate depth at P1 and M1 Vertical skeletal pattern Anteroposterior skeletal classification
Wang *et al.* 2018 (36) Academic, China	Retrospective study	*N* = 16 (MARPE *N* = 7, SARPE *N* = 9) 8 m (4 MARPE, 4 SARPE), 8 f (3 MARPE, 5 SARPE) 19–43 years 25.9 years (25.29 ± 3.86 years MARPE, 26.44 ± 6.48 years SARPE)	CBCT images at T0: pretreatment T1: 3 months posttreatment	Modified hyrax-type MARPE appliance with rigid connectors to both P1s (in some cases P2s) and M1s and precise TAD insertion openings soldered on base of Hyrax screw (Manufacturer: n.m.) Posterior position (at M1) *N*= 4; L, D: n.m. Composite resin material used to fixate TADs to expander SARPE: same hyrax design as MARPE but without the 4 TADs	MARPE: 0.27mm/d (120 degrees rotation) SARPE: 0.4mm/d (180 degrees rotation)	Skeletal: Anterior (at C) and posterior (at M1) midpalatal suture width, distance between Lt and Rt zygomaticomaxillary suture, nasal cavity and nasal floor width Dental: tipping of anchored teeth (P1 and M1, mean angle of Lt and Rt side), Periodontal: buccal alveolar height, buccal alveolar thickness (at mesiobuccal root M1)

I: incisor; C: canine; P1: first premolar; P2: second premolar; M1: first molar; ICW: intercanine width; IPW or IP1W: interpremolar width at P1; IP2W: interpremolar width at P2; IMW: intermolar width; TAD: temporary anchorage device = miniscrew; L: length; D: diameter; Rt: right; Lt: left; d: day; f: females; m: males; n.m: not mentioned.

The definition of successful expansion varied slightly across the included studies, but it was commonly considered adequate when the occlusal aspect of the lingual cusp of the maxillary first molars contacted the occlusal aspect of the buccal cusp of the mandibular first molars (32). MARPE demonstrated to be a highly successful treatment modality, with a mean success rate of 92.5% (28–35). Three studies reported a success rate of 100% (29, 31, 33), but one of them (31) only included patients with a successful opening of the midpalatal suture.

Skeletal transverse maxillary expansion was statistically significant in five out of seven studies (28, 29, 31, 32, 34). The mean skeletal expansion of 2.33 mm (1.63 mm–3.03 mm) was statistically but less so clinically different from the mean skeletal expansion by SARPE of 3.3 mm (2.8 mm–3.9 mm), as found by Bortolotti *et al.* in their systematic review (37). Considerable variation was present in the measurements performed to evaluate skeletal expansion across the studies, including midpalatal suture expansion (29, 32, 34), maxillary basal bone width increase (28, 33), width increase at the hard palate (31) and width increase at the nasal floor (32).

Furthermore, five studies reported on dental transverse maxillary expansion and found that the mean IMW increase was 6.55 mm (5.50 mm–7.59 mm) (28, 29, 32–34). Different records were used for measuring interdental distances, including dental casts (28), coronal slices of CBCT images (29), and volumetric CBCT images (32, 34), thus complicating an accurate comparison of the results. In comparison, the mean IMW increase achieved by SARPE was statistically larger (MD: 7.0 mm, 95% CI: 6.1 mm–7.8 mm), but did not clinically differ from that achieved by MARPE (37).

The mean skeletal component of expansion following MARPE, 35.6% (28, 29, 32–34), was comparable to that of expansion following RPE and SARPE, ranging from 40% to 55% (38, 39) and 21.5% to 46.3% (40–43), respectively. Based on the mean skeletal and dental expansion Bortolotti *et al.* concluded that transverse maxillary expansion is mostly due to dental movements at the molar level, while the skeletal effects were significant but contributed less to the total expansion (37).

From the additional outcome measures, duration of expansion was reported in seven studies (28, 30–35) and there was a clear association between duration and the expansion protocol that was used. In the majority of studies, a rapid protocol with a speed of 1–2 turns per day was applied and expansion took approximately 3–7 weeks (20–35 days) (30, 32, 34, 35). Choi *et al.* (28) and Li *et al.* (31) applied a slow expansion protocol of 1–2 turns every other day and, consequently, reported the longest duration. Ngan *et al.* reported that their 'appliance activation varied with the severity of transverse discrepancy between the upper and lower jaws', but there was no further elaboration (33).

