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Systematic Review/Meta-Analysis

Dentoalveolar, periodontal and skeletal effects of maxillary expansion techniques assisted by temporary anchorage devices compared with conventional protocols in growing patients with transverse maxillary deficiency: A systematic review and meta-analysis

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Keywords
Malocclusion
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Summary

Objectives > To synthesise the dentoalveolar, periodontal and skeletal changes that occur when using maxillary expansion techniques assisted by temporary anchorage devices compared to conventional protocols.

Methods > Five databases and grey literature were consulted, up to December 2023, focusing on intervention designs and excluding other type of studies. The quality assessment was conducted by using the adaptation for orthodontics of the CONSORT statement, the guidelines for reporting non-randomised studies, the RoB-2 tool, and the ROBINS-I tool. A descriptive summary and meta-analysis using RevMan 5.4 were performed.

Results > Nine clinical trials were included (n = 377 patients, mean age 13.2 $\pm$ 0.6) with a diagnosis of transverse maxillary deficiency. The analysed studies showed qualitative dentoalveolar and periodontal changes after expansion, which were greater on the maxillary first premolars in tooth-borne appliances. Meta-analyses for some effects were included from two studies (n = 64); patients who used tooth-borne appliances had greater effects of buccal

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intercoronal width between the premolars with statistically significant differences (Std Mean difference 2.34; 95% CI: 0.04–4.65 p = 0.05). Conversely, those patients who used bone-borne or hybrid appliances had greater effects of buccal intercoronal width between molars with statistically significant differences (Std Mean difference −0.64; 95% CI: −1.38–0.10; p = 0.09).
Conclusions > According to the studies analysed, all measurements increased in the intervention groups after expansion. Quantitative analyses show different findings at dentoalveolar level when tooth-borne, bone-borne or hybrid appliances are considered. Nevertheless, the results should be taken with caution due to the heterogeneity of the studies.
The protocol was registered at PROSPERO (CRD42021283170), with no funding to report.

Introduction

Transverse maxillary deficiency (TMD) affects a significant number of patients seeking orthodontic treatment, with a prevalence of 23.3% at an early age of development [1]. Its aetiology is multifactorial and can be skeletal, dental or both [2]. If TMD is not properly, corrected it can lead to a series of problems, such as occlusal disharmony, changes in the tongue posture, periodontal conditions, temporomandibular joint dysfunction and lack of space in the arch for dental alignment [3,4].

For the correction of TMD, rapid maxillary expansion (RME) using tooth-borne devices is often employed [5]. However, it is associated with various adverse effects on the periodontium [6], such as excessive buccal dental movements that can lead to significant reductions in alveolar bone levels, dehiscence and gingival recession [7]. The surgically assisted expansion could be a predictable alternative for reducing periodontal risks [8], but it has disadvantages such as high costs, morbidity and patient reluctance to undergo surgery [9].

Bone-borne RME assisted by temporary anchorage devices (TADs) has been proposed as a procedure capable of achieving transverse corrections without causing serious side effects, even in adult patients. This is because the load exerted during tooth movement is directly distributed to the palate, resulting in less rotation and tilting of the maxillary complex and reduced stress on the supporting periodontal tissues [10].

Some studies comparing the use of RME assisted by TADs with conventional expansion protocols have found that the former yields greater success in outcomes and reduces adverse effects at the end of treatment [11–13]. Copello et al. suggested that bone-borne devices may cause less loss of alveolar bone levels, but the authors also stated that the results should be evaluated with caution due to the limited evidence found of such devices' effectiveness, the studies' heterogeneity and the poor methods used by the studies [14]. According to Krüsi et al., the forces transmitted by the bone through skeletal anchorage can be associated with greater maxillary expansion after retention but few clinical trials with limited sample sizes and some risk of bias have been reported [15]. Khosravi et al. found that devices transmitting force through dental anchorage and those applying it at the bone level yield similar results in terms of maxillary expansion amount, dental inclination, stability, and perceived pain. However, this study was limited to the analysis of adult patients and non-growing individuals, contradicting results from other studies and thus preventing solid conclusions [16].

Accordingly, this systematic review and meta-analysis aimed to synthesise the dentoalveolar, periodontal and skeletal changes that occur when using expansion assisted by TADs compared to conventional protocols in patients with TMD.

Material and methods

A systematic review was conducted according to the PRISMA 2020 statement [17]. The study protocol was registered at PROSPERO (International Prospective Register of Systematic Reviews) (CRD42021283170) and approved by the Ethics Committee of the Faculty of Dentistry of the University of Antioquia (Institutional Review Board 92–2021).

PICOS question and eligibility criteria

The PICOS question and its components are detailed in *table I*. The study design encompassed clinical trials (randomised/non-randomised), with exclusion criteria comprising studies involving animals, other study designs, narrative/systematic reviews and theoretical papers.

Information sources and search strategy

The search terms were selected using the Thesaurus of Health Sciences Descriptors (DeCS) by the Latin American and Caribbean Center for Medical Sciences Information (BIREME) and its equivalence with MeSH (Medical Subject Headings) by the U.S. National Library of Medicine (*table I*). The final search equation

TABLE I
Keywords used in searching databases according to PICO.

What are the dentoalveolar, periodontal and skeletal effects of maxillary expansion techniques assisted by temporary anchorage devices compared with conventional protocols in patients with transverse maxillary deficiency?		
Concept 1: Population	**Concept 2: Intervention - Comparative**	**Concept 3: Outcome**
Patients with transverse maxillary deficiency	Maxillary expansion techniques assisted by temporary anchorage devices compared with conventional protocols	Dentoalveolar, periodontal and skeletal effects
Malocclusion (MeSH) Transverse Maxillary Deficiency Collapsed Maxillary Arches Crossbite	Palatal Expansion Technique (MeSH) Tooth-borne Maxillary Expansion Bone-borne Maxillary Expansion Orthodontic Anchorage Procedures (MeSH) MARPE Mini-screw assisted rapid palatal expansion Miniimplant Miniscrew Microscrew Microimplant Mini-implant Mini-screw Micro-screw Micro-implant	None words were used to avoid misclassification or search restrictions

was formulated using the MEDLINE (Medical Literature Analysis and Retrieval System Online) database via PubMed. The Boolean operator used was AND for Population/Intervention/Comparative, with filters applied for Humans, English, Portuguese and Spanish, from 2011/1/1 to 2023/12/31. These search syntaxes were then adjusted for other electronic databases (*table II*).

Study selection

Two reviewers (LMBC/RDMA) autonomously screened the titles and abstracts of potentially eligible articles, cross-referencing reference lists for supplementary information. All articles chosen for inclusion underwent data extraction by the same reviewers. Any discrepancies were resolved through discussion and

Table II
Search equations.

