Review

Does surgically assisted rapid maxillary expansion associated with pterygomaxillary disjunction result in changes in mandibular position? A PROSPERO-compliant systematic review of the literature

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ABSTRACT

Purpose: This study aimed to assess the effect of surgically assisted rapid maxillary expansion (SARME) associated with pterygomaxillary disjunction (PD) on mandibular positioning.
Materials and methods: A two-phase systematic review registered with the PROSPERO database was performed. Search strategies were developed for specific databases (PubMed, Scopus, Web of Science, COCHRANE, LILACS, and DOSS), including the gray literature (Open Gray, Google Scholar, and ProQuest). The methodological and evidential quality of the included studies were assessed.
Results: Among 680 studies, four were selected for inclusion. In general, a low risk of bias was observed. The studies included a total of 142 adults, and used imaging to perform linear measurements (preoperatively and postoperatively). The main outcomes were maxillomandibular transverse index (difference between effective mandibular width — distance between the left and right antagonist points — and maxillary width), sagittal (forward and backward) and vertical (impaction and extrusion) changes, dental show, chin projection, and altered mandibular position.
Conclusion: Although the study demonstrated some mandibular position changes after SARME associated with PD, there is insufficient current evidence to support this result because of the potential study limitations related to the number of investigations chosen for inclusion. Further research is required to validate this finding.

1. Introduction

Transverse maxillary deficiency is a dentofacial deformity clinically characterized by the presence of posterior crossbite, which can occur uni- or bilaterally (Koudstaal et al., 2005; Baraldi et al., 2007; Iodice et al., 2013; de Gijt et al., 2017). Untreated cases of posterior crossbite may be associated with deleterious disturbances in the temporomandibular joint, including condylar asymmetry, altered condylar position in the mandibular fossa, facial asymmetry, and midline deviation (Ellabban et al., 2018). Transverse maxillary deficiency can be observed in syndromic or nonsyndromic patients, in an isolated presentation or combined with vertical maxillary excess and Class II or III malocclusion types (Koudstaal et al., 2005; Iodice et al., 2013; de Gijt et al., 2017). Epidemiologically, there are few studies reporting the real

incidence of transverse maxillary deficiency. In young individuals, the incidence for this condition has been estimated at 8–18% (Suri and Taneja, 2008).

Surgically assisted rapid maxillary expansion (SARME) is an alternative treatment in cases of posterior crossbite in skeletally mature patients. It consists of a Le Fort I subtotal osteotomy that aims to reduce maxillary pillar resistance during transverse expansion, assisted by a bone- or dentally supported expanding orthodontic appliance. Several procedures associated with conventional SARME have been proposed, such as nasal lateral osteotomy, septal osteotomy, palatine osteotomy, and pterygomaxillary disjunction (PD) (Iodice et al., 2013; Betts, 2016; Hamedi Sangsari et al., 2016).

SARME releases bone structures that are resistant to expansion forces (Zandi et al., 2016; Camps-Pereperez et al., 2017). However, there is no consensus regarding intervention in areas of high resistance to this expansion, as well as the number of required osteotomies during the surgical procedure (Koudstaal et al., 2005; Hamedi Sangsari et al., 2016; Camps-Pereperez et al., 2017). Additionally, there is no complete agreement regarding the real impact on mandibular position and its relationship with the temporomandibular joint after performing SARME. In this context, some studies have compared different protocols of SARME associated with PD, regarding dental and transverse skeletal alterations, using sagittal reconstructions from cone beam computed tomographies (Zandi et al., 2016; Ferraro-Bezerra et al., 2018).

Remodeling of the mandibular condyle can occur as a result of intrinsic and extrinsic factors, and this process may be associated with condylar resorption or dysfunctional condylar remodeling patterns. Some risk factors have been considered, including gender (female), age ranging from 14 to 40 years, posterior inclination of the condylar neck, bimaxillary orthognathic surgery with mandibular counterclockwise rotation, and mandibular advancement superior to 10 mm (Catherine et al., 2016). Also, it is noteworthy that occlusal instability (Catherine et al., 2016) and Le Fort I osteotomy-associated maxillary intrusion may be correlated with altered mandibular positioning (de Mol van Otterloo et al., 1993; Hoppenreijs et al., 1998).

Although the pterygomaxillary region has been commonly included during SARME procedures, this important anatomical area has rarely been the focus of studies evaluating SARME. While some authors have reported an increased risk of trans-surgical bleeding after SARME associated with PD (Zandi et al., 2016), other studies have described significant clinical benefits of performing PD, such as increased maxillary posterior palatine region expansion, reduced maxillary molar inclination, tendency to open the medial palatine suture (Ferraro-Bezerra et al., 2018), and significant increases in nasopharynx and oropharynx volumes (de Medeiros et al., 2017). However, no previous systematic review has examined the available literature linking PD-associated SARME with related changes in mandibular position after performing this technique. Therefore, the main goal of this systematic review was to evaluate mandibular changes after PD-associated SARME, focusing on the following question: Do patients with transverse maxillary deficiency who underwent PD-associated SARME show altered mandibular positioning?

2. Materials and methods

2.1. Protocol and registration

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Moher et al., 2009). The protocol was registered at the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42018087567.

2.2. Eligibility criteria

2.2.1. Inclusion criteria

During the search process, clinical trials and observational studies that evaluated SARME associated with PD were considered to be eligible for initial inclusion in this systematic review. Also, the following methodological requirements were adopted as inclusion criteria: assessment of changes in any regions related to the mandible or middle third of the face, including the temporomandibular joint; evaluations using radiographic examination, or helical or cone-beam computed tomography; and studies that performed preoperative and postoperative evaluations.

2.2.2. Exclusion criteria

Studies were excluded if they fulfilled at least one of the following criteria: (1) reviews; (2) letters to the editor; (3) author's personal opinions; (4) book chapters; (5) meeting abstracts; (6) SARME performed in young individuals lacking skeletal maturity; (7) studies involving multiple treatment modalities; (8) patients with syndromes, craniofacial abnormalities, and medical impairments; (9) absence of data relating to changes in mandibular positioning; and (10) studies not written in languages using a Latin (Roman) alphabet.

