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Systematic Review

Impact of Non-Surgical and Surgically Assisted Rapid Maxillary Expansion Procedures upon the Periodontium: A Systematic Review

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Abstract: Background: Scarce evidence is available regarding the occurrence and prevalence of hard/soft tissue deficiencies among patients undergoing surgically assisted rapid maxillary expansion (SARME) as compared to non-surgical rapid maxillary expansion (NSRME) approaches. The purpose of this study is to evaluate the effect of NSRME and SARME upon the periodontal structures. Methods: A literature search was performed to identify studies that fulfilled pre-established eligibility criteria, evaluating changes in the periodontium (e.g., probing depths) and hard/soft tissue deficiencies (e.g., bone levels, gingival recession) within patients undergoing NSRME and SARME procedures. Results: A total of 21 articles were included in the present review. Four of them evaluated the outcomes of both NSRME and SARME procedures, while six and eleven studies analyzed NSRME alone and SARME alone, respectively. The incidence of hard (e.g., changes in buccal bone width/height) and soft tissue deficiencies (e.g., gingival recession, keratinized tissue, and clinical attachment level) is slightly increased among patients undergoing maxillary expansion with worsened outcomes during NSRME procedures. Conclusions: The impact of NSRME and SARME upon the periodontium remains inconclusive.

Keywords: palatal expansion technique; rapid maxillary expansion; transpalatal distraction osteogenesis; transverse maxillary distraction; periodontium

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1. Introduction

Transverse maxillary deficiency is a common condition resulting in occlusal discrepancies among non-syndromic and syndromic patients [1,2]. As such, this common maxillary deficiency entails an inadequate dental arch space and higher palatal vault, thus leading to craniofacial aberrations, including nasal obstruction [3,4]. As age increases, maxillary expansion can less readily be achieved due to the increased resistance produced by the zygomatic buttress and pterygoid plates as the patient becomes skeletally mature [5–9].

Various non-surgical and surgical treatment modalities have been suggested for the correction of maxillary deficiencies depending primarily on the type and magnitude of the deficiency, skeletal growth status, and status of periodontal tissues. When detected early in craniofacial developmental stages, conventional expansion appliances can yield predictable outcomes [10]. Conversely, the success of non-surgical maxillary expansion in skeletally mature adults is complicated due in part, but not limited to, the amount of tooth movement, extension of treatment time, and anatomical barriers [11]. The relocation of maxillomandibular jawbones via orthognathic surgery can be considered when treating severe skeletal discrepancies; however, the increased cost, risk of morbidity, and need for hospitalization create demand for alternative treatment modalities [12].

Rapid maxillary expansion was introduced as a simpler and less invasive alternative when compared to orthognathic surgery [13]. Among adult patients, mild transverse discrepancies can be camouflaged by orthopedic and orthodontic forces alone, while more severe transverse discrepancies require surgical intervention [14–16]. Aside from orthognathic surgery, surgically assisted rapid maxillary expansion (SARME) has been indicated as the preferred treatment for skeletally mature patients with a large transverse discrepancy and who are not in need of additional surgical jaw movements [14,17].

Although orthopedic expansion can successfully treat maxillary deficiencies, a complete understanding of the impact of dental expansion and craniofacial modifications upon the periodontium remains unclear. Adverse outcomes, such as osseous dehiscence (DEH) [18], vertical bone defects [19], root resorption [20], and mucogingival deformities/conditions [21], have been reported.

Scarce evidence is available regarding the occurrence and prevalence of hard/soft tissue deficiencies among patients undergoing SARME as compared to non-surgical rapid maxillary expansion (NSRME) approaches. Thus, the purpose of this systematic review was to evaluate the effect of NSRME and SARME upon the periodontal structures.

2. Materials and Methods

2.1. Protocol and Registration

The protocol was registered in an international database of systematic reviews (PROSPERO) under the ID CRD42023413766, and fully adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [22].

2.2. PICOS Question

The present review formulated a focused question using the PICOS criteria [23,24]. Do patients with transverse maxillary deficiencies (P) treated with SARME (I) compared to NSRME (C) have an increased impact on the periodontal apparatus (O) as observed in human randomized controlled trials (RCTs), cohorts, and/or case series studies (S)?

- Population: Patients with transverse maxillary deficiencies.
- Intervention: SARME.
- Comparison: NSRME.
- Outcomes: Prevalence/incidence of hard (e.g., DEH, fenestrations) and soft tissue (e.g., mucogingival deformities/conditions) deficiencies. Secondary outcomes included probing depths (PDs), bleeding on probing (BOP), clinical attachment level (CAL), gingival recession (REC), clinical crown height (CCH), keratinized tissue width (KTW), tooth mobility, plaque index (PI), gingival index (GI), marginal bone level (MBL) or equivalent, root resorption, and/or dentinal sensitivity.
- Study design: Human RCTs, prospective/retrospective cohorts, and/or case series studies (>10 patients).

2.3. Screening Process and Search Strategy

Two independent researchers (VT and CGP) conducted an electronic and manual search of the literature in several databases, including PubMed, Web of Science, EMBASE, and the Cochrane Central Register of Controlled Trials, for articles up to November 2023. Ethics approval was not required for this present review. For the selected databases, a combination of terms (MeSH) and keywords was used, where "[mh]" and "[tiab]" represent MeSH terms and a title/abstract search, as depicted in Table 1, Appendices A and B.

Furthermore, a hand search was carried out in oral-surgery-, periodontal-, and orthodontics-related journals, which included the *Journal of Periodontology*, *Journal of Clinical Periodontology*, *The Angle Orthodontist*, *Dental Press Journal of Orthodontics*, *American Journal of Orthodontics and Dentofacial Orthopedics*, *Journal of Oral and Maxillofacial Surgery*, *Oral* *and Maxillofacial Surgery*, and *Journal of Cranio-Maxillo-Facial Surgery*, to ensure a thorough screening process up to November 2023. Additionally, we reviewed the reference lists of the included articles for full-text analysis and literature review articles. Google Scholar was used to identify potential articles among gray literature that were not included in the listed databases.

Table 1. Search strategy and selection criteria.

