

Review

Is There a Difference in Mid-Palatal Suture Density after Rapid Maxillary Expansion, Surgically Assisted Rapid Maxillary Expansion, and Miniscrew-Assisted Rapid Palatal Expansion? A Systematic Review and Meta-Analysis

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Abstract: The aim of this systematic review and meta-analysis was to evaluate the density of the midpalatal suture (MPS) of individuals with maxillary expansion (rapid maxillary expansion, RME), surgically assisted rapid maxillary expansion (SARPE), and miniscrew-assisted rapid palatal expansion (MARPE) through computed tomography. An electronic search was performed in four databases, MEDLINE via PubMed, SCOPUS, Web of Science, and Cochrane Central Register of Controlled Trials (CENTRAL) in February 2023 and updated in April 2023, using previously established search strategies. Studies were retrieved without restrictions in terms of data, language, or publication status. The risk of bias assessment was based on a quality assessment tool for before-and-after studies. Ten studies were included in our systematic review, and nine studies were included for our quantitative analysis. The analyses were performed by subgroup according to the evaluation of the region, anterior, middle, and posterior, including the three types of treatment: RME, SARPE, and MARPE. Heterogeneity was high for the three regions (anterior 95%, medium 97%, and posterior 84%) and a statistical difference was found in two of the three regions (anterior $p = 0.06$, medium $p = 0.031$, and posterior $p < 0.001$). There is not enough evidence to state that the MPS density is different after 6 months of RME in the anterior and middle regions; the bone density values for SARPE and MARPE suggest that 6 or 7 months after expansion, there is still no bone density similar to the initial one in the three regions.

Keywords: bone density; palatal expansion technique; computed tomography

1. Introduction

Maxillary transverse deficiency is characterized by an upper arch with reduced transverse dimensions, which can be clinically identified by an oval or deep palate, V-shaped arch, and wide buccal corridor. Its etiology is mainly related to environmental factors, predominantly mouth breathing and persistent oral habits [1].

Rapid maxillary expansion (RME) is the conventional method for transverse maxillary deficiency treatment; it can effectively enlarge the maxilla by applying a rapid transverse force of high magnitude to the upper teeth resulting in the opening of the midpalatal suture [2]. The midpalatal suture (MPS) is a single suture that matures and structurally changes under the influence of mastication, hormones, genetics, and mechanical factors. The closure of the suture does not necessarily imply the end of skeletal body maturation. In addition, there is a high amount of individual and morphological variation [3,4].

However, in late adolescence and in adults, there is limited skeletal expansion due to the interdigitation of the MPS that occurs with increasing age [3]. Skeletal maturation during adolescence and young adulthood leads to the gradual closure of the palatine suture, starting from the back and moving forward. As a result, the skeletal response to RME decreases. In these cases, conventional RME can produce side effects, such as the failure to separate the maxilla, labial tipping of the crown, root resorption, and marginal bone resorption [5]. The most common treatment for these cases is surgically assisted rapid maxillary expansion (SARPE) [6]. It is an invasive procedure with high financial costs and requires hospitalization and general anesthesia. In this context, MARPE emerges as a less invasive and efficient option in patients without growing potential. Thus, a personalized assessment of the patient's skeletal maturation stage in the area of interest could be an important predictor of RME success [7].

To assist in the clinical decision to treat a patient using conventional RME or SARPE, indicators of MPS maturation have been proposed, which include the following: suture morphology on occlusal radiography [8], skeletal maturation indicator on hand and wrist radiography [9], indicators of cervical vertebrae maturation (CVM) in teleradiography [10], and a classification of five stages of maturation of the median palatine suture proposed by Angelieri et al. [11]. Grünheid et al. proposed a new method for evaluating the maturation of the palatine suture by determining the bone density of this region, using cone-beam computed tomography, which demonstrated a significant correlation with the amount of skeletal response to RME treatment assessed in their study [7].

An important clinical decision is the retention period after RME; the literature reports a variation from 2 to 12 months. In general, a period of 3 months is used [12]. Although it is a plausible period for RME, this time may not be enough for SARPE. Studies state that a retention period of 6 months after RME allows for suture reorganization with a similar density to that before expansion [13,14]. However, 7 months after SARPE, the density values showed that the remineralization was still incomplete, and it was questionable if the ossification present up to that time would be able to resist the forces exerted by adjacent bone structures and if recurrence could be avoided [15,16].

In recent years, clinical practice has benefited from computed tomography (CT) as it has diagnostic advantages over traditional two-dimensional images [17]. CT allows for more accurate assessments and diagnoses, is an efficient, non-invasive, and fast method, and allows for reliable linear and angular measurements [18]. Using CT, it is possible to visualize the palatine suture without any overlapping of anatomical structures [19].

Thus, the aim of this systematic review is to evaluate the density of the MPS of individuals before and after RME, SARPE, and miniscrew-assisted rapid palatal expansion of the maxilla (MARPE) through computed tomography to assist in clinical decision making regarding which procedure and device will be the most effective, have more predictable results, and have fewer unwanted side effects. In addition, we gather various findings from the literature on the ideal period for retention after expansion procedures, minimizing the risk of recurrence.

2. Materials and Methods

2.1. Protocol and Registration

This review adheres to the Cochrane Manual for Systematic Reviews of Interventions. The PRISMA checklist was utilized as a template [20].

The review protocol was prepared beforehand following the PRISMA-P declaration and registered in PROSPERO under CRD42019118948.

2.2. Eligibility Criteria

Our clinical question was formulated using the PICO (population, intervention, comparison, outcome) format and we defined our inclusion and exclusion criteria (as shown in Table 1).