Database	Search equation	Results
PubMed MEDLINE	((((((Malocclusion[MeSH Terms]) OR (Transverse Maxillary Deficiency[Title/Abstract])) OR (Collapsed Maxillary Arches[Title/Abstract]))) OR (Crossbite[Title/Abstract])) AND (((Palatal Expansion Technique[MeSH Terms]) OR (Tooth-borne maxillary expansion[Title/Abstract])) OR (Bone-borne maxillary expansion[Title/Abstract]))) AND ((((((((((Orthodontic Anchorage Procedures[MeSH Terms]) OR (Miniimplant[Title/Abstract])) OR (miniscrew [Title/Abstract])) OR (microscrew[Title/Abstract])) OR (microimplant[Title/Abstract])) OR (mini-implant[Title/Abstract])) OR (mini-screw[Title/Abstract])) OR (micro-screw[Title/Abstract])) OR (micro-implant[Title/Abstract])) OR (MARPE[Title/Abstract])) OR (mini-screw assisted rapid palatal expansion[Title/Abstract])) Filters: English, Portuguese, Spanish, from 2011/1/1 - 2023/12/31	167
EMBASE	('malocclusion'/mj OR 'transverse maxillary deficiency':ti,ab OR 'collapsed maxillary arches':ti,ab OR crossbite:ti,ab) AND (('palatal expansion technique' OR 'tooth-borne maxillary expansion':ti,ab OR 'bone-borne maxillary expansion':ti,ab) AND 'orthodontic anchorage procedures' OR miniimplant:ti,ab OR miniscrew:ti,ab OR microscrew:ti,ab OR microimplant:ti,ab OR marpe:ab,ti OR 'mini-screw assisted rapid palatal expansion':ab,ti OR 'mini implant':ab,ti OR 'mini screw' OR 'micro screw':ab,ti OR 'micro implant':ab,ti) AND [2011–2023]/py	185
Scopus	(ALL ("Malocclusion") OR TITLE-ABS-KEY ("Transverse Maxillary Deficiency") OR TITLE-ABS-KEY ("Collapsed Maxillary Arches") OR TITLE-ABS-KEY ("Crossbite") AND ALL ("Palatal Expansion Technique") OR TITLE-ABS-KEY ("Tooth-borne Maxillary Expansion") OR TITLE-ABS-KEY ("Bone-borne Maxillary Expansion") AND ALL ("Orthodontic Anchorage Procedures") OR TITLE-ABS-KEY ("Miniimplant") OR TITLE-ABS-KEY ("Miniscrew") OR TITLE-ABS-KEY ("Microscrew") OR TITLE-ABS-KEY ("Microimplant") OR TITLE-ABS-KEY ("MARPE") OR TITLE-ABS-KEY ("mini-screw assisted rapid palatal expansion") OR TITLE-ABS-KEY ("Mini-implant") OR TITLE-ABS-KEY ("Mini-screw") OR TITLE-ABS-KEY ("Micro-screw") OR TITLE-ABS-KEY ("Micro-implant")) AND PUBYEAR > 2010 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE,"English") OR LIMIT-TO (LANGUAGE,"Portuguese"))	148
Cochrane	("malocclusion"):ti,ab,kw OR (Transverse Maxillary Deficiency):ti,ab,kw OR (Collapsed Maxillary Arches):ti,ab,kw OR ("crossbite"):ti,ab,kw AND (Palatal Expansion Technique):ti,ab,kw OR (Tooth-borne Maxillary Expansion):ti,ab,kw OR (Bone-borne Maxillary Expansion):ti,ab,kw AND (Miniimplant):ti,ab,kw OR (Miniscrew):ti,ab,kw OR (Microscrew):ti,ab,kw OR (Microimplant):ti,ab,kw OR (Orthodontic Anchorage Procedures):ti,ab,kw OR (marpe):ti,ab,kw OR (mini-screw assisted rapid palatal expansion):ti,ab,kw **Filters:** 2011-2023	19
LILACS	má oclusão OR (maloclussion) OR (Maloclusión) AND (técnica de expansão maxilar OR (TECNICA DE EXPANSION PALATINA) OR (palatal expansion technique)) AND (expansión maxilar asistida por miniimplantes OR (expansión maxilar asistida por minitornillos) OR (mini-screw assisted rapid palatal expansion) OR (MARPE) OR (micro-implants) OR (mini-implants) OR (mini-screws) OR (microscrews) OR (microimplants) OR (miniscrews) OR (miniimplants) OR (miniimplantes) OR (minitornillos)) db: db:("LILACS") AND (year_cluster: [2011 TO 2023])	5
Grey literature	Google: "Malocclusion" + "Palatal Expansion Technique" + "Orthodontic Anchorage Procedures"	20
	Manual search: Bibliographic references of other studies	

consultation with at least one other member of the research team (DMRO and/or AAAS/SLGG).

Critical appraisal of the selected studies

Two authors (LMBC/RDMA) assessed the quality of the papers following a rigorous standardization process. A pilot test involving three articles was conducted, yielding a simple concordance index (Score: 90%). Methodological oversight was provided by other authors. Initially, the reporting quality was assessed using the checklist for intervention studies. Randomised clinical trials were appraised using the adaptation for orthodontics proposed by Pandis et al. [18], while non-randomised intervention studies were evaluated based on guidelines revised by Reeves and Gaus [19]. Subsequently, the risk of bias was assessed employing the Cochrane Collaboration tool for randomised clinical trials [20] and the Robins-I tool for non-randomised intervention studies [21].

Data items and synthesis methods

For each included study, descriptive data were recorded, including study information, interventions, outcomes, and other pertinent information as deemed relevant by the research team.

Finally, for two studies involving quantitative and continuous data, the sample size-weighted mean difference (MD) with 95% confidence intervals (CI) was calculated. Results were pooled using random-effects models. Forest plots were used to illustrate individual point estimates with 95% CI for each study, with a diamond symbolizing the pooled point estimate with 95% CI for each outcome of interest. Heterogeneity was assessed using the I-squared (I2) statistic, with values $\geq$ 75% indicating high heterogeneity. All meta-analyses were conducted using RevMan 5.4.

Results

Study selection

The selection process is illustrated in *figure 1*. Initially, 550 articles were retrieved, and after removing duplicates, 382 remained. Following the screening of titles and abstracts, 351 records were excluded. Subsequently, 31 articles were assessed for eligibility and, after reading the full text, 22 were excluded (Online resource supplementary table), resulting in nine studies [22–30].

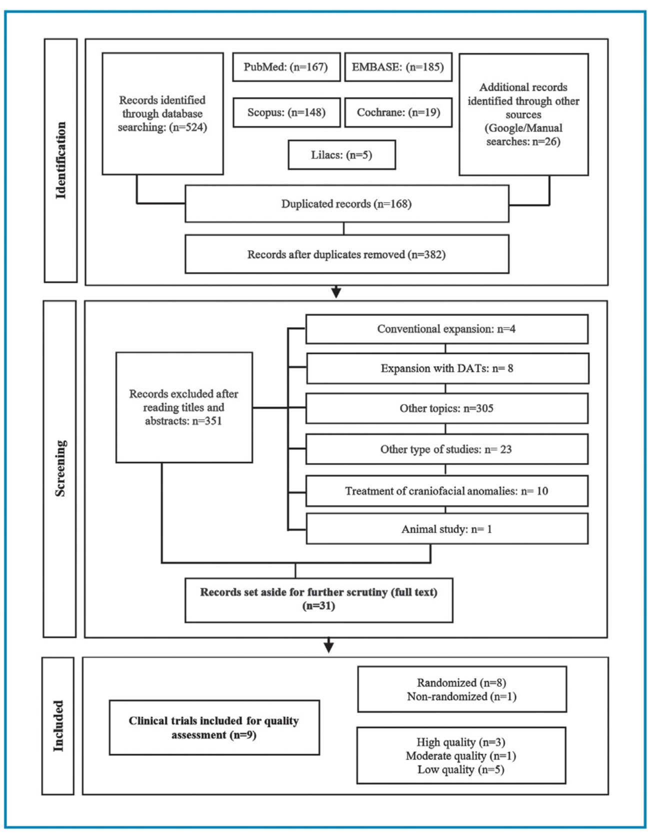

FIGURE 1

Selection process of studies for the systematic review

Study characteristics

Eight studies were randomised clinical trials [22,23,25–30], while just one was non-randomised [24]. The majority of the studies were published between 2015 and 2022 [22–28] and primarily conducted in American countries [22,25,28,29]. Four studies reported funding sources, [26,27,29,30], and most of them disclosed whether they had any conflicts of interest [22–27,30] (*table III*).