2.3. Information sources

Detailed individual search strategies for each of the following databases were performed: PubMed, Scopus, Web of Science, COCHRANE, LILACS, and DOSS. A gray literature search was also carried out, and included Google Scholar (limited to the first 50 most relevant articles), OpenGrey, and ProQuest information sources. The search included all articles published on or before July 11, 2018, with no time restrictions. Additional articles were identified by a hand search of the reference sections of papers included in the review.

2.4. Search

Appropriate truncations and word combinations were selected and adapted for each database search. Additional information on the search strategies is provided in Appendix A, which can be found in the supplemental data in the online version of this article. The software EndNote X8® (Thompson Reuters, New York, NY) was used to manage all references, removing duplicate hits.

2.5. Study selection

The selection was completed in two phases. In phase 1, two reviewers (FSRC and DAFB) independently reviewed the titles and abstracts of all electronic database citations. Phase 1 was performed using a web application for systematic reviews (Rayyan®, Qatar Computing Research Institute, Doha, Qatar) (Ouzzani et al., 2016). Articles that did not appear to meet the inclusion criteria were excluded. In phase 2, the same reviewers independently applied the inclusion criteria to the full texts of the articles. One examiner (FWGC) critically assessed the reference list of selected studies. Any disagreement in the first or second phase was resolved when the two authors reached an agreement. When they did not reach a consensus, the third and fourth authors (FWGC and TRR) participated in the final decision.

2.6. Data collection process

One author (FSRC) extracted data from the selected studies. A second author (FWGC) cross-checked all the obtained information. Any disagreements between the two authors were discussed until its complete resolution. A third author (ECSS) made the final decision when the two authors failed to reach an agreement.

2.7. Data items

The following information was recorded from the selected studies: (1) publication year; (2) study origin; (3) methodological design; (4) participants (sample size, sex, and age); (5) interventions (surgical technique and type of distractor); (6) measurement periods; (7) distraction rate; (8) presence of PD; and (9) outcomes of interest for the systematic review.

2.8. Risk of bias in individual studies

The Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI) was used to assess the risk of bias (RoB) of the included studies. The RoB was based on studies with similar methodologies, ranging from 'high' (when the study had a 'yes' score of less than 49%), to 'moderate' (50—69%), to 'low' (70% or more) (Haas et al., 2016). RevMan Software (Review Manager, version 5.3, Cochrane Collaboration, Copenhagen, Denmark) was used to generate the RoB summary, with adaptation for the MAStARI tool questions.

2.9. Quality of evidence

The quality of evidence was evaluated using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach, which is based on the reliability with which an estimate of effect or association reflects the item being assessed (Schünemann et al., 2013). The GRADE profiler summarized the evidence quality using the GRADE pro-GDT software (http://gdt.guidelinedevelopment.org). Depending on the importance of some aspects (study design, RoB, consistency, directness, heterogeneity, precision, publication bias, and others reported by studies included in the systematic review), the quality of the evidence could be downgraded by one or two levels for each aspect.

3. Results

3.1. Study selection

A total of 680 articles was initially found in the six main electronic databases. After duplicate removal, the titles and abstracts of 542 articles were screened, and 57 potentially relevant studies were selected for full-text reading. No articles were selected from the gray literature (Google Scholar, ProQuest, and OpenGrey). Four articles were found by manual search. The 57 studies were read for eligibility assessment according to the inclusion criteria. Fifty-three studies were excluded because of the absence of data relating to changes in mandibular positioning. In the end, four studies met the inclusion criteria and were considered for this systematic review. Fig. 1 shows a flow diagram of study identification, screening, and inclusion process.

3.2. Study characteristics

The four selected studies related to different populations: Italy (Iodice et al., 2013), Netherlands (Xi et al., 2017), and Brazil (Baraldi et al., 2007; Oliveira et al., 2017). They amounted to 142 participants

(44 males and 98 females), with age ranging from 18 (Xi et al., 2017) to 60 years (Oliveira et al., 2017). All patients underwent SARME associated with PD, under general anesthesia, and differed regarding the chosen distractor — for example, Hyrax (Oliveira et al., 2017; Xi et al., 2017) and transpalatal distractor (TPD) (Xi et al., 2017). The individuals were evaluated using the cone beam computed tomography scans obtained before and after surgery (Oliveira et al., 2017; Xi et al., 2017) or conventional radiographic examinationss (Baraldi et al., 2007; Iodice et al., 2013). The daily expansion protocols ranged from 1.0 mm (Xi et al., 2017) to 0.4 mm (Iodice et al., 2013). Table 1 shows a summary of the main study characteristics.

Methodologically, there were differences between the included studies. Xi et al. (2017) performed eight three-dimensional cephalometric measurements (dental show, mandibular plane angle, occlusal vertical chin position, maxillary width, posterior maxillary width, and horizontal chin position). They were evaluated preoperatively (Tpre — 1—4 weeks before surgery) and postoperatively (Tpos — after complete maxillary expansion). Oliveira et al. (2017) performed linear and angular measurements based on mandibular reference points (ipsilateral condylion, contralateral condylion, ipsilateral gonion, contralateral gonion, and menton). The authors evaluated the outcomes over three periods: T1 — preoperative, T2 — immediately after expansion, and T3 — 6 months after expansion. Baraldi et al. (2007) evaluated the maxillomandibular transverse index in posteroanterior cepahlometries, while Iodice et al. (2013) evaluated sagittal and vertical changes in lateral cephalometric radiographs. Baraldi et al. (2007) and Iodice et al. (2013) evaluated the patients at only two stages (pre- and postoperatively).

3.3. Risk of bias within individual studies

In general, the included studies showed low RoB, with 75% of studies classified as low RoB and 25% showing moderate RoB (Fig. 2). Regarding individual questions from the MAStARI tool, a high RoB was observed for the sample-related questions (#1 and #4), and an uncertain RoB was attributed to the study subjects and setting details (Fig. 3).

3.4. Results of individual studies

Baraldi et al. (2007) carried out a study aiming to evaluate changes in the nasal complex and nasal patency. Over the course of 8.2 ± 2.7 months these authors assessed the acoustic rhinometry and frontal cephalometry examinations of 13 patients with maxillary transverse deficiency, comparing these with a control group ($n = 10$). A statistically significant difference was observed in the preoperative group regarding the maxillomandibular transverse index (the difference between effective mandibular and maxillary width, reducing the index expected for ages over 16 years).