Dental side effects were reported in four studies (29, 32–34), all of which describe the post-treatment angulation as buccal dental tipping. Dental tipping of the first molar was statistically significant and ranged from 2.07° to 8.01°, which is comparable to previous studies reporting 2.5° to 7.04° of buccal tipping when RPE or SARPE is applied (44–47). Nevertheless, there were important methodological differences, with three studies measuring the angle of the tooth axis to the hard palate (29, 32, 33), but only one of them, Lim *et al.*, reported the absolute change in tooth inclination, which was calculated by subtracting the change in alveolar inclination from the change in tooth inclination (32).

Three studies (32–34) reported periodontal side-effects, more specifically by measuring buccal bone thickness (32–34) and buccal alveolar height/crest level (32, 34), defined as the distance from the buccal/mesiobuccal cusp tip to the buccal alveolar crest (34). The changes observed after MARPE were similar to those observed after conventional RPE (9, 10, 48) and, even though they were statistically

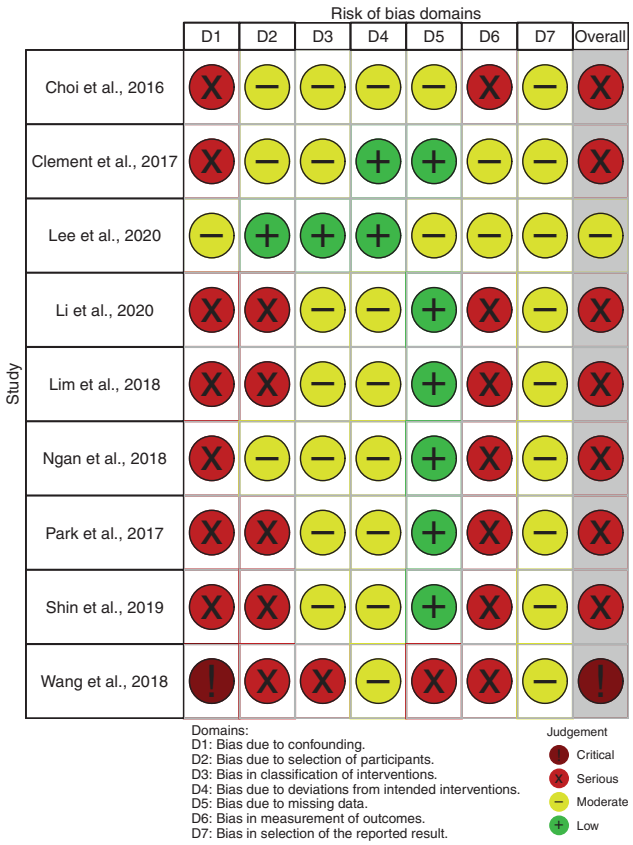

Figure 2. Results of the risk of bias assessment in the individual studies with the Risk Of Bias in Non-randomized Studies – of Interventions (ROBINS)-I tool.

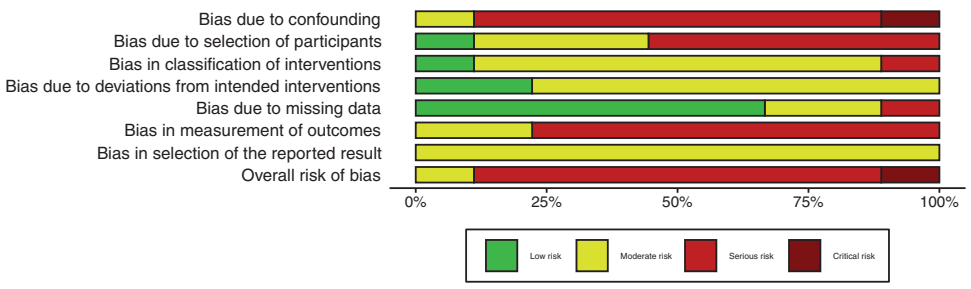

Figure 3. Risk of bias percentage per domain of all included studies assessed with the Risk Of Bias in Non-randomized Studies – of Interventions (ROBINS-I) tool.

significant in all three studies, they can be considered clinically insignificant for patients with a healthy periodontium at the start of treatment (33). However, patients with a compromised periodontal situation may be at increased risk of unwanted periodontal side effects (33).