TABLE III
Interventions.

Study	Objective	Population/patient diagnosis	Groups	Expansion appliance(s)	Expansion protocol
Kabalan et al., 2015 [22]	To determine the presence of a correlation between the nasal airway skeletal transverse dimension and air intake changes in RME using either tooth-borne or bone-borne anchored devices	61 patients **Range of ages:** 11–17 years **Sex:** Not available Maxillary transverse deficiency	**TBME group:** Not available **BBME group:** Not available **Control group:** Not available	**TBME:** Hyrax screw device, supported by 4 orthodontic bands at maxillary first premolars and molars. **BBME:** Osseo-integrated implant/onplant expander (Dresden Expander) anchored to the palate via 2 MS at the midline. **Control:** Received no treatment	**TBME:** Activation twice a day (0.25 mm per turn, 0.5 mm daily) until appropriate expansion was achieved. **BBME:** Initial activation of the appliance was delayed for 4 days' post treatment. Activation once every second day (0.125 mm/day) until appropriate expansion was achieved. **Retention protocol for both groups:** Once expansion was completed, the screw was fixed with a ligature tie and retained for approximately 5.5 months for TBME group and 4 months for the BBME group
Gunyuz Toklu et al., 2015 [23]	To evaluate and compare the periodontal, dentoalveolar, and skeletal effects of tooth-borne and tooth-bone-borne expansion devices using cone-beam computed tomography	25 patients **Mean age TBME group:** 14.3 ± 2.3 years **Mean age HME group:** 13.8 ± 2.2 years **Sex:** 14 females, 11 males Maxillary transverse deficiency associated with unilateral or bilateral posterior crossbite.	**TBME group:** 13 patients **HME group:** 12 patients	**TBME**: Hyrax screw device, supported by 4 orthodontic bands at maxillary first premolars and molars. **HME**: Hyrax hybrid appliance supported by 2 orthodontic bands at maxillary first molars, and anchored to the palate via 2 MS (1.8 × 9 mm) at the level of first premolars near the second and third palatal rugae, next to the midpalatal suture	**Both groups:** Activation twice a day (1/4 turn in the morning and 1/4 turn in the evening). The expansion was considered completed when the palatal cusp tips of the maxillary first molars were in contact with the corresponding buccal cusp tips of the mandibular first molars. **Retention protocol for both groups:** Once expansion was completed, the screw was fixed with a ligature tie and

TABLE III **(Continued).**

Study	Objective	Population/patient diagnosis	Groups	Expansion appliance(s)	Expansion protocol
					retained for 3 months. Then, the expansion device was removed and a transpalatal arch was placed
Mosleh et al., 2015 [24]	To evaluate and compare the dentoskeletal changes concurrent with 4-point bone-borne and tooth-borne RME in growing children	20 patients **Mean age:** 12 ± 0.6 years **Sex:** 20 females Maxillary transverse deficiency associated with unilateral or bilateral posterior crossbite	**TBME group:** 10 patients **BBME group:** 10 patients	**TBME:** Hyrax screw device, supported by 4 orthodontic bands at maxillary first premolars and molars **BBME:** Custom-made expander anchored to the palate via 4 MS (1.5 × 12.2 mm) inserted between the maxillary first and second premolars, and between the maxillary second premolars and first permanent molars	**Both groups:** The expander was fitted passively and the patient was instructed to activate it twice a day for 11 days until achieved overall expansion of 5.5 mm
Pham and Lagravère, 2017 [25]	To determine changes in alveolar bone levels during expansion treatments as assessed through cone-beam computer tomography	62 patients **Mean age:** Not available **Sex:** Not available Maxillary transverse deficiency	**TBME group:** 20 patients **BBME group:** 21 patients **Control group:** 21 patients	**TBME:** Hyrax screw device, supported by 4 orthodontic bands at maxillary first premolars and molars. **BBME:** Expander anchored to the palate via 2 MS inserted between the maxillary second premolars and first permanent molars 6 mm from the suture, and 2 orthodontic bands at maxillary first molars. **Control group:** Received no treatment.	**TBME:** No healing period. Activation twice a day (0.25 mm per turn, 0.5 mm daily) until 20% overcorrection was achieved. **BBME:** Healing period of approximately 1 week. Activation once every other day until 20% overcorrection from the needed expansion was achieved. **Retention protocol for both groups:** The screw was fixed with light-cured acrylic and kept in passively for 6 months. The appliance was then removed
Bazargani et al., 2017 [26]	To evaluate and compare the effects of tooth-borne and tooth-bone-borne RME on nasal airflow and resistance	40 patients **Mean age TBME group:** 9.7 ± 1.5 years **Mean age HME group:** 10.2 ± 1.4 years **Sex:** 19 females, 21 males Maxillary transverse deficiency associated with unilateral or bilateral posterior crossbite	**TBME group:** 19 patients **HME group:** 21 patients	**TBME:** Hyrax screw device, supported by 2 orthodontic bands at maxillary first molars. **HME:** Hyrax hybrid appliance supported by 2 orthodontic bands at maxillary first molars, and anchored to the palate via 2 MS (1.7 × 8 mm) at the level of first premolars	**Both groups:** Activation two-quarter turns per day (0.5 mm) until the palatal cusps of the maxillary first molars contacted the buccal cusps of the mandibular first molars. **Total expansion screw:** **TBME:** 4.8mm

