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Systematic Review
Orthognathic Surgery

The value of cone beam computed tomography imaging in surgically assisted rapid palatal expansion: a systematic review of the literature

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Abstract. This study aimed to evaluate the reliability of cone-beam computed tomography (CBCT) imaging of the maxillary structures and the postoperative dentoskeletal, nasal airway, periodontal, and facial soft tissue changes after surgically assisted rapid palatal expansion (SARPE). A systematic review of the literature on CBCT analysis of SARPE was performed. The PubMed, Embase, and Cochrane Library databases were searched. Nine articles were included, involving a total of 228 patients. The general trend was tooth-borne distraction with pterygomaxillary dysjunction. A systematic increase in all transverse dimensions at the dentoalveolar and dental levels, as well as a certain degree of tipping and extrusion of the anchorage teeth and tipping of the skeletal segments, was detected. Soft tissue findings reflected the underlying dentoalveolar changes. A decrease in the buccal alveolar bone thickness and alveolar crest level occurred. Results confirm that CBCT is an accurate and reliable method to assess anatomical changes after SARPE. Although this systematic review provides valuable preliminary information about the effects of SARPE, results should be interpreted with caution due to the low level of evidence of the publications, great heterogeneity among study groups regarding outcome variables and surgical–orthodontic protocols, and lack of long-term data.

Key words: SARPE; surgically assisted rapid palatal expansion; rapid palatal expansion; RPE; cone beam computed tomography; CBCT; distraction osteogenesis; systematic review.

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Surgically assisted rapid palatal expansion (SARPE) is the procedure of choice to manage severe transverse maxillary deficiencies in adult patients.[1–28] It has been reported to improve stability compared to non-surgical rapid palatal expansion (RPE).[1–13,16–18,20,26] Indeed, SARPE releases bone structures that are resistant to expansion forces.[1,16,19] There is no consensus regarding the areas of major resistance to maxillary expansion and the number of osteotomies required to obtain a parallel opening of the midpalatal suture,[2,5–8,24,29,30] but some authors relate pterygomaxillary dysjunction to a parallel expansion.[3,31]

The majority of studies evaluating the transverse skeletal effects of maxillary expansion have been based on conventional cephalometric analysis using posteroanterior radiographs, occlusal views, or dental casts.[4,16–19,21] The inherent limitations of all planar two-dimensional (2D) projections, such as magnification, distortion, and difficulties in landmark identification and superimposition of the anatomical structures, result in images with low accuracy and reliability and explain why these methods have been open to some criticism. With the introduction of three-dimensional (3D) imaging modalities,[3–19,22,26,32–36] a more detailed and accurate evaluation of the dentoskeletal structures has become feasible compared with conventional 2D radiographs.[3,5,6,14,17,21,34] In particular, several studies have now analysed the efficacy of SARPE using cone beam computed tomography (CBCT).[17–19,26,36] Its high potential for evaluating the maxillary structures has been confirmed, mainly due to its advantages of good resolution and accuracy (only about 2% magnification), precision, non-invasiveness, lower effective radiation dose, and shorter acquisition times (60 s).[17,19,36]

Within this context, the purpose of the present study was to conduct a systematic review of the literature on CBCT imaging and analysis of maxillary changes after SARPE in order to investigate the reliability of CBCT for maxillary analysis and to study changes in the midpalatal suture, skeletal and dental changes, changes in the nasal cavity, periodontal effects, and soft tissue facial changes.

Materials and methods

This systematic review focused on non-growing, non-syndromic human patients with skeletal maxillary transverse deficiencies treated with SARPE and studied with CBCT. The variables studied (dentoskeletal, midpalatal, nasal, periodontal, and soft tissue changes) were compared before and after treatment. Case reports, case series with a sample of $n < 10$, oral communications, posters, and theses were excluded.

The PICOS principle (participants, intervention, comparisons, outcomes, and study design) was followed.

Search strategy

A systematic review of the literature on SARPE and analysis with CBCT was performed. An electronic search in the PubMed (National Library of Medicine, NCBI), Cochrane Library, and Embase databases was performed in January 2015 and subsequently updated in July 2016. Table 1 shows the key words used to build the search strategy. The electronic search was completed by a manual search of the reference lists of selected publications.

Table 1. Primary and secondary key words used for the systematic literature search.

Primary key words	Secondary key words
1. SARPE	1. Cone-beam
2. Surgically assisted rapid palatal expansion	2. Conebeam (MeSH)
3. SARME	3. CBCT
4. Surgically assisted rapid maxillary expansion	4. CB-CT
5. Palate surgery (MeSH)	5. Digital volume tomography
6. Maxilla surgery (MeSH)	6. CVT
7. Osteogenesis distraction (MeSH)	7. Compact computed tomography
8. Palatal expansion technique (MeSH)	8. Compact CT
	9. Compact volume tomography
	10. Volumetric computed tomography
	11. Volumetric CT
	12. Ortho cubic
	13. Flat panel
	14. 3 dimensional evaluation
	15. Three dimensional evaluation

MeSH, medical subject heading term.

Study selection and quality assessment

The search strategy was performed independently by two investigators (ICP, MPG). First, all titles obtained in the electronic search were screened. When the title did not contain sufficient information for exclusion, the paper was selected for abstract evaluation; the abstracts of all potentially relevant papers were reviewed based on the study inclusion criteria. The papers were obtained in full when they appeared to fulfil the inclusion criteria the also when the abstract did not contain sufficient information for exclusion. Full-text articles were analysed for final inclusion. If there was a discrepancy in results between the two investigators, a consensus decision was taken; when an article was rejected, the reason was noted. Cohen's kappa coefficient (κ) was used to measure inter-rater agreement for title and abstract selection. The electronic search was completed by a manual search of the reference lists of selected publications with the same selection strategy as described above. The methodological quality of the studies was assessed independently by the same two investigators. The materials and methods, results, and discussion sections were analysed based on the Cochrane Collaboration tool for assessing the risk of bias.