Focused question	Do adult patients with transverse maxillary deficiencies (P) treated with SARME (I) compared to NSRME (C) have an impact on the periodontal attachment apparatus (O) as observed in human trials, cohorts, and case series studies (S)?	
PICOS	Population	Patients with transverse maxillary deficiencies
	Intervention	SARME
	Comparison	NSRME
	Outcomes	PDs, BOP, CAL, REC, CCH, KTW, mobility, PI, GI, MBL, root resorption, dentinal hypersensitivity, and hard/soft tissue deficiencies
	Study design	RCTs, prospective/retrospective cohorts, and case series
Source	PubMed	"Palatal Expansion Technique"[Mesh] OR Palatal Expansion Technique [tw] OR Palatal Expansion Techniques [tw] OR Technique, Palatal Expansion [tw] OR Palatal Expansion Technic [tw] OR Palatal Expansion Technics [tw] OR Maxillary Expansion [tw] OR (MARPE) [tw] OR mini-screw assisted rapid palatal expansion (MARPE) [tw] OR mini-screw assisted rapid palatal expansion [tw] OR nonsurgical maxillary expansion [tw] OR nonsurgical Rapid maxillary expansion [tw] OR rapid maxillary expansion [tw] OR (SARME) [tw] OR surgically assisted rapid maxillary expansion (SARME) [tw] OR surgically assisted rapid maxillary expansion [tw] OR surgically assisted rapid palatal expansion (SARME) [tw] OR transpalatal distraction osteogenesis [tw] OR transverse maxillary distraction [tw] OR "Osteogenesis, Distraction"[Mesh] OR Osteogenesis, Distraction [tw] OR Distraction Osteogenesis [tw] OR Distraction Osteogeneses [tw] OR Callotasis [tw] OR Callotases [tw] AND "Alveolar Process"[Mesh] OR Alveolar Process [tw] OR Alveolar Processes [tw] OR Alveolar Ridge [tw] OR "Bone Remodeling"[Mesh] OR Bone Remodeling [tw] OR Bone Turnover [tw] OR Bone Turnovers [tw] OR "Bone Resorption"[Mesh] OR Bone Resorption [tw] OR Bone Resorptions [tw] OR Osteoclastic Bone Loss [tw] OR Osteoclastic Bone Losses [tw] OR "Dental Cementum"[Mesh] OR Dental Cementum [tw] OR Cementum [tw] OR Cementoblasts [tw] OR Cementoblast [tw] OR "Dentin Sensitivity"[Mesh] OR Dentin Sensitivity [tw] OR Dentin Sensitivities [tw] OR Dentine Hypersensitivity [tw] OR Dentine Hypersensitivities [tw] OR Dentine Sensitivity [tw] OR Dentine Sensitivities [tw] OR Tooth Sensitivity [tw] OR Tooth Sensitivities [tw] OR Dentin Hypersensitivity [tw] OR Dentin Hypersensitivities [tw] OR "Epithelial Attachment"[Mesh] OR Epithelial Attachment [tw] OR Epithelial Attachments [tw] OR Junctional Epithelium [tw] OR "Gingiva"[Mesh] OR Gingiva [tw] OR Gums [tw] OR Gum [tw] OR Interdental Papilla [tw] OR "Gingival Recession"[Mesh] OR Gingival Recession [tw] OR Gingival Recessions [tw] OR Gingival Atrophy [tw] OR Gingival Atrophies [tw] OR Atrophy of Gingiva [tw] OR Gingiva Atrophies [tw] OR Gingiva Atrophy [tw] OR "Osteolysis"[Mesh] OR Osteolysis [tw] OR Osteolyses [tw] OR "Periodontal Ligament"[Mesh] OR Periodontal Ligament [tw] OR Periodontal Ligaments [tw] OR Alveolodental Membrane [tw] OR Alveolodental Membranes [tw] OR Alveolodental Ligament [tw] OR Alveolodental Ligaments [tw] OR Gomphosis [tw] OR Gomphoses [tw] OR "Periodontium"[Mesh] OR Periodontium [tw] OR Periodontiums [tw] OR Tooth Supporting Structures [tw] OR Tooth Supporting Structure [tw] OR Parodontium [tw] OR Parodontiums [tw] OR Paradentium [tw] OR Paradentiums [tw] OR "Root Resorption"[Mesh] OR Root Resorption [tw] OR Root Resorptions [tw] OR mucogingival deformities [tw] OR periodontal tissue [tw] OR radiographic bone loss [tw] OR clinical attachment level [tw] OR clinical attachment loss [tw] OR clinical attachment level [tw] OR clinical attachment loss [tw] OR probing depths [tw]
	EMBASE	See Appendix A
	Cochrane CENTRAL	See Appendix B
	Journals	*Journal of Periodontology, Journal of Clinical Periodontology, The Angle Orthodontist, Dental Press Journal of Orthodontics, American Journal of Orthodontics and Dentofacial Orthopedics, Journal of Oral and Maxillofacial Surgery, Oral Maxillofacial Surgery*, and *Journal of Cranio-Maxillo-Facial Surgery*

Table 1. *Cont.*

Selection criteria	Inclusion	Studies comparing SARME and/or NSRME for the treatment of transverse maxillary deficiencies
		RCTs, prospective/retrospective cohorts, and case series
		Studies including a minimum of 10 patients (entire studies or within study arms of interest)
		Hard/soft tissue deficiencies as primary outcomes. PDs, BOP, CAL, REC, mobility, PI, GI, MBL, root resorption, and dentinal hypersensitivity as secondary outcomes
	Exclusion	Studies including < 10 patients (entire studies or within study arms of interest)
		SARME and NSRME not performed
		No periodontal outcomes were evaluated or reportedPublished material in the form of an in vitro study, literature review, letters, personal opinion, and/or book chapter

SARME: surgically assisted rapid maxillary expansion; NSRME: non-surgical rapid maxillary expansion; RCTs: randomized clinical trials; MBL: marginal bone level; PDs: probing depths; BOP: bleeding on probing; CAL: clinical attachment level, REC: gingival recession; CCH: clinical crown height; KTW: keratinized tissue width; PI: plaque index; GI: gingival index; tiab: title/abstract; and tw: keyword.

2.4. Eligibility Criteria

RCTs, prospective/retrospective cohorts, and case series (>10 patients), including patients with transverse maxillary deficiencies and treated with NSRME and/or SARME procedures, were included. The prevalence of hard (e.g., DEH, fenestrations) and soft tissue (e.g., mucogingival deformities/conditions) deficiencies were considered as primary variables. Different pre-operative and post-operative variables, including PDs, BOP, CAL, REC, CCH, PI, GI, MBL (e.g., buccal bone height (BBH), buccal bone width (BBW)), mobility, root resorption, and dentinal sensitivity were deemed secondary variables. Articles were excluded if (I) case series had less than 10 patients within the study or specific study arm, (II) NSRME and SARME were not performed, (III) no periodontal outcomes were reported/evaluated, or (IV) published material was in the form of in vitro studies, literature reviews, letters, personal opinions, or book chapters (Table 1).

2.5. Study Selection

After eliminating duplicated articles, two independent authors (GNC and HAW) performed title and abstract screening followed by a full-text evaluation based on the previously mentioned inclusion and exclusion criteria. Any disagreement was resolved via discussion between the two authors. Whenever the two authors failed to reach an agreement, a third reviewer (CGP) was consulted.

2.6. Data Extraction and Analyses

The occurrence and prevalence of hard and soft tissue deficiencies were considered as the primary outcomes to assess the impact of NSRME and SARME procedures. Changes in PDs, BOP, CAL, REC, PI, GI, MBL, mobility, root resorption, and dentinal sensitivity served as secondary outcomes. Both clinical and/or radiographic parameters were recorded and evaluated prior to and/or after NSRME and/or SARME. Due to the heterogeneity of the reported outcomes of the included investigations, only a qualitative descriptive analysis was performed and systematically reviewed using tables.

2.7. Risk of Bias and Quality Assessment of the Selected Studies

The risk of bias and quality assessment of RCTs was performed following the Cochrane Handbook for Systematic Reviews of Interventions [25], whereas the Newcastle–Ottawa Scale (NOS) was followed for non-randomized cohort studies [26]. Two authors (GNC and HAW) evaluated the selected studies independently and resolved any disagreements via discussion to produce final scores. In brief, a low risk of bias was given when plausible bias was unlikely to alter the results or bias was low in all domains. An unclear risk of bias was estimated when plausible bias raised some doubts about the results or bias was unclear in one or more key domains. Ultimately, a high risk of bias was estimated when plausible bias seriously weakened confidence in the results or bias was high in one or more key domains.

3. Results

3.1. Study Selection

The initial screening of electronic databases yielded a total of 2024 articles and 11 publications identified through a manual search. Duplicated studies were eliminated, leaving 2013 articles for further examination. After reviewing the titles and abstracts of the remaining articles, 66 were chosen for full-text evaluation. Of these, 45 articles were excluded for failure to report clear periodontal outcomes, had insufficient sample sizes of less than 10 patients, and/or involved duplicate patient samples from other studies (Supplemental Table S1). Finally, 21 studies met the inclusion/exclusion criteria and were assessed in this systematic review, as shown in the PRISMA flowchart in Figure 1.