Inclusion criteria include the following: human clinical trials with prospective or retrospective design; individuals who were received RME, SARPE, or MARPE treatment; and studies in which the bone density of the palatine suture was evaluated before and after intervention by CT.

The exclusion criteria were defined as follows: case reports, case series, review articles, editorials, opinions, studies on syndromic patients, and studies on patients who are systemically compromised or who have cleft lip and/or palate.

Table 1. PICO question.

P	Patients Undergoing Maxillary Expansion
I	ERM, SARPE, and MARPE
C	Between pre- and post-treatment measurements by CT
O	Changes in palatine suture density

2.3. Electronic Search Bases and Search Strategies

Four bibliographic databases, including PubMed via MEDLINE, SCOPUS, Web of Science, and Cochrane Central Register of Controlled Trials (CENTRAL), were initially searched in February 2023 and updated in April 2023.

Specific search strategies were developed for each database and consisted of a combination of keywords, as described in Table 2. The databases were configured to send alerts via email in case of indexing of new eligible articles. In addition, a manual search of the reference lists of relevant articles and literature not published in ClinicalTrials.gov was also performed. The studies were retrieved without restrictions in terms of date, language, or publication status.

Table 2. Specific search strategy for each electronic database.

Database	Search Strategy
MEDLINE	((((((((bone density[MeSH Terms]) OR (bone density[Title / Abstract])) OR (bone mineral density[Title / Abstract])) OR (density suture*[Title / Abstract])) OR (midpalatal suture[Title / Abstract])) OR (suture maxillary[Title / Abstract])) OR (Hounsfield units[Title / Abstract])) AND (((((palatal expansion technique[MeSH Terms]) OR (expansion technique palatal[Title / Abstract])) OR (expansion maxillary[Title / Abstract])) OR (palatal expansion[Title / Abstract])) OR (RME[Title / Abstract])) AND (((((((((computed tomography, cone beam[MeSH Terms]) OR (Cone Beam computed tomography[Title / Abstract])) OR (Volume CT[Title / Abstract])) OR (CBCT[Title / Abstract])) OR (computed tomography, x ray[MeSH Terms])) OR (X Ray tomography computed[Title / Abstract])) OR (Tomography Xray computed[Title / Abstract])) OR (Computed Tomography[Title / Abstract])) OR (imaging, three dimensional[MeSH Terms])) OR (three-dimensional imaging[Title / Abstract]))
Web of Science	((((TS=(bone density)) OR TS=(density suture*)) OR TS=(midpalatal suture)) OR TS=(suture maxillary)) OR TS=(hounsfield units) AND (((TS=(palatal expansion technique)) OR TS=(expansion maxillary)) OR TS=(palatal expansion)) OR TS=(RME) AND (((((((TS=(cone beam computed tomography)) OR TS=(volume CT)) OR TS=(CBCT)) OR TS=(X-Ray computed tomography)) OR TS=(X Ray tomography computed)) OR TS=(computed tomography)) OR TS=(imaging three-dimensional)) OR TS=(three-dimensional imaging)
Scopus	((TITLE-ABS-KEY (bone AND density) OR TITLE-ABS-KEY (density AND sutures) OR TITLE-ABS-KEY (midpalatal AND suture) OR TITLE-ABS-KEY (suture AND maxillary) OR TITLE-ABS-KEY (hounsfield AND units))) AND ((TITLE-ABS-KEY (palatal AND expansion AND technique) OR TITLE-ABS-KEY (expansion AND maxillary) OR TITLE-ABS-KEY (palatal AND expansion) OR TITLE-ABS-KEY (rme))) AND ((TITLE-ABS-KEY (cone AND beam AND computed AND tomography) OR TITLE-ABS-KEY (volume AND ct) OR TITLE-ABS-KEY (cbct) OR TITLE-ABS-KEY (x-ray AND computed AND tomography) OR TITLE-ABS-KEY (x AND ray AND tomography AND computed) OR TITLE-ABS-KEY (computed AND tomography) AND TITLE-ABS-KEY (imaging AND three-dimensional) AND TITLE-ABS-KEY (three-dimensional AND imaging)))

Table 2. Cont.

Database	Search Strategy		
Cochrane	#1	MeSH descriptor: [Bone Density] explode all trees	5450
	#2	(bone density):ti,ab,kw OR (bone mineral density):ti,ab,kw (Word variations have been searched)	14,225
	#3	(density sutur*):ti,ab,kw OR (midpalatal suture):ti,ab,kw OR (suture maxillary):ti,ab,kw (Word variations have been searched)	331
	#4	Hounsfield units	327
	#5	#1 or #2 or #3 or #4	14,763
	#6	MeSH descriptor: [Palatal Expansion Technique] explode all trees	267
	#7	(expansion technique palatal):ti,ab,kw OR (expansion maxillary):ti,ab,kw OR (palatal expansion):ti,ab,kw OR (RME):ti,ab,kw (Word variations have been searched)	596
	#8	#6 or #7	596
	#9	MeSH descriptor: [Cone-Beam Computed Tomography] explode all trees	467
	#10	("cone beam computed tomography"):ti,ab,kw OR (CBCT):ti,ab,kw (Word variations have been searched)	1932
	#11	(volume CT):ti,ab,kw (Word variations have been searched)	8326
	#12	MeSH descriptor: [Tomography, X-Ray Computed] explode all trees	7048
	#13	(X-Ray Computed tomography):ti,ab,kw OR (X Ray tomography computed):ti,ab,kw OR (tomography X Ray computed):ti,ab,kw OR (computed tomography):ti,ab,kw (Word variations have been searched)	24,245
	#14	MeSH descriptor: [Imaging, Three-Dimensional] this term only	1353
	#15	(Three-dimensional imaging):ti,ab,kw OR (Three-dimensional images):ti,ab,kw (Word variations have been searched)	3167
	#16	#9 or #10 or #11 or #12 or #13 or #14 or #15	32,917
	#17	#5 and #8 and #16	

2.4. Study Selection and Data Collection

After the exclusion of duplicate articles, the list of titles and abstracts was independently reviewed by two reviewers (LMF and NCV) according to the eligibility criteria through predetermined forms. The article was read in full if the title and abstract did not provide sufficient information. Disagreements were resolved by consensus or by consulting a third reviewer (CTM) for their judgment.