TABLE III **(Continued).**

Study	Objective	Population/patient diagnosis	Groups	Expansion appliance(s)	Expansion protocol
					+ −1.39 mm **HME:** 5.48mm ± 0.98 mm
Canan and Şenışık, 2017 [27]	To compare the dentoalveolar treatment effects of 3 RME appliances, supported by different tissues, on the maxilla and the mandible	47 patients **Mean age TBME:** 12.63 ± 1.36 years **Mean age BBME:** 12.92 ± 1.07 years **Mean age HME:** 13.41 ± 0.88 years **Sex**: 25 females, 22 males Maxillary transverse deficiency associated with unilateral or bilateral posterior crossbite	**TBME:** 16 patients **BBME:** 16 patients **HME:** 15 patients	**TBME:** Hyrax screw device, supported by 4 orthodontic bands at maxillary first premolars and molars. **BBME:** Hyrax screw expander anchored to the palate via 4 MS (1.8 × 9 mm) inserted between the maxillary first and second premolars, and between the maxillary second premolars and first permanent molars. **HME:** Hyrax screw device with bands on the first permanent molars and anchored to the palate via 2 MS (1.8 × 9 mm) between the first and second premolars	**All groups:** Activation two-quarter turns per day (0.25 mm per turn, 0.5 mm daily), until a sufficient amount of expansion achieved. **Retention protocol:** The expansion screw was fixed for 6 months
Celenk-Koca et al., 2018 [28]	To evaluate and compare the dental and skeletal changes with conventional and miniscrew-supported maxillary expansion appliances in adolescents	40 patients **Mean age TBME group:** 13.84 ± 1.36 years **Mean age BBME group:** 13.81 ± 1.23 years **Sex:** 25 females, 15 males Maxillary transverse deficiency	**TBME group:** 20 patients **BBME group:** 20 patients	**TBME:** Hyrax screw device, supported by bilateral tooth-bonded plates placed on first permanent molar and first and second permanent premolars. **BBME:** Hyrax-type screw expander anchored to the palate via 4 mini-screw (1.8 × 9 mm) inserted between the maxillary first and second premolars, and between the maxillary second premolars and first permanent molars, 6–8 mm palatal to the gingival margin of the teeth	**Both groups:** Expanders were activated by two turns a day. The average activation time was 19.7 ± 3.8 days
Pasqua et al., 2022 [29]	To evaluate the dental and skeletal effects after use of the hybrid device for RME and to compare the effects generated by the conventional hyrax-type RME device in patients aged with 11 and 14 years by cone beam computed tomography examination	42 patients **Mean age TBME group:** 13.1 ± 1.4 years **Mean age HME group:** 13.3 ± 1.3 years **Sex**: 25 females, 17 males Maxillary transverse deficiency associated with unilateral or bilateral posterior crossbite	**TBME:** 21 patients **HME:** 21 patients	**TBME:** Hyrax screw device, supported by 4 orthodontic bands at maxillary first premolars and molars. **HME:** Hyrax hybrid appliance supported by 2 orthodontic bands at maxillary first molars, and anchored to the palate via 2 MS (2 × 8 mm) at the level of first premolars	**Both groups**: Activation 24 hours after cementation. First activation: A complete turn of the expander screw. Posterior activations: 2/4 turns per day (1/4 turn every 12 hours) until overcorrection of the posterior crossbite
	To evaluate the immediate and short-	40 patients **Mean age TBME**	**TBME:** 20 patients **BBME:** 20 patients	**TBME:** Hyrax screw device, supported by 4 orthodontic	**Both groups:** Activation by one

TABLE III **(Continued).**

Study	Objective	Population/patient diagnosis	Groups	Expansion appliance(s)	Expansion protocol
Chun et al., 2022 [30]	term skeletal, dentoalveolar, and periodontal effects of rapid palatal expansion (RPE) and mini-screw-assisted RPE (MARPE) in adolescent and young adult patients	**group:** 14.0 ± 4.5 years **Mean age BBME group:** 14.1 ± 4.2 years **Sex:** 26 females, 14 males Maxillary transverse deficiency associated with buccal edge-to-edge bite or crossbite		bands at maxillary first premolars and molars. **BBME:** Hyrax-type screw expander anchored to the palate surface via 4 MS (1.8 × 9 mm for the anterior region and 1.8 × 7 mm for the posterior region) inserted medially to the first premolars on a line parallel to the midpalatal suture, and in the first molars region lateral to the midpalatal suture	quarter of a turn (0.20 mm/turn) once a day, 35 times, which corresponded to 7 mm of hyrax screw expansion. **Retention protocol:** After active expansion, the devices were maintained for a 3-month consolidation period to enable connective tissue remodeling of the suture

RME: Rapid maxillary expansion; TBME: Tooth-borne maxillary expansion; BBME: Bone-borne maxillary expansion; HME: Hybrid maxillary expansion; MS: Mini-screw.

Interventions

A total of 377 patients were evaluated; seven studies reported the sex [23,24,26–30] with 154 females (60%) and 100 males (40%) (n = 254). All the studies examined growing patients with a mean age of 13.2 ± 0.6 years, diagnosed with TMD [22,25,28] associated with edge-to-edge or bilateral/unilateral crossbite [23,24,26,27,29,30]. Two studies were focused on evaluating the correlation between the nasal airway skeletal transverse dimension and air intake [22,26].

Regarding the design of the expansion appliances, all the studies used tooth-borne maxillary expansion appliances (TBME) [22–30]. Six used bone-borne maxillary expansion appliances (BBME) [22,24,25,27,28,30] and four used HME appliances [23,26,27,29].

The TBME typically consisted of a Hyrax screw, supported by four bands at the maxillary first premolars and molars [22–25,27,29,30], by two bands at the maxillary first molars with anterior extension arms [26] or by bilateral tooth-bonded plates [28].

The BBME involved expanders anchored to the palate via different types and locations of mini-screws [22,24,25,27,28,30].

The HME consisted of a Hyrax screw supported by two orthodontic bands at the maxillary first molars and anchored to the palate via two mini-screws [23,26,27,29].

There was a considerable variability in terms of activation and retention protocols (*table III*).

Outcomes

For assessing the information, the studies employed cone-beam computer tomography (CBCT) [22–25,28–30], acoustic rhinometry [22,26], and conventional or 3D dental casts [26,27].

The effects of the interventions were categorised into three groups: dentoalveolar, periodontal and skeletal (*figure 2*, *table IV*).

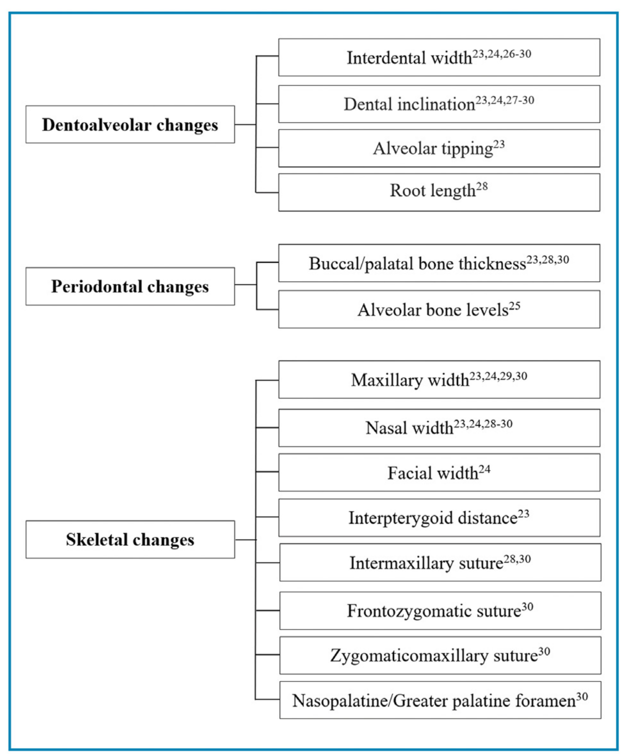

FIGURE 2
Outcomes

Table IV
Outcomes.