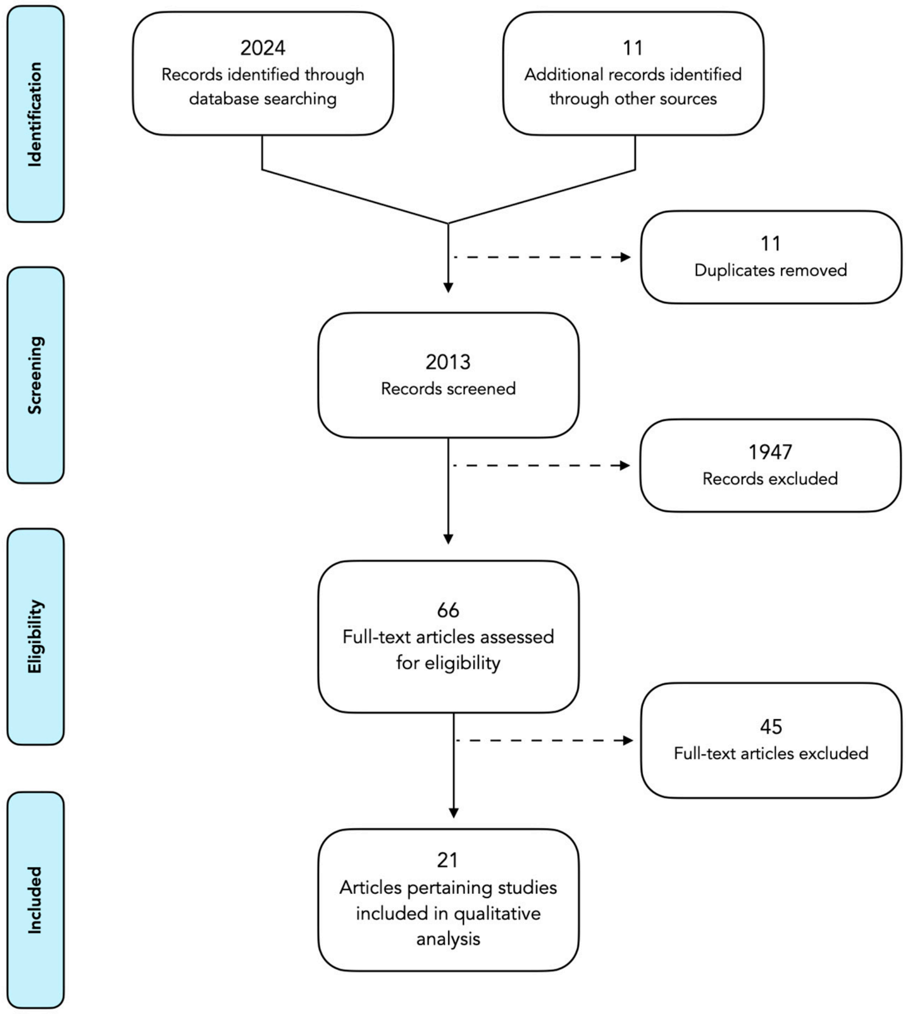

Figure 1. PRISMA flowchart of the screening process in the different databases.

The significant heterogeneity among the included investigations prevented the conduction of any quantitative synthesis. Hence, a descriptive but detailed analysis of the reported outcomes was performed. The inter-reviewer reliability in the screening and inclusion process, assessed with Cohen's κ, was 0.93 and 0.88 for the assessment of titles as well as abstracts and full-text evaluation, respectively.

3.2. Characteristics of the Included Studies

A summary of the characteristics of the included studies is presented in Table 2. Among the 21 included articles in this qualitative analysis, one was an RCT [18], fourteen were retrospective [19,27–39], and six were prospective cohort studies [7,21,40–43]. Six investigations only included patients who underwent NSRME [27,29–32,40], eleven studies presented patients who experienced SARME [7,18,19,21,35–39,42,43], and four studies reported outcomes from both NSRME and SARME procedures [28,33,34,41].

A total of 901 patients were included among all of the selected articles. Of these, 464 patients underwent SARME procedures, 289 experienced NSRME, 33 were treated with non-surgical slow maxillary expansion, and 115 served as controls without any maxillary expansion performed. The mean ages across all of the studies ranged between 13.2 and 31.4 years old, representing patients at diverse levels of skeletal maturity.

The assessment of periodontal outcomes varied between clinical and radiographic measurements. Eight studies collected clinical measurements from periodontal exams [7,19,21,27,28,34,36,42]. Conversely, nine studies measured radiographic outcomes via cone-beam computed tomography (CBCT) [18,30–34,38,39,42], one used multi-detector computed tomography [35], and two used intraoral radiographs [7,36]. Ultimately, seven investigations obtained measurements from stone cast models [7,28,29,37,40,41,43] and two through intraoral photographs [28,34].

Regarding the type of expanders used for the treatment of transverse maxillary deficiency, a total of twelve studies used Hyrax-type tooth-borne maxillary expanders [18,19,21,28,30,31,35,37–39,42,43], six studies employed bone-borne appliances [7,19,28,34–36], four studies used hybrid tooth–bone-borne devices [18,32–34], two studies used C-type tissue–bone-borne devices [31,32], and four used a Haas-type tissue–tooth-borne appliance [27,29,40,41].

3.3. Clinical and Radiographic Outcomes Following NSRME and SARME

3.3.1. Gingival Recession (REC)

The incidence of REC was examined in seven studies [7,19,21,28,34,36,41], while only two studies recorded this finding pre-operatively [7,21]. Four studies [19,28,34,36] reported REC on a patient-based level, while four reported on a site-specific level [7,21,28,41]. Most studies found that SARME resulted in increased REC among posterior teeth and mesial to the central incisors after sutural separation [7,19,21,34]. Interestingly, in a three-arm study comparing NSRME, SARME, and control patients, a notable increase in REC was reported in posterior teeth after NSRME (8.4%) as compared to SARME (3.6%) [28].

3.3.2. Clinical Crown Height (CCH)

Five studies measured the change in the CCH after maxillary expansion using stone casts [29,37,40,41,43] and one study used cross-sections from CBCT [38]. Studies using NSRME [29,40,41] reported an increased CCH in posterior teeth ranging between 0.30 and 1.30 mm, while the range for SARME was from –0.15 to 0.77 mm [37,38,41,43]. Among the observed studies, the increase in the CCH was less pronounced in SARME compared to NSRME. It can be said that an increase in the CCH is equivalent to an increase in REC and/or a decrease in buccal bone height (BBH).

3.3.3. Clinical Attachment Level (CAL)

Only two of the included studies recorded the CAL [21,27]. Following NSRME procedures, Greenbaum and Zachrisson reported slightly increased post-treatment CAL at first molars as compared to controls (0 to 0.3 mm) [27]. On the other hand, Sendyk et al. reported a statistically significant increase in the CAL ranging from 0.42 to 0.91 mm at central incisors, first premolars, and first molars [21].

Table 2. Characteristics of the included studies.

Author	Study Design	Sample Size (Patients)	Age (Years)	Groups	Gender (Females %)	Periodontal Disease (Y/N)	Smoking Status (Y/N)	Subgroups	Teeth	Type of Expansion	Method for Measurement	Follow-Up (Months)	Primary Outcome	Secondary Outcome	Outcome
Greenbaum and Zachrisson, 1982 [27]	RET	28	14.3 (2.4) Range: NR	Control	82.14	NR	NR	Right/left	First molar	NR	Clinical exam	52.8	BBH	CAL	Minimal periodontal differences were observed between the RME, SME, and control group.
		33	12.3 (2.0) Range: NR	NSSME	75.75			Right/left	First molar	Tissue–tooth-borne		50.4			
		28	13.2 (1.9) Range NR	NSRME	60.71			Right/left	First molar			58.8			
Handelman, 1996 [40]	PROS	30	30.6 (NR) Range: NR	Control	NR	NR	NR	NR	First molar First/second premolar	Tissue–tooth-borne	Stone casts	NR	Transverse expansion	CCH	RME yielded significant expansion and resulted in a 0.5 mm increase in REC as compared to 0.2 mm in the control group.
		27		NSRME					First molar First/second premolar						
Northway and Meade Jr., 1997 [41]	PROS	15	26.0 (NR) Range: 17.0–35.3	SARME	62.5	NR	NR	NR	First molar First/second premolar	Tissue–tooth-borne	Stone casts	24.12	Transverse expansion	CCH	REC was increased among NSRME groups at the premolars compared to SARME and controls (1.2 mm, 0.5 mm, and 0.6 mm).
		5	34.4 (NR) Range: 27.3–47.1	Control	43.75				First molar First/second premolar			22.32 (NR)			
		15	22.5 (NR) Range: 15.5–39.6	NSRME	57.14				First molar First/second premolar			28.32 (NR)			
Carmen et al., 2000 [28]	RET	35	17.8 (NR) Range: NR	SARME	72.28	NR	NR	NR	Maxillary arch Posterior teeth	Bone-borne	Pre-tx: stone casts, photographs Post-tx: clinical exam	4	REC	Transverse expansion	SARME considered a safer procedure than orthopedic expansion in terms of maxillary transverse diameter enlargement and gingival recession.
		26	17.4 (NR) Range: NR	NSRME	65.38				Maxillary arch Posterior teeth	Tooth-borne					
Handelman et al., 2000 [29]	RET	52	32.7 (7.4) Range: 20.9–46.3	Control	59.61	NR	NR	Males/females	First molar First/second premolar	Tissue–tooth-borne	Stone casts	25.2 (8.4)	Transverse expansion	REC	Conventional RME in adults resulted in significantly longer clinical crowns, but rarely caused exposure of buccal root cementum, and complications were of minimal consequence.
		47	29.9 (8.0) Range: 18.8–49.3	NSRME	59.57			Males/females	First molar First/second premolar			24.0 (7.2)			
Ramieri et al., 2005 [7]	PROS	29	26.4 (NR) Range: NR	SARME	72.41	Y	NR	NR	Incisors Premolars and molars	Bone-borne	Stone casts, clinical exam, and radiographs	12	Transverse expansion	Mobility	Most negative periodontal side effects of SARME involved defects between the central incisors.