After reading the titles and abstracts, the pre-selected articles were read in full according to the eligibility criteria by the two reviewers, and those that met the eligibility criteria were assigned to extract data in spreadsheet format in Excel (Version 16.77, Microsoft Corp., Redmond, WA, USA) to obtain all relevant information. The authors of some studies were contacted via email or social media to verify the eligibility criteria and provide missing data or information, especially with regard to their methodology and sample-related data.

The data collected from the included articles included the following: type of study, type of image, patient (n, sex, and age), intervention, density assessment period, measurement region, statistics, results, and conclusion.

2.5. Assessment of Methodological Quality and Risk of Bias

Methodological quality assessment and risk of bias analysis were performed by two investigators (LMF and COL) in the included studies. The authors utilized the Quality Assessment Tool for Before-and-After Studies (<https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools> (accessed on 24 April 2023)) to evaluate the study. This checklist was developed for medical articles, but it has already been used by other authors to assess the methodological quality and the risk of bias in dentistry studies [21,22] with some adaptations.

Although this tool includes 12 items, as a way of adapting to the types of studies included in this review, three items were removed and the remaining nine were used: (1) if the question or purpose of the study was clearly stated; (2) if the eligibility criteria were pre-specified and clearly described; (3) if the participants were representative of the population; (4) if all eligible participants who met the inclusion criteria were included; (5) if

the sample size was large enough to provide confidence in the results; (6) if the intervention was clearly described and consistently performed; (7) if the measurement results were pre-specified, clearly defined, valid, reliable, and consistently evaluated; (8) if the loss to follow-up after initiation of treatment was 20% or less and if these losses were accounted for in the analysis; and (9) if statistical methods were performed to assess changes in pre- and post-intervention measures and if a *p*-value was provided. For item 5, a study that presents a sample calculation or analysis of the power a posteriori, or if it presents a sample greater than 50 participants, is considered adequate.

When checking the criteria for each item, responses of ‘Yes’, ‘No’, ‘CD’ (cannot determine), ‘NA’ (not applicable), or ‘NR’ (not reported) were assigned. The studies were classified according to the answers obtained in the qualification tool, applying the following criteria: a quality of “good” for studies with seven to nine answers of “yes”, indicating a low risk of bias; a quality of “fair” for studies with four to six answers of “yes”, indicating a moderate risk of bias; and a quality of “poor” for records with one to three answers of “yes”, indicating lack of information or uncertainty, leading to a high risk of bias.

2.6. Meta-Analysis and Statistics

A meta-analysis was performed using the software Comprehensive Meta-Analysis (version 3.2.00089; Biostat, Inc., Englewood, NJ, USA).

The density of the MPS was compared in three regions: anterior, middle, and posterior. The data extracted from the articles and inserted into the software were the means of pre- and post-expansion values and standard deviations. Heterogeneity was tested using the Q-value and I^2 index. A random effects model was used, and effect measures for subgroups were presented in meta-analysis graphs (forest plots).

3. Results

3.1. Studies Selection

A flowchart of the article selection process is shown in Figure 1. The established search strategy retrieved 563 articles. After removing duplicates, 320 titles and abstracts were reviewed by two reviewers (LMF and NCV) regardless of the eligibility criteria. Twenty articles were pre-selected to be read in full. We were alerted to ten additional articles via email, but none of them were included in this review since the ten articles resulting from the application of the search strategy met the inclusion criteria and were used.

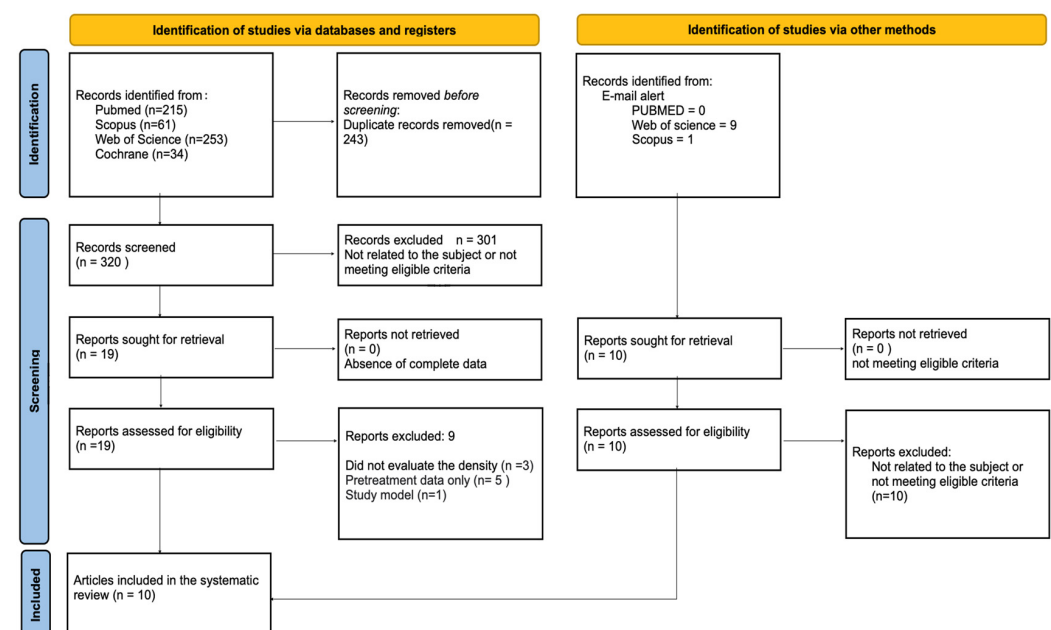


Figure 1. Flowchart of the study selection process following the PRISMA guidelines.