Iodice et al. (2013) evaluated 21 adults (mean age 25.6 ± 6.3 years) over a 3-year period. The patients had different sagittal and vertical discrepancies. Regarding the analyzed mandibular variables, the study did not show statistically significant differences in SNB ($p = 0.80$), SN-Pg ($p = 0.90$), SN¯GoGn ($p = 1.00$), and FMA ($p = 0.90$).

Xi et al. (2017) evaluated 106 patients over 6 years who were eligible for SARME. From this total, the authors included 78 individuals, which showed a prevalence of women (2:1) and a mean age of 27.7 ± 10.4 years (ranging from 15 to 60 years). The mean follow-up was 20.3 ± 6.2 months. The study also compared different expanders, as described in Table 1. 87% of the patients demonstrated a postoperative increase in dental show (defined as the distance between the landmark stomion superius and the
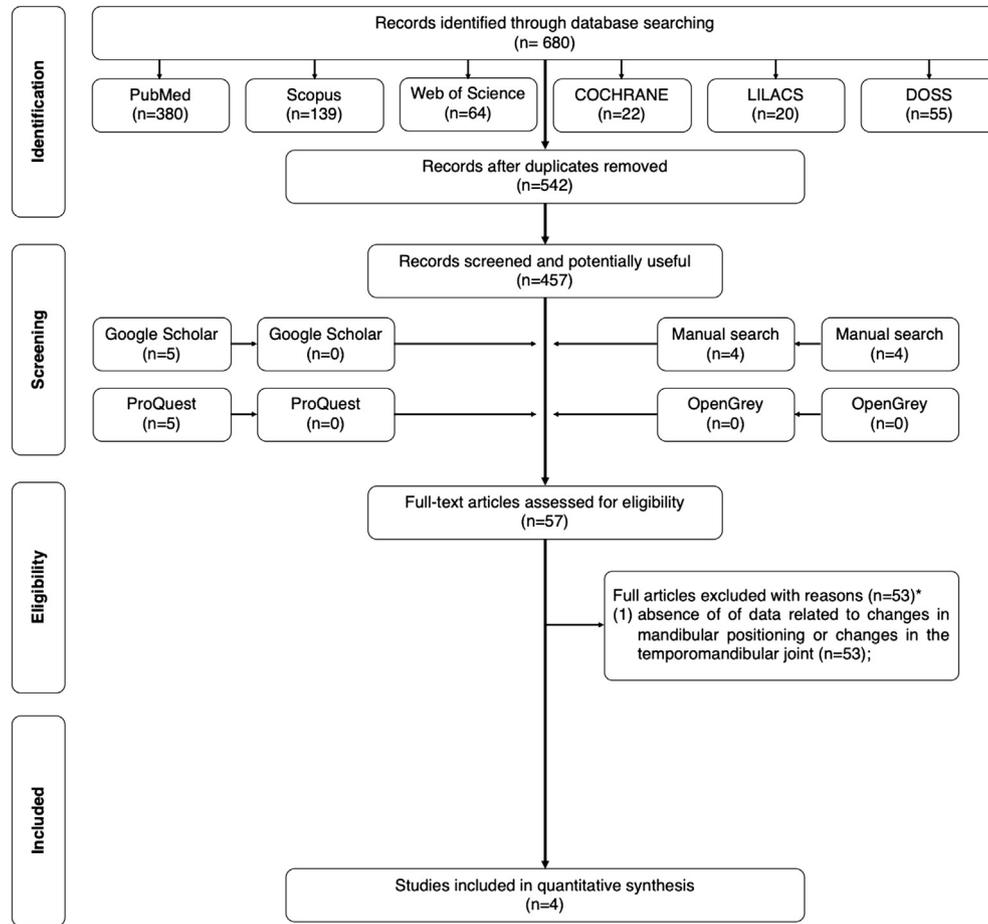
Fig. 1. Flowchart of the literature search and selection criteria. Adapted from PRISMA. *References for these 51 excluded articles are listed in Appendix B.

Table 1
Summary table of characteristics of the included studies.

Authors (year)	Study design	Origin	Participants	Intervention	Measurement periods	Distraction rate	PD	Outcome
Baraldi et al. (2007)	Retrospective study	Brazil	13 (4M, 9F) range 25.15—26.10 years	SARME*	Preoperatively and postoperatively	0.25 mm twice a day until expansion was reached	Yes	Acoustic rhinometry and posteroanterior cephalometry (MMTI)
Iodice et al. (2013)	Retrospective study	Italy	21 (7M, 14 F) range 20.2—30.1 years	SARME (11-mm expander screws)	Before treatment (T0) and 6 months after surgical expansion (T1)	0.2 mm twice a day until the planned expansions were achieved	Yes	Evaluations of sagittal and vertical changes
Xi et al., 2017	Retrospective cohort study	Netherlands	78 (22M, 56F) range 25—60 years	SARME with two types of distractor (TPD and Hyrax)	1—4 weeks prior to surgery (Tpre) and after completion of maxillary expansion (Tpos)	1.0 mm per day until the palatal cusps pf the upper teeth touched the buccal cusps of the lower teeth	Yes	Dental show and chin projection
Oliveira et al. (2017)	Retrospective study	Brazil	30 (11M, 19F) range 18.7—39.7 years	SARME with Hyrax type appliance	Preoperatively (T1); immediately after expansion (T2); and 6 months after expansion (T3)	0.2 mm (one quarter turn) 3 times a day until crossbite correction	Yes	Mandibular position

M — male; F — female; SARME — surgically assisted rapid maxillary expansion; * — distractor not identfied; PD — pterigoyd disjunction; MMTI — maxillomandibular transverse index.

upper incisor point along the vertical axis of the reference frame) of 2.7 ± 1.8 mm (overall mean increase of 2.2 ± 2.0 mm; $p < 0.01$), and 10 patients showed a reduction of 0.9 ± 0.8 mm. The postoperative mean horizontal and vertical displacements of the chin were

statistically significant (1.6 ± 2.5 mm posteriorly and 1.6 ± 2.0 mm inferiorly; $p < 0.01$).