Table 2. *Cont.*

Author	Study Design	Sample Size (Patients)	Age (Years)	Groups	Gender (Females %)	Periodontal Disease (Y/N)	Smoking Status (Y/N)	Subgroups	Teeth	Type of Expansion	Method for Measurement	Follow-Up (Months)	Primary Outcome	Secondary Outcome	Outcome
Rungcharassaeng et al., 2007 [30]	RET	30	13.8 (1.7) Range: 10.3–16.8	NSRME	43.33	NR	NR	NR	First molar	Tooth-borne	CBCT	3	BBW	Crown Tipping	Buccal crown tipping and reduction in the BBH and BBH of the maxillary posterior teeth are the expected immediate effects of conventional RME.
									Second premolar						
									First premolar						
Landes et al., 2009 [35]	RET	50	Range: 13.0–50.0	SARME	NR	NR	NR	Tooth-borne device	First/second molar	Tooth-borne	CT	NR	Transverse expansion	BBH and BBW	Bone-borne devices resulted in greater skeletal and dental maxillary expansion, more asymmetric expansion, less vestibular bone resorption, and less dental tipping than tooth-borne devices.
									First/second premolar						
								Bone-borne device	First/second molar	Bone-borne					
									First/second premolar						
Gauthier et al., 2011 [41]	PROS	14	23.0 (1.9) Range: 16.4–39.7	SARME	64.28	N	N	Right/left	Second molar	Tooth-borne	CBCT, clinical exam	6	BBW	BBH	SARME resulted in decreased BBW and BBH, but increased palatal bone thickness, and seemed to have little detrimental clinical effects on the periodontium.
									First molar						
									First/second premolar						
									Canine						
									Central incisor						
Verlinden et al., 2011 [36]	RET	63	28 (NR) Range: 9.0–59.0	SARME	63.01	Y (3.17%)	NR	NR	NR	Bone-borne	Clinical exam, radiographs	23.9	Complications	REC	Minimal periodontal damage including recession, 4–5 mm pocket depths, and external root resorption were observed among SARME-treated patients.
Wlliams et al., 2012 [19]	RET	120	29.5 (NR) Range: 22.0–39.0	SARME	62.0	NR	Y (10.8%)	NR	NR	Tooth- and bone-borne	Clinical exam	5.6	Complications	REC	Major complications after SARME were rare, yet inadequate expansion and periodontal problems involving the central incisors accounted for most complications.
Kilic et al., 2013 [37]	RET	8	21.6 (3.4) Range: 17.0–24.0	SARME with PMD	88.88	NR	NR	Right/left	First molar	Tooth-borne	Stone casts	4	Transverse expansion	CCH	PMD did not produce significant differences in expansion patterns nor clinical crown height.
									First/second premolar						
		10	20.1 (3.1) Range: 17.0–26.0	SARME without PMD				Right/left	First molar						
									First/second premolar						

Table 2. *Cont.*

Author	Study Design	Sample Size (Patients)	Age (Years)	Groups	Gender (Females %)	Periodontal Disease (Y/N)	Smoking Status (Y/N)	Subgroups	Teeth	Type of Expansion	Method for Measurement	Follow-Up (Months)	Primary Outcome	Secondary Outcome	Outcome
Sygouros et al., 2014 [38]	RET	10	18.8 (NR) Range: NR	SARME with PMD	80	NR	NR	NR	First molar First/second premolar Canine	Tooth-borne	CBCT	6	Transverse expansion	BBH and BBW	PMD did not produce significant differences in expansion patterns. Alveolar bone resorption at the first premolars was significantly reduced with PMD.
		10		SARME without PMD					First molar First/second premolar Canine						
Lin et al., 2015 [31]	RET	13	17.4 (3.4) Range: NR	NSRME with Hyrax device	100	NR	NR	Right/left	First/second molar First/second premolar	Tooth-borne	CBCT	3	Transverse expansion	CCH	Significant buccal dehiscence at the first premolar and increased CCH at the second premolar occurred in the tooth-borne group.
		15	18.1 (4.4) Range: NR	NSRME with C-expander				Right/left	First/second molar First/second premolar	Tissue–bone-borne					
Siqueira et al., 2015 [43]	PROS	18	23.3 (NR) Range: 18.0–35.0	SARME	66.66	NR	NR	Right/left	First/second molar First/second premolar Canine	Tooth-borne	Stone casts	6	Transverse expansion	Crown tipping	Among SARME patients, no statistically significant difference was found in crown height, except for the left first and second molars, although clinically irrelevant.
Kayalar et al., 2016 [18]	RCT	10	19.4 (5.0) Range: 18.0–35.0	SARME with hybrid device	55	No	NR	Hybrid device	First molar First premolar	Tooth–bone-borne	CBCT	6	Transverse expansion	Crown tipping	Dental tipping, buccal alveolar bone resorption, and root resorption were observed significantly more often with the tooth-borne devices.
		10	19.2 (3.6) Range: 18.0–35.0	SARME				Tooth-borne device	First molar First premolar	Tooth-borne					
Lim et al., 2017 [33]	RET	24	21.6 (NR) Range: 18.2–26.7	NSRME	66.66	NR	NR	NR	First molar First/second premolar	Tooth–bone-borne	CBCT	12	Transverse expansion	BBH and BBW	BBW decreased while palatal bone width increased. BBH was reduced at the first premolar.
Sendyk et al., 2018 [21]	PROS	17	Range: 25.0–45.0	SARME	52.94	Y	N	Right/left	First molar First premolar Lateral incisor Central incisor	Tooth-borne	Clinical exam	6	CAL	REC	SARME resulted in increased CAL, recession, and BOP, as well as decreased attached gingiva.
Moon et al., 2020 [32]	RET	24	19.2 (5.9) Range: NR	NSRME with hybrid device	41.66	NR	NR	Right/left	First molar	Tooth–bone-borne	CBCT	3	Transverse expansion	Alveolar inclination	Reductions in BBH and BBW, and incidence of dehiscence was greater in the tooth–bone-borne group than in the tissue–bone-borne group.
		24	18.1 (4.5) Range: NR	NSRME with C-expander	79.16			Right/left	First molar	Tissue–bone-borne					

Table 2. *Cont.*

Author	Study Design	Sample Size (Patients)	Age (Years)	Groups	Gender (Females %)	Periodontal Disease (Y/N)	Smoking Status (Y/N)	Subgroups	Teeth	Type of Expansion	Method for Measurement	Follow-Up (Months)	Primary Outcome	Secondary Outcome	Outcome
Li and Guilleminault, 2022 [34]	RET	22	25.2 (NR) Range: 26.0–36.0	SARME	NR	NR	NR	NR	NR	Bone- and tooth–bone-borne	CBCT, clinical exam, and photographs	18	Transverse expansion	Complications	Among patients presenting for a second opinion, complications included bone defects, recession, failure of sutural separation, crown tipping, and BBW decrease.
			32.6 (NR) Range: 28.0–49.0	NSRME with various appliances				AGGA	Anterior teeth	NR					
			NR					DNA	NR	NR					
			22 (NR) Range: 14.0–21.0					ALF	NR	NR					
			26.2 (NR) Range 20.0–36.0					MARPE	NR	Bone- and tooth–bone-borne					
Martin et al., 2023 [39]	RET	39	25.9 (9.2) Range: 12.0–48.0	SARME	64.10	NR	NR	Right/left	First molar	Tooth-borne	CBCT	13.8 (6.9)	BBH	BBW	BBW/BBH decreased among first molars and premolars. Root resorption and fenestration occurred at the first molar.
									First premolar						

RET: retrospective cohort; PROS: prospective cohort; RCT: randomized clinical trial; NSSME: non-surgical slow maxillary expansion; RME: rapid maxillary expansion; NSRME: non-surgical rapid maxillary expansion; SARME: surgically assisted rapid maxillary expansion; PMD: pterygomaxillary disjunction; AGGA: anterior growth guidance appliance; DNA: daytime–nighttime appliance; ALF: advanced lightwire functionals appliance; MARPE: miniscrew-assisted rapid palatal expansion; CBCT: cone-beam computed tomography; CT: computed tomography; BBH: buccal bone height; REC: gingival recession; BBW: buccal bone width; CAL: clinical attachment level; CCH: clinical crown height; SME: slow maxillary expansion; BOP: Bleeding on probing; and NR: not reported.