3.2. Characteristics of the Studies

The descriptive data of the ten included studies are summarized in Table 3, in which it is possible to observe that half of the studies were retrospective [23–27] and the other half were prospective [13,15,16,28,29]. A total of 215 patients were included: 158 females and 57 males.

The transverse maxillary deficiency was corrected by RME in five studies [13,23–25,28], by SARPE in three studies [15,16,26], and by MARPE in one study [27]. One author did not report the type of treatment used [29].

All articles analyzed the density of the suture before and after expansion and measured the density in three different regions in the median palatine suture: the anterior, middle, and posterior. All studies measured the density in Hounsfield Units (HU).

Regarding the 3D images used in the studies, five studies used CBCT [16,23,26,27,29] and five studies used CT [13,15,24,25,28]. All the studies provided the scan configuration, including the kVp, mA, field of view (FOV), voxel size, and scan time.

Table 3. Descriptive data of the ten included studies.

Arthor, Year	Type of Study	Type of Image	Patients		Intervention		Areas Measured	Statistic	Outcome	Conclusions
			N Sex (M/F)	Age Range, Years (Mean)	Procedure	Density Evaluation Period				
Bigliazzi et al., 2017 [23]	RS	CBCT	14 (5 M/9 F)	8.5–14.8 (11.7)	RME (Hyrax)	Before expansion (T0); End of expansion (T1); After 3-month retention period (T2); After 6-month retention period (T3)	BD at: Anterior portion (AP); Anterior middle portion (AMP); Posterior middle portion (PMP); Posterior portion (PP) in the midpalatal suture.	Mean differences in measurements at T0, T1, T2, and T3 were contrasted by means of the Friedman ANOVA for repeated measures, followed by Tukey post-hoc tests at significance level of 5%.	T3–T0 (HU): AP: (−24.47) AMP: (−60.25) PMP: (−4.11) PP: (3.28)	During the active phase of RME, there was a significant decrease in BD levels, which indicates that the midpalatal suture was effectively opened. However, three months after RME, the remineralization of the midpalatal suture was not yet complete. Thus, it is recommended to extend the retention time of RME to six months.
Buzatu et al., 2018 [29]	PS	CBCT	53 (26 M/27 F)	NR (16.4)	NR	Before expansion (T0) End of expansion (T1)	Anterior, middle, and posterior regions in the midpalatal suture	Mean values were calculated before and after treatment.	T1–T0 (HU) Women: Anterior: (−337.61) Middle: (−391.53) Posterior: (−134.77) Men: Anterior (−318.66) Middle: (−296.97) Posterior: (−131.71) <i>p</i> -value not reported	Following the expansion, both men and women showed reduced bone density in the front and central areas of the suture compared to the rear section.

Table 3. Cont.

Author, Year	Type of Study	Type of Image	Patients		Intervention		Areas Measured	Statistic	Outcome	Conclusions
			N Sex (M/F)	Age Range, Years (Mean)	Procedure	Density Evaluation Period				
Fastusca et al., 2020 [25]	RS	CT	30 (18 M/12 F)	10.2 ± 1.2 y	RME group SME group	Before expansion (T0) After 7-month retention period (T1)	6 ROIs: AS ROI PS ROI AB ROI PB ROI ASD ROI PSD ROI	Dependent <i>t</i> -tests were used to compare the measurements of the RME group and the SME group.	RME group: AS: (−161) PS: (−121.04) AB: (−35.15) PB: (−64.82) ASD: (−128.55) PSD: (−53.35) SME group: AS: (−94.82) PS: (−172.23) AB: (−43.7) PB: (−13.01) ASD: (−167.98) PSD: (−133.20) No SD in ROI density were found in the comparison between the two groups	No notable alterations in the density of the midpalatal suture were observed after RME treatment; however, substantial reductions in density were noted throughout the suture area following SME therapy. Comparable levels of suture restructuring occurred despite varying durations of retention.
Franchi et al., 2010 [13]	PS	Low-dose CT	17 (7M 10 F)	8–14 (11.2)	RME with butterfly palatal expander	Before expansion (T0) End of expansion (T1) After the retention period of 6 months (T2)	4 ROIs: AS ROI PS ROI AB ROI PB ROI	Variations in density from the initial time point (T0) to the second time point (T2) in both the front and rear regions of interest within the suture were analyzed using Friedman's repeated measures analysis of variance on ranks, complemented by a subsequent Tukey post-hoc examination.	No noteworthy disparities in density were observed between the two regions of interest in the suture at both T1 and T2 time points. Both the anterior suture (AS) and posterior suture (PS) regions exhibited notable drops in density from the initial to the first time points (T0 to T1), followed by significant elevations from the first to the second time points (T1 to T2). However, there were no statistically meaningful changes in density from T0 to T2.	The decline in suture density following expansion suggests that employing RME treatment prior to puberty effectively opens the midpalatal suture. After six months of maintaining the RME treatment, the midpalatal suture undergoes restructuring, returning to density levels akin to those before the treatment began.