Finally, only one study with a moderate risk of bias evaluated soft tissue changes of the nose, mainly suggesting that MARPE tends to produce slight nasal widening (30). This corresponds with findings from studies on SARPE where, among other changes, the alar width, alar base width and subnasal width also increased after treatment (49, 50). Patients, therefore, need to be informed about these effects.

Table 2. Results of individual studies for MARPE success rate.

Study	*N* (successful/total)	%
Choi *et al.* (2016) (28)	60/69	86.96
Clement *et al.* (2017) (29)	10/10	100
Lee *et al.* (2020) (30)	43/46	93.48
Li *et al.* (2020) (31)	22/22	100
Lim *et al.* (2017) (32)	33/38	86.84
Ngan *et al.* (2018) (33)	8/8	100
Park *et al.* (2017) (34)	16/19	84.21
Shin *et al.* (2019) (35)	25/31	80.65

MARPE = Miniscrew-Assisted Rapid Palatal Expansion.

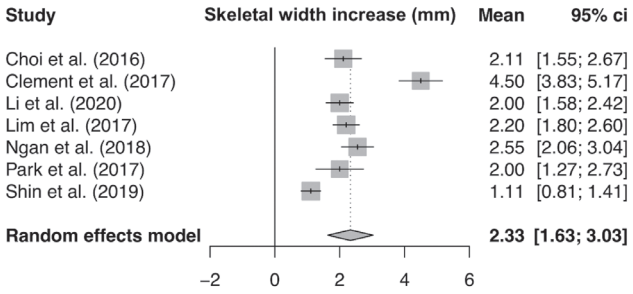

Figure 4. Forest plot of skeletal width increase after Miniscrew-Assisted Rapid Palatal Expansion (MARPE).

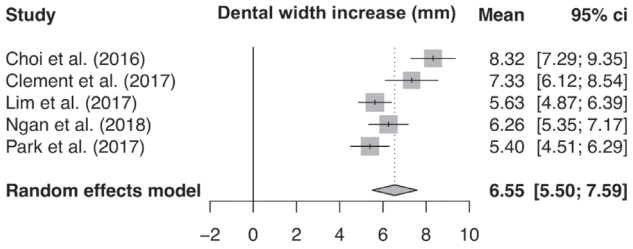

Figure 5. Forest plot of dental intermolar width increase after Miniscrew-Assisted Rapid Palatal Expansion (MARPE).

Limitations

One of the main limitations at outcome level was the serious risk of bias detected in seven out of eight studies (28, 29, 31–35), and consequently, the very low quality of evidence of the meta-analyses. This was primarily due to the observational nature of the included articles. As a consequence of the absence of high-quality literature, strong conclusions could not be drawn.

Furthermore, two groups of MARPE appliances could be distinguished: the modified hyrax-type MARPE expander (29–31, 33), and the Maxillary Skeletal Expander (MSE) (28, 32, 34, 35), both methods applied in 50% of the studies. Differences in the choice of MARPE appliance, but also appliance location, expansion protocol

Table 3b. Results of individual studies for contribution to expansion immediately post-treatment of each maxillary area: skeletal, dental, alveolar (or dentoalveolar).

Study	Maxillary area	%
Choi *et al.* (2016) (28)	Skeletal	25.4
	Dentoalveolar	74.6
Clement *et al.* (2017) (29)	Skeletal	61
	Alveolar	20
	Dental	19
Lim *et al.* (2017) (32)	Skeletal	39.1
	Alveolar	7.1
	Dental	53.8
Ngan *et al.* (2018) (33)	Skeletal	41
	Alveolar	12
	Dental	47
Park *et al.* (2017) (34)	Skeletal	37
	Alveolar	22.2
	Dental	40.7

Table 3a. Results of individual studies for skeletal maxillary expansion by MARPE. Measurement, mean ± SD (mm), 95% CI (mm), range (mm), *P*-value and effect size were described when available.