Results

Search results

The initial electronic search yielded 134 references in PubMed, 26 in Embase, and eight in Cochrane Library ($n = 168$). Eleven additional studies were identified by manual search ($n = 179$). After duplicate removal, 152 potentially relevant references were assessed. The full papers of 13 references were analysed in detail. Application of the inclusion criteria led to the exclusion of six more articles,[26,37–41] and two more references were added in an update performed in July 2016.[42,43] Finally, nine articles were found to be clinically or technically relevant to the subject of the study and were included in this systematic review.[17–19,36,42–46] A QUORUM flow diagram giving an overview of the selection process is presented in Fig. 1. The articles were categorized according to their emphasis, as shown in Table 2.

Types of studies

Out of the nine papers included in this systematic review, three were case series,[19,42,44] four were cohort studies,[17,18,36,45] and two were randomized

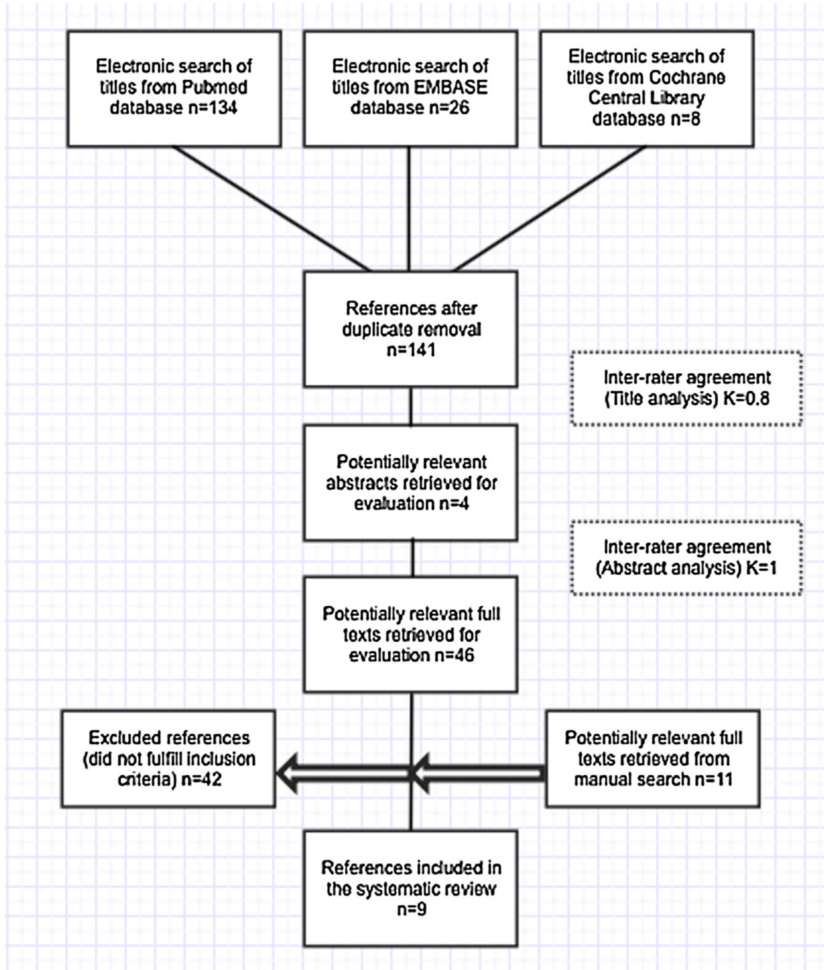

Fig. 1. QUORUM flow diagram of the article selection process.

clinical trials.[43,46] Eight studies were prospective and one was retrospective. Three (33.3%) were performed by the same study group.[17,18,36] Table 3 shows the characteristics of the studies included.

Methodological quality

The Cochrane Collaboration tool for assessing the risk of bias could not be applied in this systematic review. Consequently, the Newcastle–Ottawa scale (NOS) for assessing the quality of non-randomized studies was used (Table 4).

Regarding reporting bias, only two papers reported information about the mean screw opening during SARPE.[19,46] The correlation between screw opening and maxillary opening was not a variable studied in any of the papers analysed. Two studies reported intraoperative screw activation.[43,45] Overcorrection was performed by three study groups.[42,44,46] One study compared postoperative results between cases in which pterygomaxillary dysjunction was performed and cases in which it was not.[45] The duration of the surgical intervention was reported in one article only.[46] Orthodontic management was assessed in three publications.[19,43,46] Four out of the nine papers provided detailed information about the timing of orthodontic treatment following the completion of active distraction.[17,18,36,43] Only one paper reported postoperative complications.[46] The use of specific postoperative instructions or medication was reported in only one study.[42]

Patients

A total of 228 patients managed with SARPE were reported in the nine selected articles. The sample size ranged from 14 patients[19,42] to 45 patients,[18] and the patients ranged in age from 15 years[46] to 41.9[36] years, with a mean age at the time of surgery of 24.3 years. Of the total sample, 149 were female (66.5%) and 75 were male (33.5%).

The protocols of eight studies were approved by medical ethics committees.[17–19,36,42,43,45,46] Only one paper failed to specify this aspect.[44] Patient informed consent was specifically reported in seven papers,[17–19,36,42,43,46] while two articles omitted this information.[44,45]

Taking into account the type of distraction device, a tooth-borne distractor (TB) was used in 162 patients (69.3%), whereas a bone-borne distractor (BB) was used in 60 patients (26.3%) and a hybrid device was used in the remaining 10 (4.4%). Pterygomaxillary dysjunction (+PD) was reported in 218 patients (95.6%); no pterygomaxillary dysjunction (−PD) was performed in the remaining 10 (4.4%).