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
Kabalan et al., 2015 [22]	CBCT images and AR for all groups. **T1:** Pretreatment. **T2:** 6 months after completed expansion at the time of appliance removal. **Equipment:** I-Cat at 120 kVp, 7 mAs and 8.9 seconds image timing, 0.3 voxel size and 16 × 13 cm field of view. Eccovision 4.50 AR (Hood Laboratories, Pembroke, MA, USA) three times for each nostril; values were obtained both before and after a minimum of 10 minutes following use of decongestant spray (0.1% w/v xylometazoline hydrochloride nasal solution)	**Skeletal:** Lateral and inferior walls of the nasal cavity; base of each inferior nasal concha and the lateral wall of the nasal cavity; infra-orbital canals; airway volume	N/A	N/A	No statistically significant difference in any of the measurements in the three groups. TBME group, BBME group and the control group, showed similar variability in the results between T1 and T2	No really conclusive finding was obtained to suggest any realistic correlation between changes in the skeletal dimensions and changes in the nasal airway in any group
Gunyuz Toklu et al., 2015 [23]	CBCT images for all groups. **T1:** Pretreatment. **T2:** After removal of retention appliance. **Equipment:** Iluma device (IMTEC [3 M], Ardmore, Okla) at 3.8 mA, 120 kV, exposure time of 40 seconds, voxel size of 0.2 mm, axial slice thickness of 0.3 mm, and scanning area of 20 × 25 cm	**Dentoalveolar:** Buccal/palatal cuspal and apical width of first molar, second and first premolar, and canine; dental inclination of first molar, second and first premolar, and canine; alveolar inclination and dental tipping of first molar and first premolar. **Periodontal:** Buccal and palatal bone thickness of first molar, second and first premolar, and canine. **Skeletal:** Palatal maxillary width; maxillary width; nasal width; interpterygoid distance	The increases in interpremolar distances (first premolar buccal/palatal cuspal and apical widths; second premolar buccal/palatal cuspal widths) of the TBME were significantly greater than those in the HME group. The right and left first molar and the first premolar dental inclinations increased significantly ($P < 0.05$) in the TBME group. The left first premolar dental inclination in the TBME increased by a mean of	Statistically significant decreases were found in the right and left first molar and the first premolar buccal bone thicknesses ($P < 0.01$), whereas significant increases were noted in the first molar and the first premolar palatal bone thicknesses ($p < 0.001$) in the TBME. In the HME, only significant periodontal changes were observed in the molar measurements, whereas first interpremolar thicknesses were maintained	Palatal maxillary width, maxillary width, nasal width, and distance between the lateral pterygoid plates showed significant increases in both groups.	Both TBME and HME are effective methods for the treatment of maxillary constriction. The hyrax and the hybrid hyrax expanders resulted in similar skeletal effects. The hyrax appliance resulted in greater expansion in the premolar region than did the hybrid hyrax. Both appliances reduced the buccal bone thickness and increased the palatal bone thickness in the molar area. Buccal bone thickness decreased in the premolar area in the purely tooth-borne

TABLE IV **(Continued).**

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
			2.33° ± 3.03°, whereas it remained unchanged in the HME No significant intergroup difference was found in absolute dental tipping (P < 0.05)	Significant differences were found in the left first premolar buccal and palatal bone thicknesses between groups		group, whereas the buccal bone thickness in the hybrid hyrax group was maintained
Mosleh et al., 2015 [24]	CBCT images for all groups. **T1:** Pretreatment. **T2:** After expansion protocol was finished. **Equipment:** Scanora 3D device at 15 mA and 85 kV, and a field of view of 14.5 (diameter) 3 13 (height) cm.	**Dentoalveolar:** Coronal (buccal) and apical width of first molar and first premolar; dental inclination of first molar and first premolar in relation to Frankfort horizontal plane. **Skeletal:** Facial width; maxillary width; nasal width.	The intercoronal and interapical widths increased significantly in both groups. The TBME group had a greater significant increase for the intercoronal widths of the maxillary first premolars and the first permanent molars, but no statistically significant difference was reported for the interapical widths No statistically significant decrease was seen for the external buccopalatal inclination angle of the maxillary first premolars and first permanent molars in the BBME group. In the TBME group, a statistically significant decrease was detected only for the external buccopalatal inclination angle of the maxillary right and left first premolars. The TBME group showed a statistically significant higher decrease in the external inclination angle of the maxillary right and	N/A	Both groups showed increase in measurements. The BBME group had statistically significant increases in facial and maxillary widths; in the TBME group, a statistically significant increase was detected only for nasal width. Comparing the groups, no statistically significant difference was found for facial and maxillary widths, but a significantly greater increase was reported in the TBME group (3.5 ± 1.9 mm) for nasal width	There were significant increases in facial and maxillary widths for the BBME group and in nasal width for the TBME group. Both expanders produced basal bone expansion at the level of the hard palate. The TBME produced more dental expansion, buccal rolling, and a greater increase in nasal width than did the BBMEs. Use the BBME in patients with a questionable periodontium or missing permanent posterior teeth, or when anchorage teeth can benefit from early bonding. The TBME can be used in situations that require more dental expansion. A jackscrew with a wide range of activations and a small dimension must be used to compensate for the severe narrowing and deepening of the palatal vault

Table IV **(Continued).**

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
			left first premolars than did the BBME group. No statistical significance was detected for the external buccopalatal inclination angles of the maxillary right and left first permanent molars			
Pham and Lagravère, 2017 [25]	CBCT images for all groups. **T1:** Pretreatment. **T2:** After removal of the appliance (6 months since appliance insertion). **Equipment:** NewTom 3G device at 110 kV, 6.19 mAs, 8 mm aluminum filtration. DICOM format at a voxel size of 0.25 mm	**Periodontal:** Cusp tips, cemento-enamel junctions, and bone margins on buccal and lingual sides of the maxillary/mandibular premolars and molars	**N/A**	Changes in alveolar bone levels ranged from 0 to 1.38 mm for the BBME group, 0 to 0.99 mm for the TBME group and 1.31 mm for the control group. The mean changes of the distances from T1 to T2 were 0.27 mm, 0.20 mm and 0.51 mm for the BBME group, TBME group and control groups, respectively. These means are less than 1 mm for all three groups and therefore clinically insignificant. Bones had appropriately remodeled and there were no extensive injuries to the alveolar bone heights in all groups. Differences in bone height between the BBME and TBME groups were minimal	N/A	Both TBME and BBME do not cause clinically significant changes to alveolar bone height. Alveolar bone level changes were similar in maxillary expansion treatment and control groups
Bazargani et al., 2017 [26]	Study casts and evaluation of nasal flow and resistance by rhinomanometric registration. **T1:** Pre-expansion. **T2:** Directly post-expansion – 15 min after nasal	**Landmarks:** Intermolar distances at the gingival margins and the mesiobuccal cusp tips of the teeth. **Distances:** The shortest intermolar linear	N/A	N/A	**Nasal airflow:** Significantly higher post-expansion values for the HME group compared with the TBME group, mean difference 51.0 cm^3/s	The HME induced significantly higher nasal airway flow and lower nasal resistance values than TBME. It might be wiser to use HME in cases