3.3.4. Probing Depths (PDs)

Two studies using SARME [7,36] and one study using NSRME [27] reported PDs post-operatively. Greenbaum and Zachrisson reported no PDs greater than 3 mm after NSRME in a young population [27], whereas studies using SARME measured the incidence of PDs greater than 3 mm before and after treatment and an increase ranging between 4.3% and 12.7% [7,36]. The heterogeneity in the methodology and reported results did not allow a direct comparison of the effects of SARME and NSRME upon PDs.

3.3.5. Bleeding on Probing (BOP)

Two studies measured the change in BOP as a result of SARME and NSRME treatment [21,27]. Sendyk et al. found that of the 16 sites measured, 2 showed a significant increase in BOP frequency after treatment with SARME and a tooth-borne device (buccal and palatal sites of central and lateral incisors, respectively) [21]. Similarly, Greenbaum and Zachrisson found that differences in BOP were not statistically significant when using NSRME and a tooth-borne device [27].

3.3.6. Keratinized Tissue Width (KTW)

KTW was measured in one study using NSRME [27] and two using SARME [21,42]. Greenbaum and Zachrisson found that gender was the only variable to correlate with KTW following NSRME procedures [27]. Furthermore, both studies using SARME found that KTW was decreased post-operatively at the sites of premolars, first molars, and second molars [21,42].

3.3.7. Tooth Mobility

Only two studies measured the incidence and grade of tooth mobility prior to, during, and following SARME [7,42]. While using a bone-borne appliance, Ramieri et al. recorded mobility in only 16.7% of central incisors one year after appliance removal and not extending beyond Miller grade 1 mobility [7]. On the other hand, Gauthier and coworkers used a tooth-borne Hyrax-type appliance and found a significant increase in mobility for all teeth other than second molars 6 months after expansion [42]. It is worth remarking that grade II mobility was observed among central incisors after expansion with a tooth-borne Hyrax-type appliance.

3.3.8. Buccal Bone Height (BBH) and Dehiscence (DEH)

In the context of the present review, the BBH and DEH are inverse measurements of one another and were measured similarly. Thus, they were not distinguished but rather discussed interchangeably in the included articles. Seven studies measured the changes in the BBH and DEH after maxillary expansion using CBCT imaging [30–33,35,38,42]. Four of those studies [30–33] utilized NSRME procedures while three studies included SARME procedures [35,38,42]. The method of measurement varied slightly between studies as some investigators calculated the BBH from the buccal alveolar crest to the buccal cusp tips [30,33,38,42], cemento-enamel junction [31,32], and root apices [35]. Thus, the high heterogeneity in methodology precluded a direct comparison. Although no clear differences emerged between the effects of SARME and NSRME on the BBH, three studies demonstrated significant decreases in the BBH when tooth-borne devices were used as compared to bone-borne expansion devices [31,32,35].

3.3.9. Buccal Bone Width (BBW)

A total of seven studies measured changes in the buccal bone width (BBW) [18,30,32,33,38,39,42]. Three of these studies included patients treated with NSRME [30,32,33], and the other four utilized SARME [18,38,39,42]. Methods of measuring the BBW varied between studies, which could contribute to the variability in results. While all studies used CBCT, four studies [18,32,33,38] recorded the BBW on axial sections while three studies collected these measurements on coronal sections [30,39,42]. Additionally, some studies measured the BBW at the apico-coronal height of the first molar furcation [18,32,38], two millimeters below the first molar furcation [42], at the most vestibular point of cortical bone [39], and at the height where buccal bone deflected [30]. One study failed to describe the specific point of measurement [33]. It is important to note the apico-coronal height at which the BBW was measured since alveolar bone will undergo a remodeling process at various heights and at different degrees of extension associated with the tipping caused by tooth- and bone-borne devices.

All but one study [18] found a decrease in the BBW at every site ranging between 0.2 mm and –1.24 mm after maxillary expansion. Notably, Moon and colleagues reported no clear differences emerged between the effects of NSRME and SARME techniques on the change in BBW [32].

3.3.10. Fenestrations

Two studies reported on the development of fenestrations, one including SARME [39] and the other including NSRME procedures [32]. Using SARME and tooth-borne devices, Martin and colleagues found that the prevalence of fenestrations at the mesio-buccal root of the upper-left molar increased from 8% pre-operatively to 28% after fourteen months following the surgical procedure [39]. Moon and colleagues compared the effects of hybrid tooth–bone-borne devices to tissue–bone-borne devices during NSRME procedures and reported a 25% and 4% prevalence of fenestrations, respectively, 3 months post-expansion [32].

3.3.11. Root Resorption

Four studies, all including SARME procedures, measured the incidence of external apical root resorption [7,18,36,39]. Two evaluated patients for root resorption among device-anchoring posterior teeth [18,39], while the other two assessed resorption of the roots of the central incisors [7,36]. Kayalar and colleagues found that the magnitude of root resorption ranged from −0.3 to −1.1 mm among all maxillary first premolar and first molar roots, while Martin et al. found similar values ranging from −0.1 to −0.6 mm [18,39]. On post-operative radiographs, Verlinden and coworkers found that 19%, 8%, and 2% of central incisor roots displayed slight, moderate, and extreme root resorption, respectively, according to Sharpe's classification [36]. On the other hand, using both pre-operative and post-operative CBCT, Martin and colleagues recorded no increase in resorption of any central incisor roots as a result of SARME [39].

3.3.12. Gingival Index (GI), Plaque Index (PI), and Dentinal Hypersensitivity

None of the included studies reported measures of GI, PI, or dentinal hypersensitivity.

3.4. Quality Assessment and Risk of Bias

The risk of bias among the cohort studies included in the analysis varied considerably (Figure 2, Supplemental Table S2). It was observed that several studies received scores between six and eight stars, indicating a lower risk of bias in terms of selection, comparability, and outcome assessment [7,21,28–33,37,38,40,41,43,44]. Conversely, other studies demonstrated a higher risk of bias, lacking stars in several criteria, which potentially questions their reliability and validity [19,34,36,39,42]. The quality assessment of the only included RCT study [18] exhibited a low risk of bias in all categories (Supplemental Table S3).

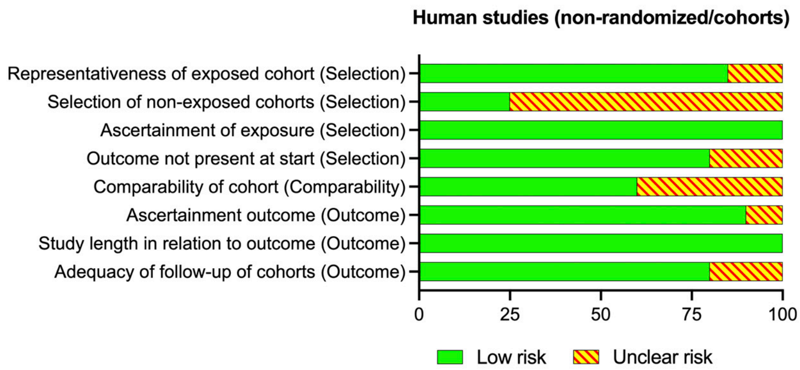

Figure 2. Assessment of quality and risk of bias of human non-randomized studies.