A TB device was used in 158 patients (69.3%). A BB device was used in 60 patients (26.3%) and a hybrid device in the remaining 10 (4.4%).

CBCT images

Table 3 summarizes the CBCT protocols and scanning parameters used in the different studies. In three studies, measurements were performed by one observer who was not directly involved in the

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Table 2. Classification of relevant papers that were analysed in detail in this study.

Category	Number of papers	References
1. Accuracy and reliability of CBCT imaging of the maxillary structures	5	Gauthier et al. 2011[19] Nada et al. 2012[18] Nada et al. 2013[36] Sygouros et al. 2014[45] Zandi et al. 2014[46]
2. Changes in midpalatal suture	1	Salgueiro et al. 2015[42]
3. Maxillary skeletal and dental changes	6	Nada et al. 2012[18] Nada et al. 2013[17] Nada et al. 2013[36] Sygouros et al. 2014[45] Zandi et al. 2014[46] Kayalar et al. 2016[43]
4. Nasal changes/upper airway changes	3	Nada et al. 2013[36] Pereira-Filho et al. 2014[44] Zandi et al. 2014[46]
5. Periodontal changes	3	Gauthier et al. 2011[19] Sygouros et al. 2014[45] Kayalar et al. 2016[43]
6. Soft tissue facial changes	3	Nada et al. 2012[18] Nada et al. 2013[17] Nada et al. 2013[36]
7. Effects of bone-borne and tooth-borne devices	4	Nada et al. 2012[18] Nada et al. 2013[17] Nada et al. 2013[36] Zandi et al. 2014[46]
8. Dental and skeletal changes with and without pterygomaxillary dysjunction	1	Sygouros et al. 2014[45]
9. Effects of tooth-borne and hybrid devices	1	Kayalar et al. 2016[43]

CBCT, cone beam computed tomography.

treatment and who was blinded to the type of treatment.[17,18,36] In another study, all measurements were performed by a blinded examiner (resident in orthodontics) under the supervision of an oral and maxillofacial radiologist.[19] Two observers, blinded to the type of treatment, were involved in another study.[46] One paper reported that measurements were made by a single examiner[45] and another that measurements were made by two operators,[43] with no further information on blinding, and the remaining articles did not describe the examiner conditions.[42,44]

Parameters were calculated twice at a 2-week,[18,19,36,45] 4-week,[43] or 8-week interval.[46] In particular, measurements were taken twice within a 2-week interval for the right teeth at T0 to establish intra-examiner reliability,[19] and 16[18] and 11[36] randomly selected CBCT scans were measured twice with a 2-week interval. The remaining articles did not provide such details.[17,42,44]

Expansion devices

Table 3 summarizes the distractor devices used in the selected articles. One of the TB device study groups reported a mean screw opening of 9.82 mm (range 7.5–12.0 mm).[19] Another paper reported 7.8 ± 2.8 mm for the TB group and 7.3 ± 2.0 mm for the BB group.[46] The remaining articles did not specify this parameter.[17,18,36,42–45] The correlation between screw opening and maxillary opening was not a variable studied in any of the articles analysed.

Surgical intervention and expansion protocol

Surgical specifications of the selected articles are summarized in Table 3. Regarding the specific expansion protocol, one study specified screw activation of 2 mm intraoperatively[45] and another reported screw activation until a diastema of 1 mm was shown.[43] Only one study performed activation–latency cycles: the screw was activated for 7 days followed by no activation for the next 7 days.[43] The clinical aim of expansion was referred to as the dimension at which the palatal cusps of the maxillary teeth touched the buccal cusps of the lower dentition,[17,18,36,42] or simply as the dimension at which ‘‘adequate expansion was achieved”.[45] Overcorrection was performed in two studies: one aimed for an overexpansion of 2–3 mm on either side,[46] and the other for a slight overcorrection of the crossbite.[44] The remaining articles did not specify these parameters.[17–19,36,42,43,45]

The distraction device was left in place after the desired expansion had been achieved for a retention period of 3 months,[17,18,36] 4 months,[19,44,46] or 6 months.[43] Two articles did not report this variable.[42,45] At the end of the consolidation period, some authors installed a transpalatal arch on the first molars.[17,18,46] In one study, a Hawley-type appliance was fitted for 8 months.[19] The remaining articles did not report the use of any post-expansion stabilization devices.[36,42–45] Orthodontic treatment was initiated 8–10 weeks after the end of active distraction,[17,18,36] or after the 6-month retention period.[43] The remaining articles did not specify when orthodontic treatment was started.[19,42,44–46] Orthodontic management was performed by a single orthodontist in one study[19,43] and by several in another.[46] The remaining articles did not specify this point.[17,18,36,42,44,45]

Complications

Only one paper reported complications after SARPE.[46] These included mild extrusion of a premolar, oedema, and haematoma.

The use of specific postoperative instructions or medication was reported in only one study.[42]

Reported inclusion/exclusion criteria for SARPE

With regard to inclusion criteria, a general inclusion criterion was adult age with skeletal maturity and a concomitant transverse maxillary deficiency. The size of the deficiency was required to be greater than 7 mm in one study,[19] greater than 5 mm in another,[36] and was left unspecified in the other seven studies included in this systematic review.[17,18,42–46]

Additional inclusion criteria were good general health, good periodontal health, no missing maxillary teeth (except lateral incisors), non-smoking status during the study period, and signature on the consent form.[19]

All patients included in this systematic review were evaluated radiologically with CBCT (Table 3).