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TABLE IV **(Continued).**

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
	decongestion (xylomethazoline). **Equipment:** Digital 6 caliper, Mauser, Winterhur, Switzerland. Rhinostream®, Interacoustics, Assens, Denmark	distance pre and post-expansion				with constricted maxilla and upper airway obstruction
Canan and Şenışık, 2017 [27]	3D dental casts for all groups. **T1:** Pretreatment, after the appliance was bonded. **T2:** Posttreatment, after the activation period. **T3:** Postretention, after 6 months of retention. **Equipment:** R700; 3Shape A/S, Copenhagen, Denmark	**Dentoalveolar:** Position of maxillary right/left central incisor, canine, first premolar, and first molar; maxillary right/left premolar and molar angle; interarch width between the mandibular canines, first premolars and first molars	There were no intergroup differences in the maxillary anterior region. The maxillary right and left central incisors and canines moved distally after the active expansion period and relapse occurred after retention in the groups. In the posterior region, the right first premolar and molar significantly moved more buccally in the TBME. The palatal cusp tips of the maxillary left first premolar were significantly extruded after expansion in the TBME and the HME groups. There were no statistically significant intergroup differences for mandibular interdental width changes between groups	N/A	N/A	All three expanders led to the expansion of maxillary dentoalveolar structures with mild relapse. However, the amount of expansion of the TBME expander on the right side was statistically lower. Spontaneous interdental expansion was observed in the mandibular dentitions in all groups
Celenk-Koca et al., 2018 [28]	CBCT images for all groups. **T1:** Before treatment. **T2:** After 6 months following a passive retention period using the same appliances. **Equipment:** CS 9000 3D,	**Landmarks:** Base of nasal cavity between first premolar and first molar. Incisive foramen at the intermaxillary suture between the right and	Right and left-side measurements of molars and premolars did not show any significant difference and were averaged for the rest of	**Buccal bone width:** Both groups decrease at the level of maxillary first premolars and first molars, but the TBME group experienced	Differences between BBME and TBME groups were significant for nasal cavity, incisive foramen and sutural width measurements between	Use of BBME appliances in the adolescent population increased the extent of skeletal changes in the range of 1.5 to 2.8 times that of TBME and did not

Table IV **(Continued).**

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
	Carestream Health device at 70 kV, 10 mA, 32.5 seconds, 76-um voxel size, and with volume dimensions of 8 cm × 8 cm	left cortices at first premolars and molars. The outermost point of the bone to the roots at the level of furcation point (bifurcation of first premolars and trifurcation of first molars). Inclinations of buccal and mesiobuccal roots of the maxillary first premolars and first molars to a horizontal line parallel to the nasal floor. Cusp tip to the apex for maxillary first premolar buccal and lingual roots, and maxillary first molar mesial-buccal, distal-buccal, and palatal roots **Distances:** Nasal cavity width; incisive foramen width; premolar and molar width and inclination of roots; root length. All measurements at T1 and T2	the statistical analysis **Premolar and molar width:** Although the BBME group produced slightly greater increases of 0.6 mm and 0.3 mm in both widths, no significant differences were noted between the two groups **Inclination of roots:** Tipping of the maxillary first molars in BBME group was significantly reduced in comparison with TBME group **Root length:** No significant changes to the roots of the anchor teeth in the study groups	significantly less buccal bone loss for both the premolars and molars	maxillary first premolars and molars **Sutural expansion:** The total increase in maxillary width were 28% and 70% in the TBME group and BBME group respectively, at the level of first premolars, and 26% and 68% at the level of the maxillary first molars. Most of the patients in both groups demonstrated a triangular-shaped opening of the suture that was wider anteriorly	result in any dental side effects
Pasqua et al., 2022 [29]	CBCT images for all groups. **T1:** Before treatment. **T2**: Three months after the activation was completed. **Equipment**: iCAT Imaging Sciences International Hatfield, Pensilvania. 120 kVp, 18 mA, exposition time 8.9 sec. Voxel 0.2 mm and field of view 160 × 60 mm	**Landmarks:** Apical root point and cusp tips of first permanent premolar and first permanent molar (buccal and lingual). Greater concavity of the lateral border and lower border of the nasal cavity. Greater concavity of the lateral border and lateral border limit of the maxilla. **Distances:** Dental width	**Intercoronal widths:** The increase in the distance between the crowns of the premolars was greater in the TBME group, with a difference of 1.8mm ± 0.7. **Interapical width:** Regarding the distance between the apices of the palatal roots of the premolars, there were no	N/A	**Nasal cavity:** HME group showed higher measurements compared to the TBME group. **Maxillary changes:** Statistically significant difference of 1.1 mm (±0.5, $p = 0.022$) was found in HME group	HME group has better skeletal effects of increasing the dimensions of the nasomaxillary structures in the region of the first premolars. In the group treated with conventional Hyrax, there was a greater dental inclination

TABLE IV **(Continued).**

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
		and angulation between right and left first permanent premolar and first permanent molar. Nasal cavity width and length. Maxillary base width and length	differences between the groups			
Chun et al., 2022 [30]	CBCT images for all groups. **T1:** Before treatment. **T2:** Immediately after expansion. **T3:** After a 3-month consolidation period. **Equipment:** Alphard 3030, exposure time: 17 s, 3.0 mA, 80 kV, feld of view [FOV]: 200 × 200 mm2, voxel size: 0.39 mm	**Landmarks and distances:** Maxillary width (MW): Distance (mm) of maxillary width tangent to the hard palate PM-MW and M-MW were measured on both upper first premolars (PM) and first molars (M) in the coronal section. Interdental width (IDW): Distance (mm) between the right and left buccal cusp tips PM-IDW and M-IDW were measured on both upper first premolars (PM) and first molars (M) in the coronal section. Dental inclination (DI): Angle between the line passing through the palatal cusp tip and palatal root apex, and the vertical line perpendicular to the hard palate measured on upper first molars in the coronal section	**Maxillary width:** A significant increase was observed in the maxillary width in the bilateral first premolar (PM-MW) and molar region (M-MW) in both groups, with particularly greater values observed in the BBME group after expansion **Interdental width:** The amount of expansion ranged from 6.1 to 6.3 mm in the premolar region (PM-IDW) and from 5.9 to 6.7 mm in the molar region (M-IDW). Moreover, this dimension is slightly reduced during the consolidation period; during consolidation, the BBME group presented a lower decrease in the PM-MW and M-MW, suggesting a greater alveolar relapse in the TBME group. Hence, through the expansion and consolidation periods there were no significant intergroup differences in all the dental dimensions except for the changes in	**Buccal and palatal bone plate thickness:** The premolar and molar on mesial and distal roots reduced throughout the expansion and consolidation periods regardless of expander types, possibly because of a skeletal relapse tendency. Specifically, during expansion, all values are reduced by 0.6 mm on average indicating buccal displacement of the anchor premolars and molars within the alveolar bone. Conversely, all values increased in both expander types. A significant intergroup difference was observed only in the premolar area. During consolidation, the bone thickness changes were distinguished according to the expander types. Both M-BBPT in relation to the mesial and distal roots reduced in the TBME group, which was contrasted by a slight	In the TBME group, midpalatal suture separation occurred in 18 out of 20 patients. The BBME group demonstrated a successful midpalatal suture opening in 19 out of 20 patients. The frequency of midpalatal suture separation was 90% and 95% for TBME and BBMEE, respectively, without statistical differences between the groups **Nasal width:** Immediately after expansion the nasal width in relation to the bilateral first molar region (M-NW) was found to be significantly increased in the BBME group compared to the TBME group **Basal bone expansion:** Significant basal expansion was noted at the zygomaticomaxillary suture, nasal width in relation to the bilateral premolar region (PM-NW), M-NW, nasopalatine foramen (NPF), and greater palatine foramen	The reinforcement of RPE with miniscrews doesn't affect the midpalatal suture separation ratio, however it appears to contribute to the maintenance of the basal bone during the consolidation period leading to less periodontal side effects, such as buccal dehiscence Influence on the greater skeletal expansion was not evident