The retrospective study performed by Oliveira et al. (2017) evaluated 30 patients, showing a prevalence among females and
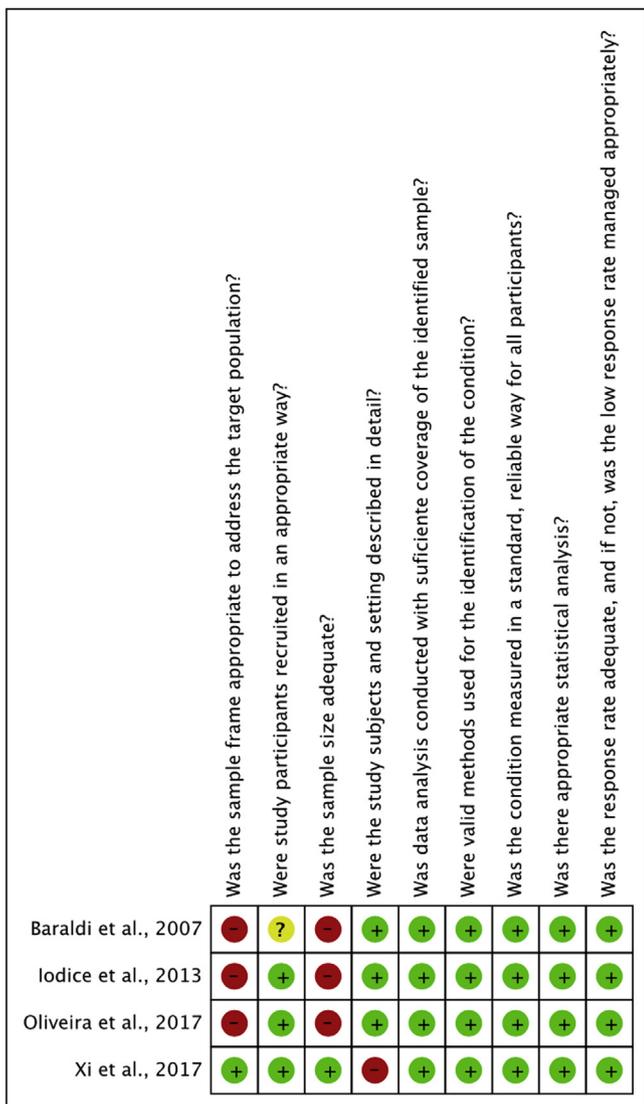
a mean age of 27.5 years (ranging from 18.7 to 39.7 years), as described in Table 1. There was no comparison between surgical protocols or types of expander. The mandible showed a mean lateral displacement of 1.08 ± 0.93 mm immediately after SARME. Statistically significant changes over time were observed regarding the 3D planes (axial view — menton and contralateral gonion; coronal view — menton; sagittal view — ipsilateral condylion, contralateral condylion, ipsilateral gonion, and contralateral gonion). The mandibular plane angle also altered significantly over the period ($p < 0.01$). Downward and backward movements of the menton immediately after expansion were observed, as well as postoperative mandibular transitional clockwise rotation.

3.5. Synthesis of results

Two studies (Xi et al., 2017; Oliveira et al., 2017) demonstrated significant mandibular changes in patients who underwent SARME associated with PD. The main results observed after surgical intervention were dental show and chin projection (Xi et al., 2017), and altered mandibular position (Oliveira et al., 2017). The studies evaluating two-dimensional imaging examinations (Baraldi et al., 2007; Iodice et al., 2013) did not show significant changes regarding mandibular positioning.

3.6. Additional analysis and confidence in cumulative evidence

According to the assessment based on GRADE criteria, certainty was considered very low. From the characteristics evaluated, the risk of bias, inconsistency, and imprecisions severely impacted on the overall quality of evidence. Further explanations of evidence appraisal are available in Table 2.

4. Discussion

The available systematic reviews of SARME-related studies (Buck et al., 2016; Ellabban et al., 2018; Camps-Pereperez et al., 2017; Hamedi Sangsari et al., 2016; Verstraaten et al., 2010) have emphasized the importance of controlled clinical investigations (Hamedi Sangsari et al., 2016). These should be methodologically designed to avoid heterogeneity regarding the instituted surgical protocols (Camps-Pereperez et al., 2017), in order to understand the clinical outcomes after SARME.

Fig. 2. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.
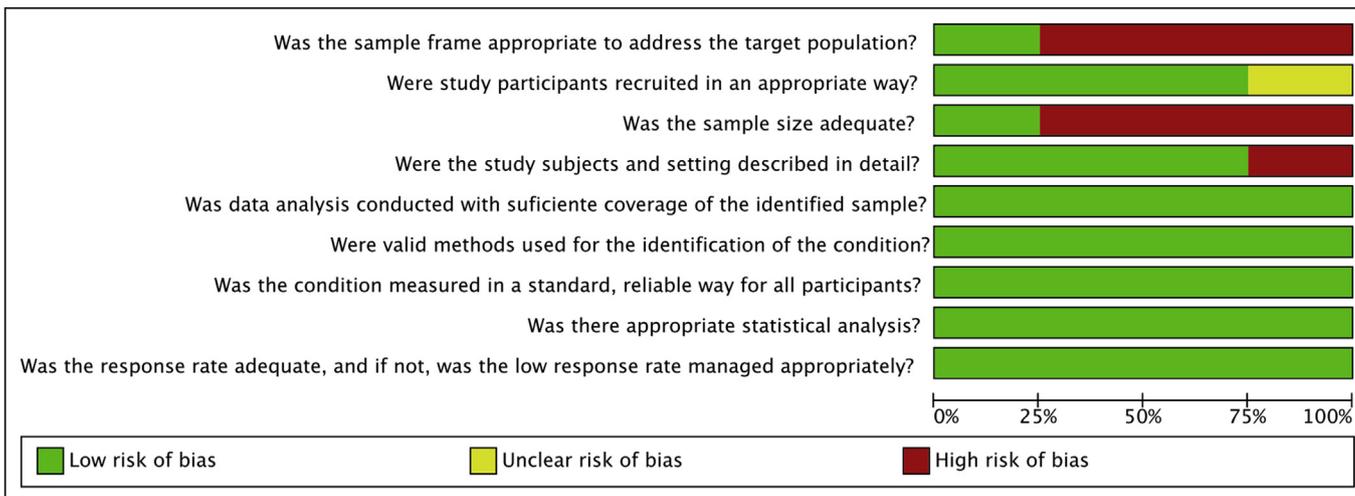

Fig. 3. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

Table 2
Summary of findings table (GRADE criteria).