With regard to exclusion criteria, according to the papers included in this systematic review, patients were excluded from SARPE if the following conditions were present: developmental maxillofacial deformities[17,18,36,44–46] or craniofacial anomalies that could alter the effects of expansion,[44–46] systemic disease,[42] prior

Table 3. Overview of the studies included.

First author, year of publication	Origin	Study design	Sample size and distribution	Mean age at time of surgery (range), years	Distraction device	Latency period (days)	Distraction rate	PD	GA	Same surgical procedure/ same surgeon	CBCT time points	Scanning parameters	Aim of the study
Kayalar 2016[43]	Turkey/ Germany	Prosp., RCT	20 (9 M/11 F)	19.37 ± 4.18 (18–35)	Hyrax/hybrid device	NR	0.5 mm/d	Yes	Yes	Yes/yes	T0: before SARPE T1: 14 d later T2: 6 m later	Scanora 3D (0.24-mm voxel size, 14.5 cm FOV)	To compare the dental, skeletal, and periodontal effects of TB and TB/hybrid appliances in SARME
Salgueiro 2015[42]	Brazil	Prosp., CS	14 (5 M/9 F)	25.3 Type I: 23.9 Type II: 33.5	Hyrax/Haas	5	0.5 mm/d	Yes	Yes	NR/yes	T0: before SARPE T1: 15 d later T2: 60 d later T3: 180 d later	i-CAT device	To evaluate the opening pattern and bone neoformation process at the midpalatal suture
Pereira-Filho 2014[44]	Brazil	Prosp., CS	15 (6 M/9 F)	30.2 ± 7.4	Hyrax	7	0.75 mm/d	Yes	NR	NR/NR	T0: before SARPE T1: after expansion T2: 6 m later	i-CAT device (22 × 16 FOV)	To evaluate upper airway changes
Sygouros 2014[45]	Greece/ Turkey	Retrosp., cohort	20 (4 M/16 F) 10 −PD 10 +PD	−PD: 19.2 +PD: 18.4	Hyrax	3	0.5 mm/d	−PD group +PD group	NR	Yes/NR	T0: before SARPE T1: 3–6 m later	NR	To evaluate and compare skeletal, dental, dentoalveolar, and periodontal changes with and without PD
Zandi 2014[46]	Iran	Prosp., RCT	28 (9 M/19 F) 13 TB 15 BB	TB: 20.3 (15–27) BB: 19.4 (15–23)	Hyrax/TPD	7	0.5–0.6 mm/d	Yes	NR	Yes/yes	T0: before SARPE T1: 4 m later	Newton device (0.4-mm voxel size, 12 cm FOV)	To evaluate and compare skeletal and dental changes using TB and BB devices
Nada 2013[17]	Netherlands/ Egypt	Prosp., cohort	40 (13 M/27 F) 25 TB 15 BB	TB: 25.4 ± 9 BB: 30 ± 10	Hyrax/TPD	7	1 mm/d	Yes	Yes	NR/yes	T0: before SARPE T1: 22 m later	i-CAT device (0.4-mm voxel size, 22 × 16 cm FOV)	To assess and compare soft tissue facial changes using TB and BB distractors
Nada 2013[36]	Netherlands/ Egypt	Prosp., cohort	32 (11 M/21 F) 19 TB 13 BB	TB: 24.2 ± 7 BB: 31.9 ± 10	Hyrax/TPD	7	1 mm/d	Yes	Yes	Yes/yes	T0: before SARPE T1: 22 m later	i-CAT device (0.4-mm voxel size, 22 × 16 cm FOV)	To assess the effects of BB and TB on the volumes of the nose and nasal airway
Nada 2012[18]	Netherlands/ Egypt/ Czech Republic	Prosp., cohort	45 (17 M/28 F) 28 TB 17 BB	TB: 24.5 ± 9 BB: 29.4 ± 10	Hyrax/TPD	7	1 mm/d	Yes	Yes	Yes/yes	T0: before SARPE T1: 22 m later	i-CAT device (0.4-mm voxel size, 22 × 16 cm FOV)	To evaluate the long-term effects of TB and BB devices
Gauthier 2011[19]	Canada	Prosp., CS	14 (5 M/9 F)	23.0 ± 1.9 (16.4–39.7)	Hyrax	NR	NR	Yes	NR	NR/yes	T0: before SARPE T1: 6 m later	i-CAT device (0.2-mm voxel size, 22 × 16 cm FOV)	To evaluate the periodontal effects of SARPE

BB, bone-borne; CBCT, cone beam computed tomography; CS, case series; d, days; F, female; FOV, field of view; GA, general anaesthesia; m, months; M, male; NR, not reported; PD, pterygomaxillary dysjunction; −PD, without pterygomaxillary dysjunction; +PD, with pterygomaxillary dysjunction; Prosp., prospective; RCT, randomized clinical trial; Retrosp., retrospective; SAPME, surgically assisted rapid maxillary expansion; SARPE; surgically assisted rapid palatal expansion; TB, tooth-borne; TPD, transpalatal distractor.

Table 4. Newcastle–Ottawa quality assessment scale (NOS): range from 0 to 9.