Table 3. Cont.

Arthor, Year	Type of Study	Type of Image	Patients		Intervention		Areas Measured	Statistic	Outcome	Conclusions
			N Sex (M/F)	Age Range, Years (Mean)	Procedure	Density Evaluation Period				
Holzinger et al., 2022 [26]	RS	CBCT	19 (10 M/19 F)	18.7–39.7 (24.8)	SARPE (Hyrax). (Two groups, G1 and G2 with different protocols)	Before surgery (T0), Immediately after surgery (T1) 6 months after surgery (T2)	For all patients, the region of interest was limited to the cranial area, defined by the upper incisors’ apex, central incisors’ medial root, enamel-cement junction, and nasopalatine foramen.	The data were analyzed using the Mann–Whitney test	T2–T0 G1 (–243.96) G2 (–123.51) BD did not differ significantly between G1 and G2	In the study, both sets of protocols showed a marked decrease in bone density between the incisors. Additionally, no distinct benefit was observed for using one distraction method over the other. Bone reconstruction remained incomplete throughout the six-month retention timeframe.
Lione et al., 2013 [28]	PS	Low-dose CT	17 (7 M/10 F)	8–14 (11.2)	RME (butterfly palatal expander—Haas)	Before expansion (T0); End of expansion (T1); After 6-month retention period (T2)	BD at anterior, middle, posterior regions in the midpalatal suture	Variations in density from the initial point (T0) to the second point (T2) were analyzed using Friedman’s repeated measures ANOVA on ranks, supplemented by subsequent Tukey post-hoc examinations.	T2–T0 (HU). Anterior: (–53.8) Middle: (–105.5) Posterior: (–93.5)	By the conclusion of the six-month retention phase, density levels across the transverse suture rose, although they did not return to the values measured before treatment.
Naveda et al., 2022 [27]	RS	CBCT	21 (6 M/15 F)	20.1–45.1 (29.1)	MARPE expander with four paramedian miniscrews	Before expansion (T1) After a retention period of at least 6 months (T2)	BD (T1 and T2) coronal sections passing by the anterior, median, and posterior regions of the hard palate.	Paired <i>t</i> -tests to evaluate T1–T2 changes in bone density at the midpalatal suture	T2–T1 Anterior (–284.35) Median (–586.96) Posterior (–392.01) A significant decrease in bone density from the pre-expansion to post-retention phase	Following the retention period, a decline in bone density was noted: 33% in the front region, 77% in the middle area, and 52% in the rear zone.

Table 3. Cont.

Arthor, Year	Type of Study	Type of Image	Patients		Intervention		Areas Measured	Statistic	Outcome	Conclusions
			N Sex (M/F)	Age Range, Years (Mean)	Procedure	Density Evaluation Period				
Petrick et al., 2011 [15]	PS	Axial CT	16 (7 M/9 F)	17.5–36.2 (24.5)	SARPE (Desdren Distractor)	Before expansion (T1); Average of 7 months after SARPE (T2)	Anterior, middle, posterior regions in the midpalatal suture.	Paired <i>t</i> -test to identify differences in the midpalatal sutures's bone density between T1 and T2	T2–T1 (HU): Anterior: (−491) Middle: (−393) Posterior: (−260) The 3 regions showed statistical differences.	In the front, middle, and rear sections of the suture, the bone density fell to 48%, 53%, and 75%, respectively. The midpalatal suture's stability is inadequate for warding off regression. Extending the retention period is advised to permit bone mineralization and strengthen it against significant forces.
Salgueiro et al., 2015 [16]	PS	CBCT	14 (5 M/9 F)	19–38 (25.28)	SARPE (Hyrax or Haas)	Before expansion (T0); 15 days after expansion (T1); 2 months after expansion (T2); 6 months after expansion (T3).	Anterior, middle, and posterior regions in the midpalatal suture	ANOVA was applied for statistical analysis. Statistically significant differences were seen in the Tukey test.	T3–T0 (HU) Anterior: (−232.492) Middle: (−246.65) Posterior: (−145.728) <i>p</i> -value was not reported for each region	The bone density (BD) in the front, central, and rear regions dropped to 30.4%, 43.3%, and 65.7% of the starting values, respectively. After a six-month retention phase, the BD figures were lower than the initial measurements (T0), indicating that this duration was inadequate for full bone regeneration.

Table 3. Cont.

Arthor, Year	Type of Study	Type of Image	Patients		Intervention		Areas Measured	Statistic	Outcome	Conclusions
			N Sex (M/F)	Age Range, Years (Mean)	Procedure	Density Evaluation Period				
Schauseil et al., 2014 [24]	RS	Low-dose CT	14 (4 M/8 F)	13.5–23 (15.8)	RME (Haas or Hybrid Hyrax)	Before expansion (T0); End of expansion (T1); After 6-month retention period—only in 6 patients (T2)	AS ROI PS ROI AB ROI PB ROI	Changes in the sutural density between the different points of time were examined using paired <i>t</i> -tests	In the midpalatal suture, all three regions exhibited a statistically meaningful reduction in density from the initial to the second time point (T0 to T2), with a <i>p</i> -value of 0.002. Average values were not reported. Hybrid RME led to a more substantial drop in density (469 ± 82 HU) compared to traditional RME (365 ± 88 HU), with a <i>p</i> -value of 0.041.	Six months of retention is inadequate for complete suture restructuring. As a result, extending the retention phase beyond six months appears to be advantageous for averting setbacks in patients who are past puberty.