4. Discussion

Transverse maxillary deficiency can be adequately treated through various established modalities, including camouflaging via dental expansion, NSRME, SARME, and Le Fort 1 osteotomy with palatal segmentation. Since some of these methods place more physiologic stress on the periodontium than others, the patient's periodontal health should be considered when determining the best treatment modality.

4.1. NSRME vs. SARME

Through releasing the osseous centers of resistance, SARME is thought to reduce the physiologic burden placed upon the periodontium. After releasing the circummaxillary sutures, the force necessary to create palatal expansion should be less than that produced in NSRME. The prediction of a successful rapid maxillary expansion is influenced by suture bone density and the fracture resistance increasing with age (<25 years vs. >25 years [45]. Thus, this surgical intervention will allow the maxillary halves to separate transversely without major disadvantages in younger individuals (<25 years) [45], with less buccal migration of the teeth, and reduce the occurrence of REC and/or DEH in patients with thin periodontal phenotypes [42,46].

Multiple studies have shown that both NSRME and SARME are individually associated with REC primarily located at posterior teeth and between central incisors [7,19,21,28,36,41,47]; however, only two studies within this review included both NSRME and SARME study arms directly comparing the two groups with similar average ages [28,41]. Moreover, these studies reported that the incidence and amount of REC in posterior maxillary teeth were significantly greater for NSRME (8.4%, 1.2 mm) as compared to SARME (3.6%, 0.5 mm). Such findings were corroborated by the aggregation of reported changes in the CCH among the included studies, showing an increased magnitude of mucogingival deformities among NSRME-treated patients [29,37,38,40,41,43]. Ramieri and colleagues showed that REC that developed on posterior teeth during SARME persisted 1 year after appliance removal; however, no defects greater than 3 mm were observed [7]. Additionally, mild papillary REC affecting maxillary central incisors following SARME has been reported [48,49]. Observations from the present review suggest that SARME is associated with a lesser incidence of soft tissue deficiencies when compared to NSRME.

The current literature supports the idea that orthodontic treatment, with or without palatal expansion, may be associated with an immediate decrease in buccal alveolar bone dimensions that is alleviated over time. Zachrisson and Alnaes showed a decrease in alveolar bone height immediately after orthodontic treatment [50]; however, Polson and Reed showed that there is no difference in bone levels among orthodontically treated and untreated individuals 10 years after the completion of orthodontic treatment [51].

It is not clear whether specific orthodontic treatment modalities are more strongly associated with alveolar bone loss than others [52]. Sygouros and colleagues found that among patients undergoing SARME, those who were treated with PMD experienced less BBW reduction as compared to those without this additional procedure [38]. However, our results were unable to find a significant difference of the change in BBH, BBW, DEH or fenestrations between SARME and NSRME-treated patients. The variability in measurement techniques and patient response to treatment may contribute to the inconsistent results found across the included studies. Ultimately, there is insufficient data to differentiate the effects of SARME and NSRME on CAL, PD, and KTW due to the lack of controlled clinical trials reporting these outcomes.

No significant differences were found in the amount of transverse dental expansion achieved via SARME and NSRME. Among SARME study-arms, average gains in dental arch width ranged from 3.6 to 9.8 mm at the first premolars, and 3.1 to 9.8 mm at the first molars [7,18,28,35,37–39,41,43]. The amount of expansion achieved in NSRME study-arms ranged from 3.3 to 6.0 mm at the first premolars, and 3.1 to 9.3 mm at the first molars [27–33,40,41]. Studies directly compared NSRME and SARME found no statistically significant differences between the amount of dental expansion in either modality [28,41]. However, Northway and Meade found that SARME resulted in greater skeletal expansion through palatal width increase than NSRME, and thus, suggesting a higher ratio of skeletal to dental expansion [41]. No direct comparison between the amount of expansion gained through each modality was possible since the transverse expansion needs vary between patients and the type of intervention (SARME or NSRME) was not subject of randomization. Additionally, insufficient evidence was available to correlate the amount of expansion to the magnitude of adverse periodontal effects.

In the present review, multiple studies showed varied rates of successful sutural separation potentially affected by patient age and type of intervention (e.g., SARME). Handelman and colleagues found that diastema formation between the central incisors rarely occurred among an all-adult cohort (mean age: 29.9 years) treated with NSRME and tissue-tooth-borne expanders [29]. On the other hand, Lin and associates observed a successful suture opening in every patient of an all-female population (average age: 17.4–18.1 years) treated with NSRME, tooth-borne and tissue-bone-borne expanders [31]. Similarly, a study by Capelloza-Filho and colleagues found that NSRME and tissue-tooth-borne expanders in adults resulted in successful diastema formation in 81.5% of patients [53]. Given the available evidence, it can be presumed that the surgical release of the circummaxillary sutures gives the greatest likelihood of achieving a sutural separation in skeletally mature individuals.

4.2. Tooth- vs. Bone-Borne Appliances

While both tooth- and bone-borne appliances have been associated with a decrease in BBH, we found the magnitude of MBL changes to be less pronounced among patients with bone-borne appliances as compared to those with tooth-borne appliances [31,32,35]. Lin and colleagues found that tooth-borne devices led to a significantly increased magnitude of buccal DEH at the first premolar of 5.1 mm noted for tooth-borne devices compared to 0.1 mm noted for bone-borne devices [31]. Moreover, expansion appliances with tooth-borne anchorage, including hybrid tooth–bone-borne, were associated with a higher prevalence of fenestrations than those with purely bone- or tissue–bone-borne attachments [32,39]. A systematic review by Muñoz and colleagues also concluded that tooth-borne devices were associated with more adverse periodontal outcomes as compared to bone-borne devices [54]. Furthermore, Gauthier and colleagues found that tooth-borne appliances resulted in a significant increase in the tooth mobility of all maxillary teeth, whereas Ramieri and coworkers recorded that a bone-borne appliance resulted in an increase in mobility in only central incisors in few cases (16.7%), again showing a decreased incidence of adverse periodontal effects associated with bone-borne appliances [7,42]; however, a study by Laudemann and coworkers found that bone-borne appliances led to greater attachment loss between the maxillary central incisors due to the larger amount of expansion experienced as a result of bone-borne anchorage [55]. Thus, it appears that while bone-borne appliances mitigate the adverse periodontal effects on the areas of the posterior teeth, they can increase the risks to central incisors. It is worth noting, however, that some researchers question the diagnostic validity of fenestrations via CBCT [56,57].

The increased incidence of tooth mobility and decrease in BBH associated with tooth-borne appliances can be plausibly attributed to the increased stress on the PDL and resorption of the buccal alveolar bone caused by tooth-borne anchorage [54].

The magnitude and shape of palatal expansion are significantly impacted by both treatment modality (SARME versus NSRME) and the anchorage of the expander (e.g., bone-borne, tooth-borne, tissue–bone-borne, and/or tooth–bone-borne), but not by PMD [58]. Among NSRME-treated patients, Lin and colleagues showed that tissue–bone-borne appliances led to much greater skeletal but less dental expansion (16.9 mm sutural, 2.4 mm nasal floor, and 4.0 mm dental expansion) than tooth-borne appliances (8.2 mm sutural, 1.2 mm nasal floor, and 4.6 mm dental expansion) [31]. In fact, Moon et al. concluded that tooth–bone-borne palatal expanders lead to similar increases in nasal floor width, but more dental expansion, compared to tissue–bone-borne devices [32].

Among SARME-treated patients, the amount of expansion achieved was not statistically different between tooth-borne, bone-borne, and tooth–bone-borne devices; however, Kayalar et al. [18] found that employing a hybrid tooth-bone-borne device with SARME including PMD resulted in more crown expansion of the first molars than the first premolars. These results may likely be due to the hybrid device being banded to the first molars posteriorly and by temporary-anchorage-devices in the anterior zone. While this expansion differs from the traditional patterns, it is important to note that the pattern of expansion at the hard palate followed a more anterior than posterior skeletal expansion. In the same study, tooth-borne devices resulted in an expansion pattern that was more parallel in the antero-posterior plane. Adding more context to these findings, Landes et al. [33] used a similar SARME protocol with PMD but compared completely bone-borne devices to tooth-borne devices. It was found that the bone-borne device without a banded anchorage to first molars resulted in a greater anterior than posterior expansion, while the tooth-borne device provided a more symmetrical expansion antero-posteriorly.