First author, year of publication	Study type	Sample and distribution	NOS results
Kayalar 2016[43]	Prospective, RCT	20 (9 male, 11 female)	Not applicable
Salgueiro 2015[42]	Prospective, case series	14 (5 male, 9 female)	Not applicable
Pereira-Filho 2014[44]	Prospective, case series	15 (6 male, 9 female)	Not applicable
Sygouros 2014[45]	Retrospective, cohort	20 (4 male, 16 female) (10–PD, 10 +PD)	7
Zandi 2014[46]	Prospective, RCT	28 (9 male, 19 female) (13 TB, 15 BB)	Not applicable
Nada 2013[17]	Prospective, cohort	40 (13 male, 27 female) (25 TB, 15 BB)	8
Nada 2013[36]	Prospective, cohort	32 (11 male, 21 female) (19 TB, 13 BB)	8
Nada 2012[18]	Prospective, cohort	45 (17 male, 28 female) (28 TB, 17 BB)	8
Gauthier 2011[19]	Prospective, case series	14 (5 male, 9 female)	Not applicable

BB, bone-borne; −PD, without pterygomaxillary dysjunction; +PD, with pterygomaxillary dysjunction; RCT, randomized clinical trial; TB, tooth-borne.

maxillary trauma or previous surgery,[46] absence of more than four teeth in the posterior maxillary arch,[17,18,36] radiological signs of fluid accumulation in the maxillary sinuses,[36] age under 18 years, absence of maxillary first molars, previous periodontal disease, previous orthodontic treatment, and genetic disease.[43] For one study group, the exclusion criteria were summarized as any health problem that contraindicated surgery.[19] Methodologically, one study excluded patients who were missing the required set of CBCT scans[45] and another excluded patients whose lips were not at rest during CBCT scan acquisition.[17]

Reliability of CBCT imaging of the maxillary structures

The reliability of CBCT for the diagnosis of transverse maxillary deficiency and for the postoperative evaluation of SARPE was assessed with the analysis of reported correlation coefficients. Globally, intra-examiner reliability ranged from 0.550 to 0.996. Individually, values ranged from 0.966 to 0.996,[19] 0.70 to 0.96,[46] and 0.55 to 0.98.[18] One paper gave a single value of 0.93,[36] and another reported that the intraclass correlation coefficient showed that all measurements could be repeated with an insignificant error not affecting the results.[45] Four articles did not specify this parameter.[17,42–44] Only one paper reported the inter-observer correlation coefficient, which ranged between 0.60 and 0.95.[46]

Changes in the midpalatal suture

Radiographic analysis (CBCT) of postoperative changes in the midpalatal suture was performed in one selected study only[42] (Table 5). The authors reported a type I opening pattern of the midpalatal suture (opening from the anterior to the posterior nasal spine) in 85.7% of the patients, while a type II opening (opening from the anterior nasal spine to the transverse palatal suture) was observed in the remaining 14.2%. They related the opening pattern to the patient's age: older individuals showed a tendency to a V-shaped opening. Bone density values after 180 days of retention were smaller than those of the preoperative period, and it was concluded that a retention period of more than 6 months is necessary.

Skeletal and dental changes

Immediately postoperative

Radiographic analysis (CBCT) of the immediate maxillary dental and skeletal changes was not reported in any of the selected articles.

After retention

Radiographic analysis (CBCT) of the maxillary dental and skeletal changes after retention was performed by three study groups[43,45,46] (Table 5). One of them reported a V-shaped expansion of the dentoskeletal structures in the coronal plane and greater widening of the dental arch (range 6.53–7.23 mm) than of the palatal bone (range 3.92–4.33 mm), with comparable dental and skeletal changes between TB and BB devices.[46] Postero-anteriorly, parallel expansion of the dental arch and palatal bone was observed.[46] In another study group, an increase in all transverse measurements at the dentoalveolar and dental levels and a true anterior skeletal expansion were detected, although the posterior aspect of the maxilla showed no expansion.[45] The −PD group exhibited a constriction in the middle area and more pronounced buccal alveolar bending and buccal tipping, but without statistical significance.[45] The final article found significantly less anterior dental expansion in the hybrid devices group than in the TB group, and posterior dental expansion was comparable in the two groups.[43] The first molars tipped buccally to a greater extent in the TB group, but moved upright during the retention phase. Mean skeletal maxillary widening was found to be similar in the two groups, with a V-shaped pattern.[43]

After orthodontic treatment

Radiographic analysis (CBCT) of the maxillary dental and skeletal changes after orthodontic treatment and prior to the second orthognathic surgery procedure was performed by one study group in three publications[17,18,36] (Table 5). The authors concluded that BB and TB SARPE produced comparable results at the end of fixed appliance treatment with regard to skeletal changes.[18] Soft tissue changes reflected the underlying dentoalveolar changes, with a significant positive correlation between alveolar and soft tissue changes in the anterior region, but a poor correlation in the cheek area.[17]

Nasal airway changes

Three publications assessed upper airway changes after SARPE[36,44,46] (Table 5). One publication reported a significant increase in the smallest transverse section area of the nasal airway immediately after SARPE, although a tendency to relapse 6 months later was observed.[44] The authors concluded that maxillary expansion, as an isolated procedure, does not result in a statistically significant improvement in the airway dimensions (area and volume)

Table 5. Overview of studies included in the systematic review: skeletal, dentoalveolar, and dental changes, nasal changes, periodontal changes, facial soft tissue changes, and midpalatal suture changes.