All the studies recorded baseline measurements, called T0 or T1, before expansion. Seven articles evaluated patients for 6 months after expansion [13,16,23,24,26–28], two articles evaluated patients for 7 months [13,25], and one article did not specify the assessment time after expansion [29]. The evaluation of the suture by the authors was performed by various methods: two authors evaluated the suture in the coronal view [15,27], seven authors evaluated the suture in the axial view [13,15,16,23–25,29], and one author evaluated the suture in the front view [26].

The assessment of the risk of bias in the included studies is presented in Table 4. Of the ten studies included in this review, one was classified as “good” [26], indicating a low risk of bias, eight studies were classified as “fair” [15,16,23–25,27–29], indicating a moderate risk of bias, and one article was rated “poor”, presenting a high risk of bias [13].

Table 4. Assessment of the risk of bias in the included studies.

Criteria	Bigliazzi et al., 2017 [23]	Buzatu et al., 2018 [29]	Fastuca et al., 2020 [25]	Franchi et al., 2010 [13]	Holzinger et al., 2022 [26]	Lione et al., 2013 [28]	Naveda et al., 2022 [27]	Petrack et al., 2011 [15]	Salgueiro et al., 2015 [16]	Schauseil, et al., 2014 [24]
1. Was the study question or objective clearly stated?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2. Were eligibility /selection criteria for the study population prespecified and clearly described?	NO	YES	NO	NO	YES	NO	YES	NO	NO	NO
3. Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?	CD	CD	CD	CD	YES	CD	CD	CD	CD	CD
4. Were all eligible participants that met the prespecified entry criteria enrolled?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5. Was the sample size sufficiently large to provide confidence in the findings?	NO	YES	YES	NO	YES	YES	YES	NO	NO	NO
6. Was the test/service/intervention clearly described and delivered consistently across the study population?	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES
7. Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?	YES	YES	YES	CD	YES	YES	YES	YES	YES	YES
8. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
9. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests performed that provided <i>p</i> -values for the pre-to-post changes?	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES
Quality	Fair	Fair	Fair	Poor	Good	Fair	Fair	Fair	Fair	Fair

CD—Cannot Determine; NA—Not Available; NR—Not reported.

Among the ten articles selected, seven studies did not report clear eligibility criteria [13,15,16,23–25,28], and in the 10 included articles, it was not possible to determine whether all eligible participants who met the pre-specified entry criteria were included. Four authors described sample calculations or analyses of the power of the study a posteriori [25–28], and one study had a sample of more than 50 participants [29].

3.3. Meta-Analysis

Five articles [15,23,25,27,28] were included in the meta-analysis because they presented comparable data. The corresponding authors of the articles were contacted twice by e-mail for clarification or provision of additional data.

Initially, a comparison was made considering the anterior, middle, and posterior regions as subgroups, according to the anatomical limits used by the authors to divide the regions evaluated. In the meta-analysis of the anterior region, it was possible to include five articles, three of which were about RME, one was about SARPE, and one was about MARPE. In the middle and posterior regions, it was possible to include four studies, two of which were about RME, one was about SARPE, and one was about MARPE.

The heterogeneity result, represented by the I^2 index, in the anterior region was 95%, in the middle region was 97%, and in the posterior region was 84%, thus being considered as having a high level of heterogeneity.

The meta-analysis results by region were significantly present in two regions, the middle ($p = 0.031$) and posterior ($p < 0.001$), whereas the anterior region showed no difference ($p = 0.06$) (Figure 2). The data showed that RME tended to have less difference in density when compared to that of SARPE and MARPE in all evaluated regions.

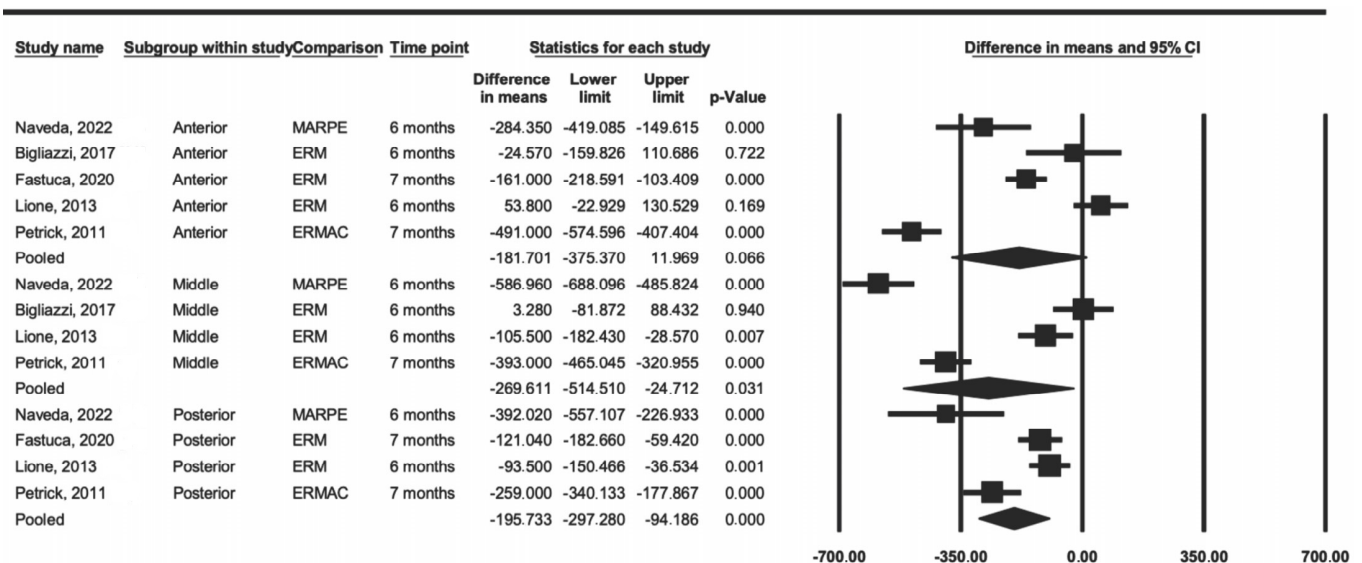


Figure 2. Comparison of the average difference by region (anterior, middle, and posterior) [15,23,25,27,28].