Table IV **(Continued).**

Study	Assessing of information method	Measurements	Dentoalveolar changes	Periodontal changes	Skeletal changes	Conclusions
			the PM-MW and M-MW **Dental inclination:** The PM-IDW, M-IDW and upper first molar axes (M-DI) did not present statistical significance between groups. The M-DI increased immediately after expansion followed by a minor decrease during the consolidation period in both groups, which resulted in a similar overall M-DI	decrease or increase in the BBME group, resulting in significant intergroup difference. A similar pattern was observed in the premolar area with no statistical significance. This result indicates that consolidation with the use of the BBME device may lead to less buccal alveolar bone loss Through the expansion and consolidation periods, the difference between the expander types was remarkable, exhibiting statistical significance in all measurements. This implied that lesser buccal displacement of the anchor teeth occurs within the alveolar bone in the BBME group for a given amount of expansion	(GPF) in both groups, but not at the frontozygomatic suture (FZS), implying an overall triangular maxillary expansion. The BBME group presented a significant increase at the GPF compared to that in the TBME group. Following the 3-month consolidation period, the TBME and BBME groups presented reductions in PM-NW, M-NW, and NPF over time overall, throughout the expansion and consolidation periods, both the treatment groups showed significant increases in all dimensions, except at the FZS and in the M-NW in the TBME group. Significant differences between the groups were observed for PM-NW, M-NW and GPF, with significantly greater increases in these parameters in the BBME group compared with the TBME group	

CBCT: Cone-beam computer tomography; AR: Acoustic rhinometry; TBME: Tooth-borne maxillary expansion; BBME: Bone-borne maxillary expansion; HME: Hybrid maxillary expansion.

Regarding the dentoalveolar changes, the interpremolar width and the dental inclinations increased significantly more in the TBME group than in the BBME and HME groups [23,24,27–29]. The intermolar width increased slightly more in the BBME group [28]. No significant intergroup difference was found for the apical width [23,24,29], the alveolar tipping [23] and the root length [28].

In terms of periodontal changes, buccal bone thickness decreased [23,28,30] and palatal bone thickness increased on premolars in the TBME group [23,30] and on first molars in the TBME and HME groups [23]. When the BBME or HME techniques were used, bone loss was reduced or maintained. The differences in vertical alveolar bone level between the TBME and BBME groups were minimal [25].

Finally, four studies showed that BBME and HME resulted in increased skeletal measurements compared with TBME [24,28–30]. Studies comparing the effects of RME on nasal airflow have been inconclusive [22,26].

Results of subgroup analyses

Subgroup analyses were performed for selected dentoalveolar and skeletal effects of patients included in two studies (n = 64) [23,29], (*figure 3*). Regarding dentoalveolar analyses, TBME patients had greater effects on buccal intercoronal width

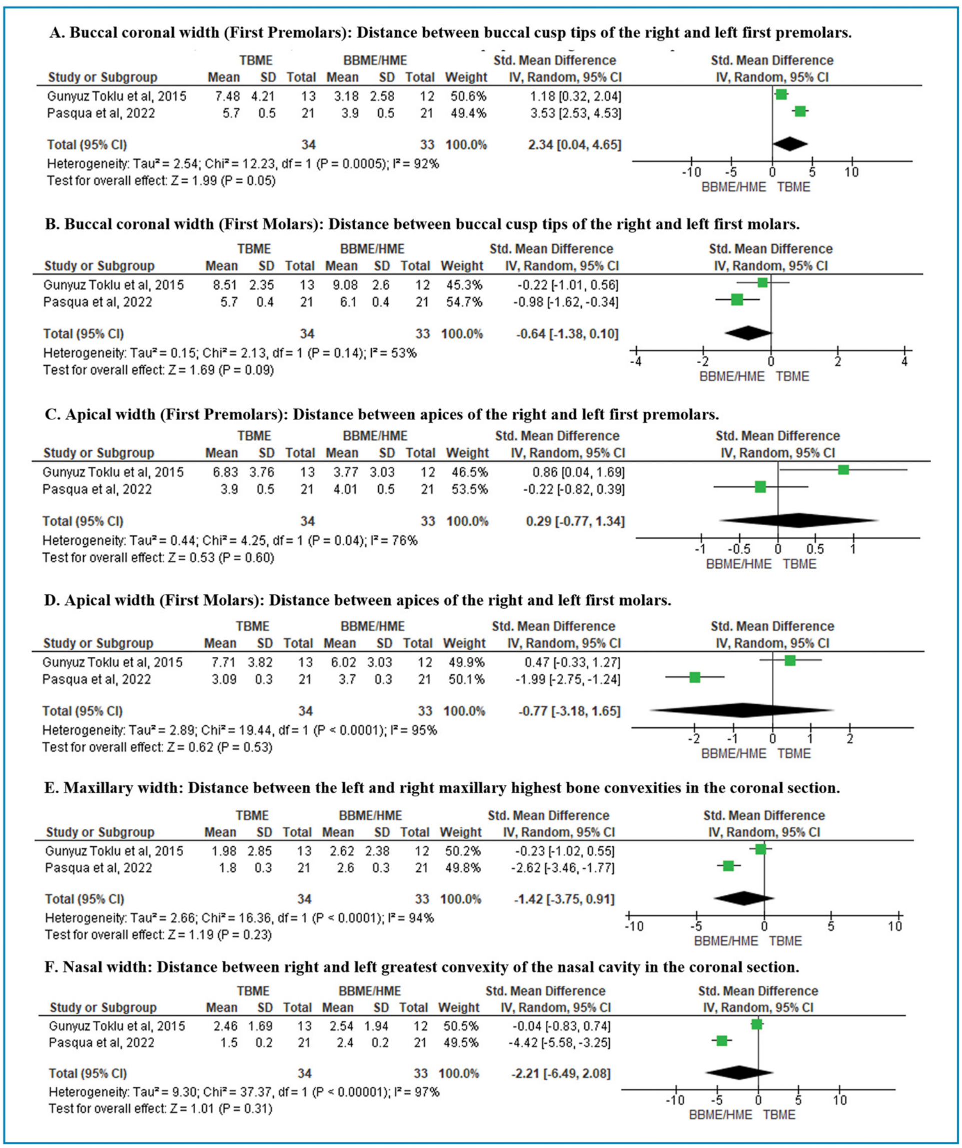

FIGURE 3

Forest plots of subgroup analyses

between premolars, with statistically significant differences (mean difference std 2.34; 95% CI: 0.04–4.65 $p = 0.05$). Conversely, patients who used BBME/HME had greater effects on buccal intercoronal width between molars with statistically significant differences (mean std difference −0.64; 95% CI: −1.38 − 0.10; $p = 0.09$). At the apical level, no statistically significant differences were found between patients using TBME and BBME/HME. In terms of skeletal effects, although the results showed a greater change in maxillary width and nasal width in patients who used BBME/HME, we did not find any statistically significant differences.

Risk of bias

According to the ROB-2 tool, five studies showed a high risk of bias [22,23,25,27,29] while the remaining three studies [26,28,30] showed a low risk of bias. The critical items were bias due to deviations from intended interventions and bias due to missing outcome data.

For the non-randomised study [24], the final evaluation, according to ROBINS-I was a moderate risk of bias. The critical items were: domain 5: no information bias due to missing data, and domain 6: bias in the measurement of outcomes (*figure 4*).