First author/year	CBCT T1/T2	Skeletal, dentoalveolar, and dental changes	Nasal changes	Periodontal changes	Facial soft tissue changes	Midpalatal suture changes
Kayalar 2016[43]	T1: 14 d T2: 6 m	• Less anterior dental expansion in the hybrid devices group than in the TB group • Posterior dental expansion was comparable in the two groups • The first molars tipped buccally more in the TB group, but moved upright during the retention period • The mean skeletal maxillary widening was found to be similar in the two groups, with a V-shaped pattern • Hybrid devices produced less tipping and reduced tooth resorption compared to TB expanders	NR	• A decrease in the BABT • Neither the hybrid nor the TB distractor involved any risk of periodontal damage to the molars • Hybrid devices produced less bone resorption than TB expanders	NR	NR
Salgueiro 2015[42]	T1: 15 d T2: 60 d T3: 180 d	NR	NR	NR	NR	• Type I opening pattern: 85.7% • Type II opening pattern: 14.2% • Older individuals showed a tendency to a V-shaped opening • The bone density values after 180 d of retention were smaller than those of the preoperative period
Pereira-Filho 2014[44]	T1: after expansion T2: 6 m	NR	• A significant increase in the smallest transverse section area of the nasal airway at T1 and a tendency to relapse at T2 • Maxillary expansion, 6 m after SARPE, does not result in a significant improvement in the airway dimensions (area and volume)	NR	NR	NR
Sygouros 2014[45]	T1:3–6 month	• Buccal tipping of all posterior teeth but not of the canines • Vestibular tipping of the alveolar crest, more in the −PD group; differences not statistically significant • An increase in all transverse measurements at the dentoalveolar and dental levels, with more alveolar bending and more buccal tipping in the −PD group • A true skeletal anterior expansion, no posterior expansion, and a constriction in the middle area (in the −PD group) • No statistically significant differences between −PD and +PD groups	NR	• A decrease in the BABT and BACL • A greater decrease in the premolar area in the −PD group	NR	NR

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Table 5 (*Continued*)

First author/year	CBCT T1/T2	Skeletal, dentoalveolar, and dental changes	Nasal changes	Periodontal changes	Facial soft tissue changes	Midpalatal suture changes
Zandi 2014[46]	T1: 4 m	• In the coronal plane, a V-shaped expansion with more widening at the dental arch than in the palatal bone • Postero-anteriorly, a parallel expansion • Comparable dental and skeletal changes between TB and BB groups	• A small increase in the nasal floor width without differences between TB and BB groups	NR	NR	NR
Nada 2013[17]	T1: 22 m	• Posterior alveolar expansion and anterior alveolar retropositioning, without statistically significant differences between TB and BB groups • Increased retro-inclination of the upper incisors, with no differences between groups	NR	NR	• Posterior retropositioning of the upper lip and increased projection of the cheek area, with no statistically significant differences between TB and BB groups	NR
Nada 2013[36]	T1: 22 m	• An expansion at the level of the root apices of the first molars, without statistically significant differences between TB and BB groups	• An increase in nasal airway volume 2 years after SARPE, with no statistically significant differences between TB and BB groups	NR	• Nasal alar width increased; differences between TB and BB groups were not statistically significant	NR
Nada 2012[18]	T1: 22 m	• Expansion at the level of the root apices of premolars and molars, without statistically significant differences between TB and BB groups • Posterior alveolar expansion and anterior alveolar retropositioning, without statistically significant differences between TB and BB groups	NR	NR	• Posterior retropositioning of the upper lip and increased projection of the cheek area, with no statistically significant differences between TB and BB groups	NR
Gauthier 2011[19]	T1: 6 m	NR	NR	• A decrease in the BABT and BACL • An increase in the PABT • A tendency towards a decrease in the IACL on the mesial aspect of the central incisors	NR	NR

BABT, buccal alveolar bone thickness; BACL, buccal alveolar crest level; BB, bone-borne; CBCT, cone beam computed tomography; d, days; IACL, interproximal alveolar crest level; m, months; NR, not reported; PABT, palatal alveolar bone thickness; −PD, without pterygomaxillary dysjunction; +PD, with pterygomaxillary dysjunction; SARPE; surgically assisted rapid palatal expansion; TB, tooth-borne.

Table 6. Distribution of published articles on CBCT imaging and analysis of the maxillary changes after SARPE yielded by the PubMed (National Library of Medicine, NCBI), Cochrane Library, and Embase searches, performed on 31 January 2015 and updated in July 2016 and analysed in this systematic review.

Publication year	Number of publications
2011	1
2012	1
2013	2
2014	3
2015	1
2016	1

CBCT, cone beam computed tomography; SARPE, surgically assisted rapid palatal expansion.

and that wide variations in individual responses should be expected.[44] Another paper reported a small increase in the nasal floor width that ranged from 1.33 to 1.62 mm at 4 months after SARPE, with no difference between the TB and BB groups.[46] The final study provided information for 2 years after maxillary expansion and found an increase in nasal airway volume that ranged from 9.7% to 12.9%, with no difference between the TB and BB groups.[36]

Periodontal changes

Three publications assessed the periodontal effects of SARPE using CBCT[19,43,45] (Table 5). Reported effects included a decrease in the buccal alveolar bone thickness (BABT)[19,43,45] and alveolar crest level (BACL),[19,45] an increase in palatal alveolar bone thickness (PABT),[19] and a tendency towards a decrease in the interproximal alveolar crest level (IACL) on the mesial aspect of both central incisors.[19] The first molars were found to be the most affected teeth.[19] Sygouros et al. found a greater decrease in BABT and in BACL in the premolar area of the −PD group, suggesting that additional significant strain is put on the periodontal apparatus when pterygomaxillary dysjunction is not performed.[45] Kayalar et al. concluded that neither hybrid nor TB appliances involved any risk of periodontal damage to the molars.[43] Hybrid devices had significant benefits in terms of less tipping and reduced bone and tooth resorption.

Facial soft tissue changes

CBCT assessment of orofacial soft tissue changes after SARPE was reported by Nada et al. in three articles[17,18,36] (Table 5). Posterior repositioning of the upper lip (mean −1.25 mm) and increased projection of the cheek area (mean 1.66 mm) was found, with no differences between the BB and TB groups. These soft tissue variations were found to reflect the underlying dentoalveolar changes: alveolar posterior expansion and posterior displacement of the anterior alveolar region.[17,18] For every 1 mm of retraction in the middle alveolar region of the maxilla, a 0.88-mm retraction of the central part of the upper lip would be expected.[17] In addition, an alar width increase of 1.2 mm in the TB group and 1.4 mm in the BB group was found in one study,[36] but differences were not statistically significant.