Subsequently, a sensitivity analysis was performed including only the articles that used RME [23,24,28]. The data showed a decrease in heterogeneity for the anterior and middle regions ($I^2 = 89\%$ and 71% , respectively), and the posterior heterogeneity was minimal ($I^2 = 0.0\%$) (Figure 3). In this same analysis, the difference remained significant only in the posterior region ($p < 0.001$).

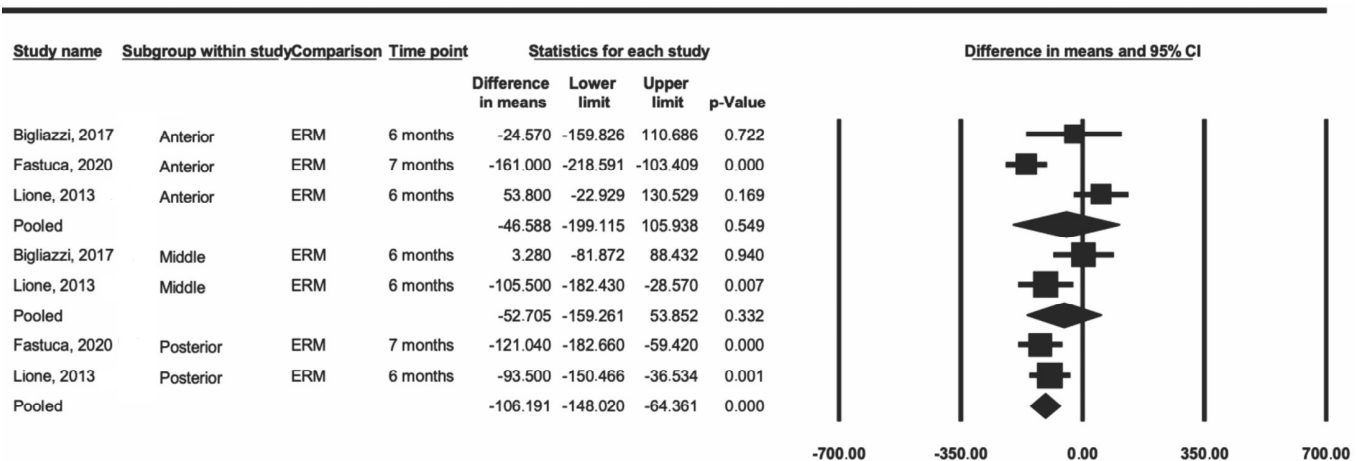


Figure 3. Comparison of the average difference for ERM [23,25,28].

Another sensitivity analysis included two articles that used MARPE and SARPE [13,27]. The data showed a decrease in heterogeneity in the three regions ($I^2 = 84\%$ in the anterior region, 89% in the middle region, and 50% in the posterior region) when compared to the values from the first analysis. The difference was statistically significant for the three regions ($p < 0.001$) (Figure 4).

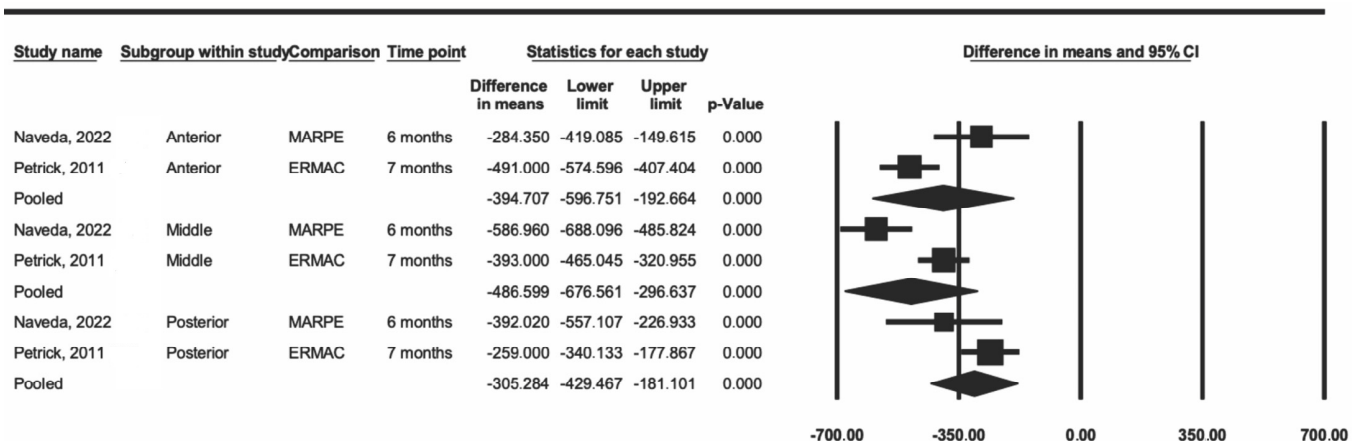


Figure 4. Comparison of the average difference between ERMAC and MARPE [15,27].