Outcome No. of participants (studies)	Relative effect (95% CI)	Anticipated absolute effects (95% CI)			Certainty	What happens
				Difference		
Changes to mandibular position 142 (four observational studies)	Not estimable	0.0%	**0.0%** (0.0–0.0)	**0.0% fewer** (0 fewer to 0 fewer)	⊕◯◯◯ Very low[a]	Clockwise rotation and lateral shift of the mandible are transient effects of SARME. Increase in dental show and a posterior and inferior displacement of the chin should be considered prior to SARME to prevent undesirable postoperative changes to facial esthetics.

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: Confidence interval.
GRADE Working Group grades of evidence:**High certainty:** We are very confident that the true effect lies close to that of the estimate of the effect.**Moderate certainty:** We are moderately confident in the effect estimate. The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.**Low certainty:** Our confidence in the effect estimate is limited. The true effect may be substantially different from the estimate of the effect.**Very low certainty:** We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of the effect.
  [a] There is a risk of non-standardization of head positioning at different imagenological evaluation times.

The main methods that have been used to evaluate maxillary expansion and its effects on posterior crossbite are: measurements of dental casts (Schimming et al., 2000; Ciambotti et al., 2001; Ramieri et al., 2005; Laudemann et al., 2010; Kilic et al., 2013; Asscherickx et al., 2016; Kunz et al., 2016; Barrabé et al., 2018), conventional cephalometric analysis (Bretos et al., 2007; Iodice et al., 2013; Asscherickx et al., 2016; Barrabé et al., 2018), posteroanterior cephalograms (Schwarz et al., 1985; Byloff and Mossaz, 2004; Baraldi et al., 2007; Habersack et al., 2014), and computed tomographic assessment (Goldenberg et al., 2007; Landes et al., 2009; Laudemann et al., 2009, 2011; Pereira et al., 2012; Sygouros et al., 2014; Zandi et al., 2014; Yao et al., 2015; Kayalar et al., 2016; Moura et al., 2016; Ferraro-Bezerra et al., 2018). Two studies included in this systematic review used an advanced method of three-dimensional cephalometric analysis, which may offer a more reliable evaluation of alterations after different SARME protocols (Oliveira et al., 2017; Xi et al., 2017). Such an evaluation method can ensure that small mandibular changes apparently not noticeable in conventional imaging examinations (Baraldi et al., 2007; Iodice et al., 2013) may be detected (Oliveira et al., 2017; Xi et al., 2017).

Although the included studies had performed the same surgical protocol, some variables differed. The Hyrax device was used in two investigations; however, Xi et al. (2017) added a comparison group of individuals who received a TPD. Iodice et al. (2013) used an 11 mm screw, and Baraldi et al. (2007) did not specify the appliance used. There is a general lack of standardization regarding the use of these appliances. Studies differ in relation to the use of Hyrax (Glassman et al., 1984; Byloff and Mossaz, 2004; Goldenberg et al., 2007; Oliveira et al., 2017; de Medeiros et al., 2017; Ferraro-Bezerra et al., 2018), Hass (Kraut, 1984; Loddi et al., 2008), and TPD (Ramieri et al., 2005; Asscherickx et al., 2016). In addition, some methodological aspects differ among the studies, including the expansion activation protocol (Bretos et al., 2007; Ferraro-Bezerra et al., 2018; Barrabé et al., 2018), imaging follow-up, and the adopted criteria for evaluating the observed changes after SARME (Oliveira et al., 2017; Xi et al., 2017). These aspects contributed to the heterogeneity of the included studies, which was considered a limitation to producing robust scientific evidence using a meta-analysis approach.

Regarding the methodological aspects and their impact on evidence quality, the observation of some issues, including sample characterization, clear group definition, well-defined methods of patient recruitment, and appropriate statistical description resulted in low RoB. In addition, the studies were strengthened by the adoption of 3D-cephalometric analysis because it was more suitable for demonstrating significant mandibular spatial alterations in comparison with conventional bidimensional evaluations (Parhiz et al., 2011). However, there were some noteworthy weaknesses to report in some studies in this systematic review. Firstly, none of the included studies performed a sample size calculation to validate the sample used. Although the diagnosis of maxillary transverse deficiency was considered when this measurement surpassed 5 mm, the method used for this diagnosis was not described. Maxillary transverse deficiency diagnosis is important because of the possibility of relative cross-bite, which usually disappears when manipulating the dental casts for Angle Class I (Silverstein and Quinn, 1997; Koudstaal et al., 2005; Laudemann et al., 2011).

Furthermore, there are reports in the literature of maxillary anterior and inferior displacement occurring during the postoperative period, which consequently generated mandibular clockwise rotation and a consequent increase in facial height (Chung and Font, 2004; Farronato et al., 2011; Altindis et al., 2016). However, these studies were performed in patients during the growth phase. A high RoB regarding changes in the mandible was possible here because of the mandibular vector development. Thus, this finding led to the selection of studies that only included skeletally mature individuals.

In spite of the use of three-dimensional analysis in two studies (Oliveira et al., 2017; Xi et al., 2017), only the work of Xi et al. (2017) performed imaging alignment of the different evaluation periods based on the cranial base, forehead, and zygomatic arches of the patients. However, these authors did not describe the measurement reliability, which is important for internal study validity purposes. On the other hand, Oliveira et al. (2017) evaluated the reliability of the measurements using the intraclass correlation coefficient, which ranged from 0.929 to 0.996. However, these authors were restricted to cranial alignment based on the Frankfurt and median sagittal reference planes. It should be noted that the alignment of the head before the tomographic measurements can interfere with the obtaining of results (Ruellas et al., 2016).