Study	Measurement	Mean ± SD (mm)	95% CI lower/upper	Range (mm)	*P* value	Effect size
Choi *et al.* (2016) (28)	J–J width	2.11	1.54/2.68		<0.001	
Clement *et al.* (2017) (29)	Suture opening at M1	4.5	3.62/4.98		0.000	4.53
Li *et al.* (2020) (31)	Maxillary width at hard palate	2.0 ± 1.0			<0.001	
Lim *et al.* (2017) (32)	Nasal floor width	2.20 ± 1.01			<0.001	
Ngan *et al.* (2018) (33)	Midpalatal suture expansion at the middle of the palate	2.55 ± 0.71		2.03 – 4.06		
Park *et al.* (2017) (34)	J–J width on PA ceph	2.0 ± 1.4			0.000	
Shin *et al.* (2019) (35)	Midpalatal suture opening width	0.90 ± 0.81 (Total) 1.11 ± 0.76 (Separation group) 0.001 ± 0.02 (Non-separation group)				

MARPE: Miniscrew-Assisted Rapid Palatal Expansion; J-J width: basal bone width; PA ceph: posteroanterior cephalogram; SD: standard deviation.

Table 4. Results of individual studies for dental expansion by MARPE. Measurement, mean ± SD (mm), 95% CI (mm), p-value and effect size were described when available.

Study	Measurement	Mean ± SD (mm)	95% CI lower/upper	*P* value	Effect size
Choi *et al.* (2016) (28)	ICW	2.86	2.07/3.64	<0.001	
	IPW	6.09	5.37/6.81	<0.001	
	IMW	8.32	7.27/9.37	<0.001	
Clement *et al.* (2017) (29)	ICW	5.83 ± 1.32	3.76/5.44	0.000	3.92
	IPW	5.33 ± 1.72	3.47/5.53	0.043	3.14
	IMW	7.33 ± 1.96	5.69/8.31	0.004	3.83
Lim *et al.* (2017) (32)	ICW	3.02 ± 1.25		<0.001	
	IPW	5.96 ± 1.20		<0.001	
	IMW	5.63 ± 1.90		<0.001	
Ngan *et al.* (2017) (33)	IMW	6.26 ± 1.31			
Park *et al.* (2017) (34)	IPW	5.5 ± 1.4		0.000	
	IMW	5.4 ± 1.7		0.000	

MARPE: Miniscrew-Assisted Rapid Palatal Expansion; ICW: inter-canine width; IPW: inter-premolar width; IMW: inter-molar width CI: confidence interval; SD: standard deviation.

and number and features of the miniscrews could have significantly impacted the resulting success rate, transverse maxillary expansion, treatment duration, soft tissue and other side effects. In the study of Ngan *et al.* there was even variation in appliance design and features within the same study sample (33). In addition, there were large methodological differences in measurements across the studies, as previously mentioned, as well as in record collection. Six out of eight studies (29, 31–35) used CBCT images, but lateral (31, 35) and posteroanterior cephalograms (28), dental casts (28), maxillary anterior periapical radiographs (35) and 3D stereo-photogrammetry (30) were used for measurements as well. Moreover, the timing at which these records were collected was the same for all studies before and at the beginning of the expansion, but varied widely after expansion. The heterogeneity limited the meta-analysis to be performed on an exploratory basis, rather than to achieve conclusive results.

Conclusions

This systematic review demonstrated that MARPE is a successful treatment modality for maxillary expansion (mean success rate: 92.5%), inducing both skeletal (MD: 2.33 mm) and dental (MD: 6.55 mm) transverse maxillary expansion. These results are clinically comparable to the expansion achieved by SARPE. Furthermore, there is limited evidence showing that, despite its relatively short treatment duration, MARPE may induce dental and periodontal side effects and affect peri-oral soft tissues.

Due to the serious risk of bias in the majority of the included studies, careful data interpretation is necessary. High-quality studies in the form of randomized clinical trials and prospective cohort studies with a well-defined appliance design and treatment protocol are strongly recommended to deliver a higher quality of evidence on the efficacy of MARPE.

Supplementary material

Supplementary material is available at *European Journal of Orthodontics* online.

Acknowledgements

We would like to thank Dr. Imke L.J. Adams, PhD, and Alice H.J. Tillema, Scientific Information Specialists at the Radboud University Nijmegen, the Netherlands for their assistance with the systematic literature search. We are also grateful to Ewald M. Bronkhorst, Statistician and Methodologist at the Radboud University Nijmegen for his assistance with the meta-analysis.

Funding

No grants or any other support funding were received for conducting this systematic review and meta-analysis.

Conflicts of interest

All authors have no conflicts of interest to declare.

Ethics approval information

No ethical approval was requested for this systematic review and meta-analysis.

Data availability

The data underlying this article are available in the article and in its online supplementary material.

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