Evidence suggests that bone-borne anchorage devices are associated with a lesser increase in both dental and alveolar inclination as a result of maxillary expansion [30–32]. Rungcharassaeng and colleagues [30] found that tooth-borne expansion appliances resulted in 6 to 11 degrees of dental buccal tipping, while Lin et al. [31] reported the same value to be between 3 and 12 degrees. In contrast, these same studies and one by Moon et al. concluded that tissue–bone-borne expanders resulted in only 0 to 1.5 degrees of dental tipping, while tooth–bone-borne devices resulted in 2 to 3 degrees [30–32]. Regarding alveolar bending, devices with a bony anchorage (tissue–bone-borne and tooth–bone-borne) resulted in a change of less than 2.5 degrees, while tooth-borne devices caused up to 4 degrees of alveolar inclination [31,32]. It is plausible that the increased buccal dental inclination associated with tooth-borne expanders may be related to the REC and decreased BBH seen with such devices.

4.3. Limitations

The included studies enrolled a wide range of participants of varying ages, a diverse range of appliances (e.g., tissue-, bone-, or tooth-supported expanders) for treatment, and outcome measurements in diverse ways and at diverse time points. Only 11 of the 21 studies evaluated the baseline periodontal status, and 6 controlled the impact of medical/environmental conditions (e.g., smoking, tissue phenotype, and many predisposing/precipitant factors). The periodontal status (health/history of periodontitis), tissue phenotype (thin/thick), activation protocols of orthodontic appliances, severity of transverse maxillary deficiency, and the wide age range of the included patients undergoing these procedures could have a significant impact on the onset of hard/soft tissue deficiencies. It is expected that NSRME and/or SARME would have less detrimental effects on periodontal structures during active developmental growth among younger individuals compared to adults with skeletal maturity. This phenomenon might be influenced by the above-mentioned factors; however, no conclusions could be derived with the available data. On the other hand, while many studies measured expansion parameters, very few quantified the occurrence of successful sutural separation or disclosed the severity of the transverse maxillary deficiency precluding further correlations. The high heterogeneity among the selected studies prevented the formation of a meta-analysis.

4.4. Future Directions

An abundance of literature has found that rapid maxillary expansion, both surgical and non-surgical, is associated with decreased alveolar bone dimensions and increased buccal dental tipping, necessitating a healthy supporting periodontium [18,27,30–32,34,38,39,42,44]. Fortunately, the amount of bone resorption is generally well tolerated in a healthy dentition, although mild and severe complications do occur [19]. Therefore, periodontally compromised patients might benefit from reducing the physiological burden placed upon the dentition through the use of SARME and/or bone-borne appliances in place of NSRME or tooth-borne devices. Sygouros et al. recommended that PMD be performed in periodontally compromised patients receiving SARME due to the reduction in alveolar bone caused by SARME without PMD [38]. The increased cost, invasive nature, and morbidity associated with SARME should be weighed against the potential periodontal and skeletal benefits of SARME [19]. As such, the authors highly encourage clinicians to perform a comprehensive periodontal exam prior to maxillary expansion procedures. Clear interdisciplinary communication between orthodontists and periodontists will help prevent avoidable complications. Pre-operative soft tissue augmentation procedures (e.g., sub-epithelial connective tissue grafts, free gingival grafts) are intended to prevent the onset of hard and soft tissue deficiencies discussed in the present review. Yet, available scientific evidence remains scarce to provide solid conclusions [59].

Ultimately, the results of the present review should be interpreted carefully as more RCTs evaluating SARME, NSRME, and tooth- as well as bone-borne appliances are necessary to control a large variety of confounding factors (e.g., age, magnitude of maxillary expansion needed, history of periodontal disease, tissue phenotype (thin/thick), KTW, and smoking status, among others). On the other hand, the qualitative analysis suggested that the onset of hard and soft tissue deficiencies is relatively higher among patients undergoing NSRME procedures when compared to SARME.

5. Conclusions

Based on the present review, the impact of NSRME and SARME upon the periodontium remains inconclusive.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14041669/s1, Table S1: Excluded articles; Table S2: Quality assessment of non-randomized studies based on the Newcastle–Ottawa scale (NOS); Table S3: Bias risk assessment of RCTs using the Cochrane Risk of Bias Tool for Randomized Controlled Trials.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Search strategies for EMBASE.

Filters Used: English Language & Human Studies

'palatal expansion'/exp OR 'palatal expansion':ti,ab OR 'palatal expansion procedure':ti,ab OR 'palatal expansion technique':ti,ab OR 'palatal expansion techniques':ti,ab OR 'maxillary expansion'/exp OR 'maxillary expansion':ti,ab OR '(marpe)':ti,ab OR 'miniscrew assisted rapid palatal expansion (marpe)':ti,ab OR 'nonsurgical maxillary expansion':ti,ab OR 'nonsurgical rapid maxillary expansion':ti,ab OR 'rapid maxillary expansion'/exp OR 'rapid maxillary expansion':ti,ab OR '(sarme)':ti,ab OR 'surgically assisted rapid maxillary expansion (sarme)':ti,ab OR 'surgically assisted rapid maxillary expansion'/exp OR 'surgically assisted rapid maxillary expansion':ti,ab OR 'surgically assisted rapid palatal expansion (sarme)':ti,ab OR 'transpalatal distraction osteogenesis':ti,ab OR 'transverse maxillary distraction':ti,ab OR 'distraction osteogenesis'/exp OR 'bone distraction (procedure)':ti,ab OR 'distraction bone regeneration':ti,ab OR 'distraction osteogenesis':ti,ab OR 'distraction osteosynthesis':ti,ab OR 'osteo-distraction':ti,ab OR 'osteodistraction':ti,ab OR 'osteogenesis distraction':ti,ab OR 'osteogenetic distraction':ti,ab OR 'osteogenic distraction':ti,ab OR 'osteogenical distraction':ti,ab OR 'callus distraction'/exp OR 'callotasis':ti,ab OR 'callotatic distraction':ti,ab OR 'callus distraction':ti,ab OR 'callotasis':ti,ab

AND

'alveolar bone'/exp OR 'alveolar arch':ti,ab OR 'alveolar bone':ti,ab OR 'alveolar process':ti,ab OR 'lower jaw alveolar arch':ti,ab OR 'lower jaw alveolar part':ti,ab OR 'lower jaw alveolus arch':ti,ab OR 'mandible alveolar part':ti,ab OR 'mandible alveolar process atrophy':ti,ab OR 'mandible alveolus arch':ti,ab OR 'mandibular alveolar arch':ti,ab OR 'mandibular alveolar part':ti,ab OR 'mandibular alveolus arch':ti,ab OR 'alveolar processes':ti,ab OR 'alveolar ridge':ti,ab OR 'bone remodeling'/exp OR 'bone reconstruction':ti,ab OR 'bone remodeling':ti,ab OR 'bone remodelling':ti,ab OR 'bone repair':ti,ab OR 'osteoplasty':ti,ab OR 'bone turnover':ti,ab OR 'bone turnovers':ti,ab OR 'osteolysis'/exp OR 'bone loss':ti,ab OR 'bone resorption':ti,ab OR 'essential osteolysis':ti,ab OR 'osteolysis':ti,ab OR 'osteolytic activity':ti,ab OR 'resorption, bone':ti,ab OR 'bone resorptions':ti,ab OR 'osteoclastic bone loss':ti,ab OR 'osteolyses':ti,ab OR 'tooth cementum'/exp OR 'cementum':ti,ab OR 'coronal cementum':ti,ab OR 'dental cementum':ti,ab OR 'molar cementum':ti,ab OR 'tooth cementum':ti,ab OR 'cementoblasts':ti,ab OR 'cementoblast':ti,ab OR 'dentin sensitivity'/exp OR 'dentin sensitivity':ti,ab OR 'dentin sensitivities':ti,ab OR 'dentine hypersensitivity':ti,ab OR 'dentine sensitivity':ti,ab OR 'tooth sensitivities':ti,ab OR 'tooth sensitivity':ti,ab OR 'dentin hypersensitivity'/exp OR 'dentin hypersensitivity':ti,ab OR 'epithelial attachment'/exp OR 'epithelial attachment':ti,ab OR 'epithelial attachments':ti,ab OR 'junctional epithelium'/exp OR 'junctional epithelium':ti,ab OR 'gingiva'/exp OR 'gingiva':ti,ab OR 'gum'/exp OR 'gum':ti,ab OR 'gums':ti,ab OR 'interdental papilla'/exp OR 'inter-dental papilla':ti,ab OR 'interdental gingiva':ti,ab OR 'interdental gingivae':ti,ab OR 'interdental papilla':ti,ab OR 'interdental papillae':ti,ab OR 'papilla interdentalis':ti,ab OR 'gingiva disease'/exp OR 'gingiva disease':ti,ab OR 'gingiva recession':ti,ab OR 'gingival diseases':ti,ab OR 'gingival recession':ti,ab OR 'pericoronitis':ti,ab OR 'tooth crown inflammation':ti,ab OR 'tooth exfoliation':ti,ab OR 'gingival recessions':ti,ab OR 'gingival atrophy':ti,ab OR 'atrophy of gingiva':ti,ab OR 'periodontal ligament'/exp OR 'periodontal ligament':ti,ab OR 'periodontal ligaments':ti,ab OR 'alveolodental ligament':ti,ab OR 'gomphosis':ti,ab OR 'periodontium'/exp OR 'parodontia':ti,ab OR 'parodontic tooth':ti,ab OR 'parodontium':ti,ab OR 'periodontal slide':ti,ab OR 'periodontal space':ti,ab OR 'periodontium':ti,ab OR 'periodontiums':ti,ab OR 'tooth supporting structures':ti,ab OR 'tooth supporting structure':ti,ab OR 'paradentiums':ti,ab