The evaluation of SARME-related mandibular changes was enhanced in the studies that used superimposition of reconstructed volumes through cone beam computed tomography (Oliveira et al., 2017; Xi et al., 2017), which is a useful method for evaluating such modifications. This methodology is based on the construction of volumes and estimation of three-dimensional structural displacements, using a vectorization process (Cevidanes et al., 2005; Gomes et al., 2016). For this purpose, a static segment of the obtained

volume (e.g. skull base) is used as an alignment reference during the imaging analysis (Cevidanes et al., 2009). This methodology could have improved interpretation of the results because it would have avoided any bias related to cranial positioning, and the imaging evaluation would not be restricted to a specific craniometric point. In contrast, the studies that used conventional radiographic examinations did not show significant mandibular changes (Baraldi et al., 2007; Iodice et al., 2013). This finding can be attributed to the limitation of two-dimensional cephalometric analyses.

Changes were observed in the positioning of the chin in two studies (Oliveira et al., 2017; Xi et al., 2017), and they showed statistically significant differences when the follow-up periods were compared. Xi et al. (2017) found alterations in the immediate postoperative mandibular positioning after SARME in both evaluated groups, and there was no observed statistically significant difference in the measures when the expansion device variable was evaluated. However, considering the variable dental exposure, a statistically significant difference was observed for the angle of the occlusal plane and chin advancement in patients with increased postoperative dental exposure. Oliveira et al. (2017) also reported statistically significant differences regarding the evaluation of the chin position in comparison with the baseline period. However, the values were reestablished at the end of the expansion period. The same finding was observed concerning spatial changes in laterality. Both spatial changes could not be predicted, but the trend of mandibular clockwise rotation and lateral displacement may occur as a transient effect following SARME (Oliveira et al., 2017). Similar findings were found by Baratieri et al., 2011; however, these authors used an age group that included children and adolescents. Melgaco et al., 2014 found the same results relating to mandibular positioning.

Studies that evaluate the positional changes of the maxillomandibular complex through three-dimensional analysis provide more reliable results. However, the data comparison is compromised due to differences in evaluation method. Xi et al. (2017) proposed an analysis of measurements between craniometric points, while Oliveira et al. (2017) measured the craniometric points in relation to axial, coronal, and sagittal planes.

The mandibular changes found after SARME with PD (Parhiz et al., 2011; Oliveira et al., 2017; Xi et al., 2017) may have decisive repercussions for the final esthetic result, or they could be transitory due to the possibility of relapse, especially dental (Oliveira et al., 2017). Therefore, special attention is required during the surgical planning (Xi et al., 2017), as well as after the completed expansion period (Iodice et al., 2013; Ferraro-Bezerra et al., 2018).

4.1. Limitations

With only four studies considered eligible for this systematic review, only a qualitative analysis of the data obtained individually in each study was possible. Despite the low risk of bias observed in all studies, other issues affected the quality of scientific evidence. In addition, it was not possible to perform a meta-analysis because the methodologies for measuring the outcomes — regarding the head alignment process and the evaluation method of mandibular changes — as well as the analyzed parameters were heterogeneous.

5. Conclusion

This systematic review emphasizes the gap in the available knowledge regarding the repercussions of SARME associated with PD for mandibular positioning. Although it included a limited number of studies, SARME associated with PD was shown to be associated with dental show, chin projection, and altered mandibular position. This study also reinforced the weaknesses and limitations of available evidence in relation to this topic. Conventional imaging examinations may not have sufficient accuracy to demonstrate changes in mandibular positioning. These limitations suggest the need for further clinical research.

Declaration of interest

The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcms.2019.02.009.

References

Altindis S, Toy E, Başçiftçi FAP: Effects of different rapid maxillary expansion appliances on facial soft tissues using three-dimensional imaging. Angle Orthod 86(4): 590—598, 2016

Asscherickx K, Govaerts E, Aerts J, Vande Vannet B: Maxillary changes with bone-borne surgically assisted rapid palatal expansion: a prospective study. Am J Orthod Dentofacial Orthop 149(3): 374—383, 2016

Baraldi CE, Pretto SM, Puricelli E: Evaluation of surgically assisted maxillary expansion using acoustic rhinometry and postero-anterior cephalometry. Int J Oral Maxillofac Surg 36(4): 305—309, 2007

Baratieri C, Alves Jr M, Sant'anna EF, Nojima Mda C, Nojima LI: 3D mandibular positioning after rapid maxillary expansion in class II malocclusion. Braz Dent J 22(5): 428—434, 2011

Barrabé A, Meyer C, Bonomi H, Weber E, Sigaux N, Louvrier A: Surgically assisted rapid palatal expansion in class III malocclusion: our experience. J Stomatol Oral Maxillofac Surg 119(5): 384—388, 2018

Betts NJ: Surgically assisted maxillary expansion. Atlas Oral Maxillofac Surg Clin North Am 24(1): 67—77, 2016

Bretos JLG, Pereira MD, Gomes HC, Hino CT, Ferreira LM: Sagittal and vertical maxillary effects after surgically assisted rapid maxillary expansion (SARME) using Haas and Hyrax expanders. J Craniofac Surg 18(6): 1322—1326, 2007

Buck LM, Dalci O, Darendeliler MA, Papadopoulou AK: Effect of surgically assisted rapid maxillary expansion on upper airway volume: a systematic review. J Oral Maxillofac Surg 74(5): 1025—1043, 2016

Byloff FK, Mossaz CF: Skeletal and dental changes following surgically assisted rapid palatal expansion. Eur J Orthod 26(4): 403—409, 2004

Camps-Pereperez I, Guijarro-Martinez R, Peiro-Guijarro MA, Hernandez-Alfaro F: The value of cone beam computed tomography imaging in surgically assisted rapid palatal expansion: a systematic review of the literature. Int J Oral Maxillofac Surg 46(7): 827—838, 2017

Catherine Z, Breton P, Bouletreau P: Condylar resorption after orthognathic surgery: a systematic review. Rev Stomatol Chir Maxillofac Chir Orale 117(1): 3—10, 2016