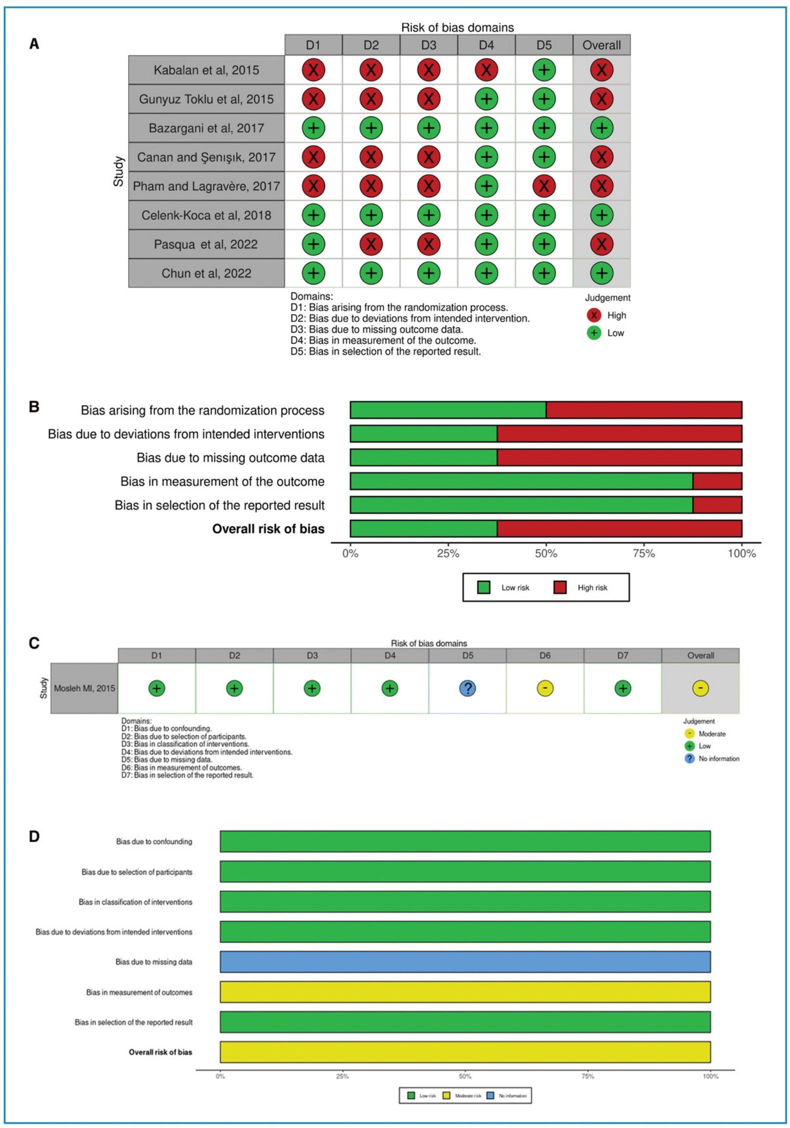

FIGURE 4

Risk of bias. A: Assessment for the individual studies (randomized-ROB-2 tool); B: Percentage per domain for all includes randomized studies according to the ROB-2 tool. C: Assessment for the non-randomized study (ROBINS-I tool). D: Percentage per domain of the non-randomized studies according to the ROBINS-I tool

Discussion

The primary aim of this systematic review and meta-analysis was to synthesise the dentoalveolar, periodontal, and skeletal changes occurring with expansion assisted by TADs compared to conventional protocols in patients with TMD. A primary dentoalveolar outcome expected in crossbite correction is a widening of the coronal width between the right and left sides of the maxillary posterior teeth, a parameter most studies were interested in evaluating and confirming [23,24,26–30]. The interpremolar width was higher in the TBME groups, while BBME was associated with reduced bilateral buccal tipping of the first premolars and first molars, a finding also reported by Bi et al. [31]. Dental inclination increased more in the TBME group than in the BBME/HME groups, particularly for the first premolars [23,24,27–29], a result consistent with Krüsi et al. [15]. This effect may be intuited insofar as the first premolars, serving as anchorage via their bands, tend to receive more force and therefore have a greater expansive effect. Other dentoalveolar aspects, such as alveolar tip or root length, have been poorly investigated, leading to inconclusive evidence.

Periodontal changes related to bone thickness primarily occurred in the anchorage teeth. [6,14,32]. This finding is confirmed by the present analysis, as the included studies reported a decrease in buccal thickness [23,28,30] and an increase in palatal thickness [23,30] for the first premolars for the TBME group, with similar changes present for the molars for the HME group [23]. This phenomenon is due to the fact that the two tooth-anchored expansion appliances rely solely on the premolars and molars, unlike pure bone-supported appliances. This explains the dentoalveolar changes with more dental inclination than translation. Although no quantitative subgroup analysis of periodontal measurements has been performed, it could be suggested that BBME/HME may have a protective effect and result in less loss of buccal alveolar bone thickness than conventional RME [14].

Bone height has been reported in one study [25], the findings of which support adequate bone remodelling between the groups. This is further corroborated by the results of the systematic review and meta-analysis by Bi et al. [31].

At the skeletal level, it is anticipated that RME will result in a non-parallel opening of the midpalatal suture, with the widest opening observed anteriorly and decreasing towards the posterior part of the palate [33]. In the horizontal plane, significant lateral displacement of the maxillary and zygomatic bones is expected post-treatment [34]. These horizontal forces are expected to lead to a lateral enlargement of the structures related to the maxilla and nasal cavity. This systematic review confirms this expectation, as all expansion techniques showed increases in skeletal measurements [23,24,28–30], including maxillary width, nasal width, facial width, distance between the lateral pterygoid plates, intermaxillary suture and other structures, such as frontozygomatic suture, zygomaticomaxillary suture, nasopalatine and greater palatine foramen.

Although quantitative subgroup analyses for maxillary and nasal widths showed greater changes with BBME/HME appliances, they were not statistically significant, which is consistent with the findings of Krüsi et al. [15] and Bi et al. [31]. This suggests that the greater width of the nasal cavity after expansion may be associated with the opening of the mid-palatal suture.

With regard to the airway, the evidence is inconclusive on how expansion techniques can contribute to improving nasal airflow efficiency, which is consistent with the results of other systematic reviews on the topic [15].

The present systematic review has several strengths, including protocol registration in PROSPERO, the comprehensive bibliographic search, the calibration between the evaluators, and the fact that 88% of the studies included were randomised. However, there are also certain limitations, such as the availability of clinical trials, the high clinical heterogeneity and a high risk of bias among the evaluated studies. Additionally, it should be noted that all 377 patients included in the studies were in their growth stage, precluding conclusions regarding any particular benefits of the techniques in adult patients.

Regarding clinical considerations, it is challenging to recommend a specific expansion protocol due to the substantial heterogeneity of information reported in studies comparing TBME and BBME/HME. It is also important to note that there is a lack of information on the long-term stability of the results, as the included studies primarily assess the immediate effects of expansion. Therefore, clinicians may need to select the type of anchorage based on the primary desired effect and which option would be the least detrimental to the periodontal tissue.

Conclusion

The descriptive analyses of the primary studies showed that RME techniques resulted in changes in dentoalveolar, periodontal and skeletal measurements after the application of expansion protocols. The differences in effects depend on the specific measure and the type of protocol.

The quantitative analyses revealed statistically significant differences in some dentoalveolar measures: TBME had greater effects on buccal intercoronal width between premolars, and BBME/HME had greater effects on buccal intercoronal width between molars.

The results should be interpreted with caution due to the heterogeneity of the studies.

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