Discussion

The efficacy of SARPE for the correction of a transverse maxillary deficiency in non-growing patients is widely acknowledged in the scientific literature.[1–28] Most studies evaluating transverse skeletal changes have been based on dental casts or conventional 2D radiographs.[4,16–19,21] Compared to this, 3D techniques may enable a more exact evaluation of dental and skeletal movement. In particular, CBCT has become an unprecedented technique for diagnosis and treatment follow-up in oral and maxillofacial surgery and orthodontics due to its non-invasiveness, high accessibility, high accuracy, and good resolution.[17–19,36] It allows the visualization of slices as well as 3D reconstructions like medical CT scanning, but with a lower radiation dose, easier access, shorter acquisition times, and lower costs.[18] In addition, when used in conjunction with the appropriate software, it permits the construction and superimposition of 3D models.[17]

These characteristics make CBCT an appropriate method to evaluate the maxillary anatomy. Consequently, while extensive literature on the analysis of SARPE with CT exists,[3–10,12–16,22,26,32–35,37] the number of publications based on CBCT evaluation has increased significantly during recent years (Table 6). Several studies have confirmed the accuracy and reliability of CT for quantifying transverse maxillary changes in surgical[4–7,21] and non-surgical rapid palatal expansion[47] and have confirmed adequate intra-observer and inter-observer agreement.[17,18,36,45,46]

The nine publications included in this systematic review were chosen on the basis of strict selection criteria and represent only a small proportion of the available literature on SARPE. Immediate postoperative changes in linear transverse maxillary dimensions were not evaluated in any of the selected papers. Three publications reported changes after expansion retention,[43,45,46] and three studies performed by the same study group evaluated changes after orthodontic treatment and prior to the second surgery.[17,18,36] No papers included in this systematic review studied long-term changes.

An increase in all transverse measurements was found systematically at the dentoalveolar and dental levels.[17,18,36,43,45,46] In one paper, a true anterior skeletal expansion was detected, with no differences between the −PD and +PD groups.[45] In another, a V-shaped expansion of the dentoskeletal structures was found in the coronal plane, with more expansion of the dental arch than the palatal bone and comparable changes obtained with TB and BB devices.[46] Reported findings after orthodontic treatment included anterior alveolar retropositioning, with comparable results in the TB and BB groups.[17,18,36] Outside of this systematic review, although transverse dimensions are reported to increase systematically, quite disparate skeletal results have been found. These discrepancies in results could be related to various technical factors as well as methodological weaknesses.

The transverse movement of the midpalatal suture after SARPE was a variable studied in only one of the selected articles.[42] An opening from the anterior to the posterior nasal spine was reported in most patients (85.7%), while an opening from the anterior nasal spine to the transverse palatal suture was observed in the remaining 14.2%. An association between a V-shaped opening and older age was suggested. Outside this systematic review, the midpalatal suture has often been studied with occlusal radiographs,[48,49] in which the evaluation of the posterior area of the midpalatal suture has been hindered by the overlapping of cranial structures. Conversely, 3D methods are not affected by any anatomical interference and enable perfect visualization of this region. These advantages have given way to a classification of midpalatal suture openings.[4,16]

It is important to point out that no consensus exists in the scientific literature regarding the dental and skeletal landmarks to be used when analysing SARPE. Researchers should make an effort to overcome this aspect in order to facilitate the integration of information. The systematic reporting of results would reduce reader confusion, enable unbiased comparisons between studies, and contribute to more robust conclusions.

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Likewise, there is no consensus regarding the best surgical technique and distraction device (TB or BB). Regarding the latter aspect, only a limited number of studies have directly compared the two types of device with long-term 3D imaging follow-up.[7–10,17,18] Within this systematic review, four papers provided information on dentoskeletal changes when a Hyrax device was used,[19,42,44,45] one article compared changes with Hyrax and hybrid devices[43], and four publications assessed and compared post-SARPE changes between TB and BB devices.[17,18,36,46] Although the information on dental and skeletal tipping was very limited, it seems clear that SARPE does not entirely eliminate tipping and extrusion of the anchorage teeth or tipping of the skeletal segments.[17,45] Outside this systematic review, more information in relation to dental and skeletal tipping is available. Some authors restrict BB expanders to patients with missing teeth or periodontal problems.[3–6,19,46] On the other hand, supporters of BB devices argue that fewer complications arise compared to TB distractors (root resorption, attachment loss, bony dehiscence, and loss of pulp vitality), more skeletal expansion is provided, no anchorage teeth are required, less periodontal damage and dental tipping occurs, and less relapse is to be expected.[9,11,13,14,20,22] Direct expansion forces onto the bone could lead to a genuine expansion of the bony basis, increasing the skeletal component of the expansion and reducing the negative side effects associated with TB devices.[12,14] Acknowledged drawbacks include the increased cost of the BB device, extended operating time, risk of distractor loosening, the fact that placing it parallel without injuring the premolar roots and controlling the direction of distraction may be difficult in some cases, and the necessity of a second operation to remove the device.[3] In conclusion, the lack of consensus regarding the type of distraction device calls for customized selection based on individual patient requirements.