OR ‘tooth disease’/exp OR ‘dental decalcification’:ti,ab OR ‘dental disease’:ti,ab OR ‘dental disorder’:ti,ab OR ‘dental erosion’:ti,ab OR ‘dental leakage’:ti,ab OR ‘dental root resorption’:ti,ab OR ‘ectopic teeth’:ti,ab OR ‘ectopic tooth’:ti,ab OR ‘ectopic tooth eruption’:ti,ab OR ‘impacted molar’:ti,ab OR ‘impacted tooth’:ti,ab OR ‘root resorption’:ti,ab OR ‘tooth abrasion’:ti,ab OR ‘tooth ankylosis’:ti,ab OR ‘tooth attrition’:ti,ab OR ‘tooth decalcification’:ti,ab OR ‘tooth demineralization’:ti,ab OR ‘tooth disease’:ti,ab OR ‘tooth diseases’:ti,ab OR ‘tooth dystopia’:ti,ab OR ‘tooth erosion’:ti,ab OR ‘tooth eruption, ectopic’:ti,ab OR ‘tooth luxation’:ti,ab OR ‘tooth resorption’:ti,ab OR ‘tooth root resorption’:ti,ab OR ‘tooth wear’:ti,ab OR ‘root resorptions’:ti,ab OR ‘periodontal tissue’/exp OR ‘periodontal tissue’:ti,ab OR ‘radiographic bone loss’:ti,ab OR ‘clinical attachment level’/exp OR ‘clinical attachment level’:ti,ab OR ‘clinical attachment loss’/exp OR ‘clinical attachment loss’:ti,ab OR ‘probing depths’:ti,ab

Appendix B

Search strategies for Cochrane CENTRAL.
Filters Used: English Language & Human Studies (Filters unavailable)
#1 MeSH descriptor: [Palatal Expansion Technique] explode all trees
#2 (Palatal Expansion Technique):ti,ab,kw
#3 (Palatal Expansion Techniques):ti,ab,kw
#4 (Maxillary Expansion):ti,ab,kw
#5 ((MARPE)):ti,ab,kw
#6 (nonsurgical maxillary expansion):ti,ab,kw
#7 (rapid maxillary expansion):ti,ab,kw
#8 ((SARME)):ti,ab,kw
#9 (surgically assisted rapid maxillary expansion):ti,ab,kw
#10 (surgically assisted rapid palatal expansion (SARME)):ti,ab,kw
#11 (transverse maxillary distraction):ti,ab,kw
#12 MeSH descriptor: [Osteogenesis, Distraction] explode all trees
#13 (Distraction Osteogenesis):ti,ab,kw
#14 {OR #1-#13}
#15 MeSH descriptor: [Alveolar Process] explode all trees
#16 (Alveolar Process):ti,ab,kw
#17 (Alveolar Processes):ti,ab,kw
#18 (Alveolar Ridge):ti,ab,kw
#19 MeSH descriptor: [Bone Remodeling] explode all trees
#20 (Bone Remodeling):ti,ab,kw
#21 (Bone Turnover):ti,ab,kw
#22 (Bone Turnovers):ti,ab,kw
#23 MeSH descriptor: [Bone Resorption] explode all trees
#24 (Bone Resorption):ti,ab,kw
#25 (Bone Resorptions):ti,ab,kw
#26 (Osteoclastic Bone Loss):ti,ab,kw
#27 (Osteoclastic Bone Losses):ti,ab,kw
#28 MeSH descriptor: [Dental Cementum] explode all trees
#29 (Dental Cementum):ti,ab,kw
#30 (Cementum):ti,ab,kw
#31 (Cementoblasts):ti,ab,kw
#32 (Cementoblast):ti,ab,kw
#33 MeSH descriptor: [Dentin Sensitivity] explode all trees
#34 (Dentin Sensitivity):ti,ab,kw
#35 (Dentin Sensitivities):ti,ab,kw
#36 (Dentine Hypersensitivity):ti,ab,kw
#37 (Dentine Hypersensitivities):ti,ab,kw
#38 (Dentine Sensitivity):ti,ab,kw

#39 (Dentine Sensitivities):ti,ab,kw
#40 (Tooth Sensitivity):ti,ab,kw
#41 (Tooth Sensitivities):ti,ab,kw
#42 (Hypersensitivity):ti,ab,kw
#43 (Dentin Hypersensitivities):ti,ab,kw
#44 MeSH descriptor: [Epithelial Attachment] explode all trees
#45 (Epithelial Attachment):ti,ab,kw
#46 (Epithelial Attachments):ti,ab,kw
#47 (Junctional Epithelium):ti,ab,kw
#48 MeSH descriptor: [Gingiva] explode all trees
#49 (Gingiva):ti,ab,kw
#50 (Gums):ti,ab,kw
#51 (Gum):ti,ab,kw
#52 (Interdental Papilla):ti,ab,kw
#53 MeSH descriptor: [Gingival Recession] explode all trees
#54 (Gingival Recession):ti,ab,kw
#55 (Gingival Recessions):ti,ab,kw
#56 (Gingival Atrophy):ti,ab,kw
#57 (Atrophy of Gingiva):ti,ab,kw
#58 (Gingiva Atrophy):ti,ab,kw
#59 MeSH descriptor: [Osteolysis] explode all trees
#60 (Osteolysis):ti,ab,kw
#61 (Osteolyses):ti,ab,kw
#62 MeSH descriptor: [Periodontal Ligament] explode all trees
#63 (Periodontal Ligament):ti,ab,kw
#64 (Periodontal Ligaments):ti,ab,kw
#65 (Gomphosis):ti,ab,kw
#66 MeSH descriptor: [Periodontium] explode all trees
#67 (Periodontium):ti,ab,kw
#68 (Periodontiums):ti,ab,kw
#69 (Tooth Supporting Structures):ti,ab,kw
#70 (Tooth Supporting Structure):ti,ab,kw
#71 (Parodontium):ti,ab,kw
#72 MeSH descriptor: [Root Resorption] explode all trees
#73 (Root Resorption):ti,ab,kw
#74 (Root Resorptions):ti,ab,kw
#75 (mucogingival deformities):ti,ab,kw
#76 (periodontal tissue):ti,ab,kw
#77 (radiographic bone loss):ti,ab,kw
#78 (clinical attachment level):ti,ab,kw
#79 (clinical attachment loss):ti,ab,kw
#80 (probing depths):ti,ab,kw
#81 {OR #15-#80}
#82 #14 AND #81

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