Cevidanes LH, Franco AA, Gerig G, Proffit WR, Slice DE, Enlow DH, et al: Comparison of relative mandibular growth vectors with high-resolution 3-dimensional imaging. Am J Orthod Dentofacial Orthop 128(1): 27—34, 2005

Cevidanes LH, Heymann G, Cornelis MA, DeClerck HJ, Tulloch JF: Superimposition of 3-dimensional cone-beam computed tomography models of growing patients. Am J Orthod Dentofacial Orthop 136(1): 94—99, 2009

Chung CH, Font B: Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. Am J Orthod Dentofacial Orthop 126(5): 569—575, 2004

Ciambotti C, Ngan P, Orth C, Durkee M, Kohli K, Kim H: A comparison of dental and dentoalveolar changes between rapid palatal expansion and nickel-titanium palatal expansion appliances. Am J Orthod Dentofacial Orthop 119(1): 11—20, 2001

de Gijt JP, Gul A, Tjoa ST, Wolvius EB, van der Wal KG, Koudstaal MJ: Follow up of surgically-assisted rapid maxillary expansion after 6.5 years: skeletal and dental effects. Br J Oral Maxillofac Surg 55(1): 56—60, 2017

de Medeiros JR, Ferraro Bezerra M, Gurgel Costa FW, Pinheiro Bezerra T, de Araujo Alencar CR, Studart Soares EC: Does pterygomaxillary disjunction in surgically assisted rapid maxillary expansion influence upper airway volume? A prospective study using Dolphin Imaging 3D. Int J Oral Maxillofac Surg 46(9): 1094—1101, 2017

de Mol van Otterloo JJ, Dorenbos J, Tuinzing DB, van der Kwast WAM: TMJ performance and behaviour in patients more than 6 years after Le Fort I osteotomy. Br J Oral Maxillofac Surg 31(2): 83—86, 1993

Ellabban MT, Abdul-Aziz AI, Fayed MMS, AboulFotouh MH, Elkattan ES, Dahaba MM: Positional and dimensional temporomandibular joint changes after correction of posterior crossbite in growing patients: a systematic review. Angle Orthod 88(5): 638—648, 2018

Farronato G, Giannini L, Galbiati G, Maspero C: Sagittal and vertical effects of rapid maxillary expansion in class I, II, and III occlusions. Angle Orthod 81(2): 298—303, 2011

Ferraro-Bezerra M, Tavares RN, de Medeiros JR, Nogueira AS, Avelar RL, Studart Soares EC: Effects of pterygomaxillary separation on skeletal and dental changes after surgically assisted rapid maxillary expansion: a single-center, double-blind, randomized clinical trial. J Oral Maxillofac Surg 76(4): 844—853, 2018

Glassman AS, Nahigian SJ, Medway JM, Aronowitz HI: Conservative surgical orthodontic adult rapid palatal expansion: sixteen cases. Am J Orthod 86(3): 207—213, 1984

Goldenberg DC, Alonso N, Goldenberg FC, Gebrin ES, Amaral TS, Scanavini MA, et al: Using computed tomography to evaluate maxillary changes after surgically assisted rapid palatal expansion. J Craniofac Surg 18(2): 302—311, 2007

Gomes LR, Gomes MR, Goncalves JR, Ruellas AC, Wolford LM, Paniagua B, et al: Cone beam computed tomography-based models versus multislice spiral computed tomography-based models for assessing condylar morphology. Oral Surg Oral Med Oral Pathol Oral Radiol 121(1): 96—105, 2016

Haas LF, Dutra K, Porporatti AL, Mezzomo LA, De Luca Canto G, Flores-Mir C, et al: Anatomical variations of mandibular canal detected by panoramic radiography and CT: a systematic review and meta-analysis. Dentomaxillofac Radiol 45(2): 20150310, 2016

Habersack K, Becker J, Ristow O, Paulus GW: Dental and skeletal effects of two-piece and three-piece surgically assisted rapid maxillary expansion with complete mobilization: a retrospective cohort study. J Oral Maxillofac Surg 72(11): 2278—2288, 2014

Hamedi Sangsari A, Sadr-Eshkevari P, Al-Dam A, Friedrich RE, Freymiller E, Rashad A: Surgically assisted rapid palatomaxillary expansion with or without pterygomaxillary disjunction: a systematic review and meta-analysis. J Oral Maxillofac Surg 74(2): 338—348, 2016

Hoppenreijs TJM, Freihofer HPM, Stoelinga PJW, Tuinzing DB, van't Hof MA: Condylar remodelling and resorption after Le Fort I and bimaxillary osteotomies in patients with anterior open bite: a clinical and radiological study. Int J Oral Maxillofac Surg 27(2): 81—91, 1998

Iodice G, Bocchino T, Casadei M, Baldi D, Robiony M: Evaluations of sagittal and vertical changes induced by surgically assisted rapid palatal expansion. J Craniofac Surg 24(4): 1210—1214, 2013

Kayalar E, Schauseil M, Kuvat SV, Emekli U, Firatli S: Comparison of tooth-borne and hybrid devices in surgically assisted rapid maxillary expansion: a randomized clinical cone-beam computed tomography study. J Craniomaxillofac Surg 44(3): 285—293, 2016

Kilic E, Kilic B, Kurt G, Sakin C, Alkan A: Effects of surgically assisted rapid palatal expansion with and without pterygomaxillary disjunction on dental and skeletal structures: a retrospective review. Oral Surg Oral Med Oral Pathol Oral Radiol 115(2): 167—174, 2013

Koudstaal MJ, Poort LJ, van der Wal KG, Wolvius EB, Prahl-Andersen B, Schulten AJ: Surgically assisted rapid maxillary expansion (SARME): a review of the literature. Int J Oral Maxillofac Surg 34(7): 709—714, 2005

Kraut RA: Surgically assisted rapid maxillary expansion by opening the midpalatal suture. J Oral Maxillofac Surg 42(10): 651—655, 1984

Kunz F, Linz C, Baunach G, Böhm H, Meyer-Marcotty P: Expansion patterns in surgically assisted rapid maxillary expansion: transpalatal distractor versus Hyrax appliance. J Orofac Orthop 77(5): 357—365, 2016