In eight out of nine papers, pterygomaxillary dysjunction was performed during surgery.[17–19,36,42–44,46] Only one study compared postoperative effects in +PD and −PD groups.[45] The most frequently discussed technical aspects are related to the extent and number of the osteotomies required.[2,5,21] Although no definitive consensus exists, the most common design consists of a bilateral Le Fort I osteotomy associated with an inter-incisal vertical osteotomy and pterygomaxillary dysjunction.[1,4,17–19,36,45,46] However, there are some voices advocating not separating the pterygomaxillary suture because of the risk of intraoperative bleeding and fracture,[34,50] except in cases where the posterior portion of the maxilla is significantly constricted.[5,6] As with the type of distractor, the lack of scientific evidence suggests that the surgical technique as well as the location of the expander should be individualized based on patient age and the compression site.[8,16]

In five of the selected publications, patients were operated on under general anaesthesia.[17,18,36,42,43] The remaining articles did not specify this aspect. Information on postoperative complications was limited and was present in only one publication.[42] These complications were mild extrusion of a premolar, oedema, and haematoma. Outside this systematic review, general anaesthesia with hospital admission has been advocated for SARPE, the argument being that pterygomaxillary dysjunction is too traumatic to be performed under sedation.[3–6] Bays and Greco proposed local anaesthesia plus sedation for an ambulatory procedure, but only in cases where pterygomaxillary dysjunction was not needed.[51] Hernández-Alfaro et al. described a minimally invasive surgical technique that included PD, under local anaesthesia and sedation.[1,52] In general, SARPE has traditionally been associated with low morbidity.[48,50] The most commonly reported problems include pain, oedema, and palatal tissue irritation, although tooth damage and dental mobility can happen too.[3,6,8,10,13,26,50] Other events such as haemorrhage and aberrant fractures with the potential to injure the carotid artery or optic nerve can be considered anecdotal.[50]

Further technical aspects for which no consensus exists include intraoperative activation of the device,[45] latency period prior to expansion,[17,18,36,42,44–46] distraction rate,[17,18,36,42,43] the need for overcorrection,[17,18,36,44–46] the extent of the consolidation period after SARPE,[17–19,36,43,44,46] type of retention appliance used,[17–19,46] and the timing of orthodontic treatment after surgery.[17,18,36]

Simultaneous transverse enlargement of the maxillary apical base seems to modify the dimensions of the nose and the nasal cavity.[44,46] Nada et al. found an increase in nasal airway volume 2 years after SARPE with comparable results for TB and BB devices.[36] Pereira-Filho et al. reported that isolated maxillary expansion does not result in an improvement in the airway dimensions (area and volume), and wide variations in individual responses should be expected.[44] Finally, Zandi et al. reported only a small increase in the nasal floor width 4 months after SARPE, with no differences between TB and BB devices.[46] Outside this systematic review, inconsistent findings have been reported: an increase in nasal volume with great individual variability,[12,14] an increase in the nasal isthmus with a V-shaped opening,[26] and a clinically significant improvement in nasal airflow and breathing.[5,6,9,12–14]

Regarding the potential periodontal effects of SARPE, limited information is available. Within this systematic review, three publications evaluated this aspect using CBCT.[19,43,45] Buccal alveolar bone thickness and alveolar crest level decreased in most teeth after SARPE,[19,43,45] whereas palatal bone thickness increased.[19] A decrease in the interproximal alveolar crest level on the mesial aspect of both central incisors was also found.[19] It was found that the first molars were the teeth most affected during SARPE.[19] At any rate, SARPE seemed to have limited detrimental clinical effects on the periodontium. Sygouros et al. reported that additional significant strain is put on the periodontal apparatus when pterygomaxillary dysjunction is not performed.[45] Outside of this review, it was suggested that TB devices concentrate their force at the periodontal level thereby producing more vestibular bone resorption, whereas BB devices show minimal vestibular bone resorption.[9]

Facial soft tissue changes were assessed with 3D CBCT models by one study group.[17,18,36] Soft tissue findings were found to reflect the underlying dentoalveolar changes: alveolar posterior expansion and posterior displacement of the anterior alveolar region. The authors emphasized that following SARPE, slight retropositioning of the upper lip and increased projection of the cheeks is to be expected. There were no significant differences between the TB and BB groups. In addition, an alar width increase was found.[36] Outside this systematic review, Magnusson et al. demonstrated nose widening and an anteroinferior displacement of the whole nasomaxillary complex after SARPE.[33]

The results confirm that CBCT is an accurate and reliable method to assess anatomical changes, but there is no consensus regarding the ideal dental and skeletal landmarks that should be used. Further issues of discrepancy include the type of distraction device, surgical technique, latency period prior to expansion, distraction rate, need for overcorrection, length of the consolidation period, type of retention appliance, and starting point of orthodontic treatment after surgery. While SARPE results in a systematic increase in all transverse dimensions at the dentoalveolar and dental levels, the pattern and extent of expansion may be influenced by the type and location of the distractor, patient age, and surgical technique. This increase in all transverse measurements includes the base of the nose and nasal cavity, thereby modifying the dimensions of the upper airway. Soft tissue findings reflect the underlying dentoalveolar changes. Regardless of the distractor used, it seems that a certain degree of tipping and extrusion of the anchorage teeth and tipping of the skeletal segments can happen. While deleterious periodontal effects have been reported, especially at the buccal aspect of the alveolar bone of the first molars, these seem to be clinically irrelevant. Although this systematic review provides valuable preliminary information about the effects of SARPE, the low level of evidence of the publications retrieved, great heterogeneity among study groups regarding outcome variables and surgical–orthodontic protocols, and lack of long-term data call for careful data analysis and limit the conclusions that can be drawn. Researchers should make efforts towards performing well-designed randomized clinical trials, with systematized variable reporting and long-term follow-up, in order to help protocolize SARPE and allow unbiased comparisons between studies.

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