4. Discussion

4.1. Summary of Evidence

In the present systematic review, articles that evaluated RME, SARPE, and/or MARPE by CT in the treatment of maxillary deficiency were included. The CT images were analyzed using Hounsfield units (HU), which is the most current method to determine bone density and has been used by dentists to quantify the structure and quality of maxillary and mandibular bone [30,31].

The five articles included in the meta-analysis measured bone density in different areas of the MPS [15,23,25,27,28]. Despite variations in the articles' way of measuring, the presented measures were grouped into the anterior, middle, and posterior regions. In the anterior region, it was possible to include five articles, of which three were about RME [23,25,28], one was about SARPE [15], and one was about MARPE [27]. In the middle and posterior regions, it was possible to include four studies, two of which were about RME [23,28], one was about SARPE [15], and one was about MARPE [27]. The variation in the way that the measurement is performed and the fact that they are different procedures with different effects on bone density after expansion may be contributing factors to the high values found for heterogeneity, even after our sensitivity analyses.

The posterior region showed a significant decrease in suture density, regardless of the procedure, and minimal heterogeneity in cases in which only RME studies were used [23,25,28] and moderate heterogeneity in cases in which SARPE and MARPE were used [15,27]. These data suggest that, for the posterior region, a longer retention time is needed so that the bone density after expansion is close to the initial value. The results of three studies [16,24,26] included in the review—and not in the meta-analysis—corroborate that (a) 6 months after RME [24] and (b) 6 to 7 months after SARPE [16,26], the bone density of the posterior region had not yet reached the baseline level.

In the anterior and middle regions, from the meta-analysis results, there is no evidence to state that the density of the palatine suture is different 6 months after RME. A study included in the review and not in the meta-analysis found a similar result: 6 months after expansion with RME, there no significant changes reported [13]. Similarly, a study based on the tomographic evaluation of 17 children aged 5 to 10 years showed a completely ossified suture after 8 to 9 months of retention [32].

Although only one SARPE study was included in the meta-analysis [15], three articles were included in the review and all showed decreased suture density [15,16,26]; among these, the greatest differences in density were found in the anterior and middle regions. Only one study that evaluated MPS density after MARPE was included in the review and meta-analysis [27]; its results showed a greater decrease in bone density in the median region and in the midline. These differences between the results for SARPE and MARPE may be related to the injuries caused by the use of the chisel in the anterior region of the palate during the SARPE procedure [27] and also the mini-implants' location in cases of MARPE, which is usually in the middle portion of the palate, where consequently there will be a greater concentration of force during the active phase [27,33], negatively influencing bone repair.

According to the data presented in the meta-analysis, RME tended to have less of a difference in bone density than SARPE and MARPE. The literature reports that bone repair has been associated with the initial age of the patient when performing an expansion [34]; taking into account that SARPE and MARPE are treatment alternatives for adult patients with no growth potential, the age of the patients can then be a possible response for this difference. These data can also impact the retention time; the literature reports that the retention period after expansion ranges from 2 to 12 months [35]. All studies included in this meta-analysis evaluated suture density up to 6 [21,25,26] or 7 months [16,25] after expansion. Despite being a plausible period for suture reorganization in cases of RME [13,15], this time may not be sufficient for patients treated with SARPE and MARPE. Density values show that 7 months after SARPE, remineralization was still incomplete and it was questionable whether the ossification present up until that point would be able to resist the forces exerted by adjacent bone structures and whether recurrence could be avoided [15,16].

The MPS fusion first occurs posteriorly and then progresses anteriorly with new bone formation. For this reason, the opening of the suture takes place in the form of a triangle with the base located in the anterior part of the maxilla and the expansion occurring predominantly in the anterior and middle regions [29]. The bone density in the posterior region examined via occlusal radiographs was reported to decrease more than in the anterior region [35], similar to our results. It is reasonable to assume that after RME or SARPE, the density of the maxillary suture may differ depending on the level of bone density prior to expansion, which, according to the Misch classification, would be D3 (350 to 850 Hounsfield units) [36]. Specifically, if the posterior part of the maxilla has already undergone ossification, then the suture density in this region is likely to be higher after expansion compared to the anterior and middle regions, where the lower pre-expansion density may result in little to no difference in suture density. More studies are needed to prove this theory and a longer period of anterior retention may be recommended to prevent relapses.

4.2. Methodological Quality Assessment

In our analysis, the risk of bias was assessed using a tool specifically designed for before-and-after studies. It is important to underscore that the methodological quality that labeled the reviewed articles as “good” or “fair” applies specifically to the context of before-and-after studies. Compared to randomized clinical trials and controlled clinical trials, which are considered the gold standard for systematic reviews, the risk of bias is higher. Ethical considerations preclude randomization in choosing between treatments such as RME, SARPE, or MARPE, as each patient should receive the most effective available surgical option. Additionally, the nature of these treatments makes blinding participants impractical [21].

4.3. Limitations

Ten non-randomized clinical studies were included in this review, which can be considered as a limitation of this review. Furthermore, some of the studies did not report enough data, such as the statistical tests used, the *p*-values, the standard deviation, or whether the sample size was sufficient, indicating the need for better studies on the subject.

5. Conclusions

There is not enough evidence to say that suture density is different after 6 months of RME in the anterior and middle regions; bone density values for SARPE and MARPE suggest that 6 or 7 months after expansion, the bone density is still not similar to the initial one in the three regions. More studies are needed to evaluate the density behavior in the posterior region of the midpalatal suture and to directly compare the differences in suture density between RME, SARPE, and MARPE.

These results should be interpreted with caution due to the number of trials included and the difficulty of methodological standardization, which may affect the risk of bias. Future studies with long-term follow-ups, paired control groups, and standard methodologies are needed for clinical recommendations based on evidence with predictable results.

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