Landes CA, Laudemann K, Schübel F, Petruchin O, MacK M, Kopp S, et al: Comparison of tooth- and bone-borne devices in surgically assisted rapid maxillary expansion by three-dimensional computed tomography monitoring: transverse dental and skeletal maxillary expansion, segmental inclination, dental tipping, and vestibular bone resorption. J Craniofac Surg 20(4): 1132—1141, 2009

Laudemann K, Petruchin O, Mack MG, Kopp S, Sader R, Landes CA: Evaluation of surgically assisted rapid maxillary expansion with or without pterygomaxillary disjunction based upon preoperative and post-expansion 3D computed tomography data. Oral Maxillofac Surg 13(3): 159—169, 2009

Laudemann K, Petruchin O, Nafzger M, Ballon A, Kopp S, Sader RA, et al: Long-term 3D cast model study: bone-borne vs. tooth-borne surgically assisted rapid maxillary expansion due to secondary variables. Oral Maxillofac Surg 14(2): 105—114, 2010

Laudemann K, Santo G, Revilla C, Harth M, Kopp S, Sader RA, et al: Assessment of surgically assisted rapid maxillary expansion regarding pterygomaxillary disjunction using thin volume-rendering technique: in variance analysis and in reliability, accuracy, and validity. J Oral Maxillofac Surg 69(10): 2631—2643, 2011

Loddi P, Pereira M, Wolosker A, Hino C, Kreniski T, Ferreira L: Transverse effects after surgically assisted rapid maxillary expansion in the midpalatal suture using computed tomography. J Craniofac Surg 19(2): 433—438, 2008

Melgaco CA, Columbano Neto J, Jurach EM, Nojima Mda C, Nojima LI: Immediate changes in condylar position after rapid maxillary expansion. Am J Orthod Dentofacial Orthop 145(6): 771—779, 2014

Moher D, Liberati A, Tetzlaff J, Altman DG: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6(7): e1000097, 2009

Moura L, Spin-Neto R, Sverzut C, Monnazzi M, Trivellato A, Gabrielli M, et al: Evaluation of the palatal split pattern in surgically rapid maxillary expansion — comparison of two techniques. Oral Maxillofac Surg 20(3): 255—258, 2016

Oliveira TFM, Pereira-Filho VA, Gabrielli MFR, Goncales ES, Santos-Pinto A: Effects of surgically assisted rapid maxillary expansion on mandibular position: a three-dimensional study. Prog Orthod 18(1): 22, 2017

Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A: Rayyan-a web and mobile app for systematic reviews. Syst Rev 5(1): 210, 2016

Parhiz A, Schepers S, Lambrichts I, Vrielinck L, Sun Y, Politis C: Lateral cephalometry changes after SARPE. Int J Oral Maxillofac Surg 40(7): 662—671, 2011

Pereira MD, De Abreu RAM, Prado GPR, Ferreira LM: Strategies for surgically assisted rapid maxillary expansion according to the region of transverse maxillary deficiency. Int J Oral Maxillofac Surg 41(9): 1127—1130, 2012

Ramieri GA, Spada MC, Austa M, Bianchi SD, Berrone S: Transverse maxillary distraction with a bone-anchored appliance: dento-periodontal effects and clinical and radiological results. Int J Oral Maxillofac Surg 34(4): 357—363, 2005

Ruellas AC, Tonello C, Gomes LR, Yatabe MS, Macron L, Lopinto J, et al: Common 3-dimensional coordinate system for assessment of directional changes. Am J Orthod Dentofacial Orthop 149(5): 645—656, 2016

Schimming R, Feller KU, Herzmann K, Eckelt U: Surgical and orthodontic rapid palatal expansion in adults using Glassman's technique: retrospective study. Br J Oral Maxillofac Surg 38(1): 66—69, 2000

Schünemann H, Brożek J, Guyatt G, Oxman A: GRADE handbook for grading quality of evidence and strength of recommendations. Updated October 2013. The GRADE Working Group. Available from: guidelinedevelopment.org/handbook; 2013

Schwarz GM, Thrash WJ, Byrd DL, Jacobs JD: Tomographic assessment of nasal septal changes following surgical-orthodontic rapid maxillary expansion. Am J Orthod 87(1): 39—45, 1985

Silverstein K, Quinn PD: Surgically-assisted rapid palatal expansion for management of transverse maxillary deficiency. J Oral Maxillofac Surg 55(7): 725—727, 1997

Suri L, Taneja P: Surgically assisted rapid palatal expansion: a literature review. Am J Orthod Dentofacial Orthop 133(2): 290—302, 2008

Sygouros A, Motro M, Ugurlu F, Acar A: Surgically assisted rapid maxillary expansion: cone-beam computed tomography evaluation of different surgical techniques and their effects on the maxillary dentoskeletal complex. Am J Orthod Dentofacial Orthop 146(6): 748—757, 2014

Verstraaten J, Kuijpers-Jagtman AM, Mommaerts MY, Berge SJ, Nada RM, Schols JG: A systematic review of the effects of bone-borne surgical assisted rapid maxillary expansion. J Craniomaxillofac Surg 38(3): 166—174, 2010

Xi T, Laskowska M, van de Voort N, Ghaeminia H, Pawlak W, Berge S, et al: The effects of surgically assisted rapid maxillary expansion (SARME) on the dental show and chin projection. J Craniomaxillofac Surg 45(11): 1835—1841, 2017

Yao W, Bekmezian S, Hardy D, Kushner HW, Miller AJ, Huang JC, et al: Cone-beam computed tomographic comparison of surgically assisted rapid palatal expansion and multipiece Le Fort I osteotomy. J Oral Maxillofac Surg 73(3): 499—508, 2015

Zandi M, Miresmaeili A, Heidari A: Short-term skeletal and dental changes following bone-borne versus tooth-borne surgically assisted rapid maxillary expansion: a randomized clinical trial study. J Craniomaxillofac Surg 42(7): 1190—1195, 2014

Zandi M, Miresmaeili A, Heidari A, Lamei A: The necessity of pterygomaxillary disjunction in surgically assisted rapid maxillary expansion: a short-term, double-blind, historical controlled clinical trial. J Craniomaxillofac Surg 44(9): 1181—1186, 2016