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Review

Stability and surgical complications of tooth-borne and bone-borne appliances in surgical assisted rapid maxillary expansion: a systematic review

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Abstract

The objective of this systematic review was to evaluate the stability and complications of tooth-borne (TB), bone-borne (BB) and hybrid (TB-BB) appliances in surgically assisted rapid maxillary expansion (SARME). Database searches were conducted (PubMed, Embase, Cochrane Library and SciELO), as well as a grey literature search (Google Scholar) and hand searches of reference lists. Forty-six articles were included after study selection ($\kappa = 0.854$). After eligibility assessment, 16 articles and one article from the grey literature were processed ($\kappa = 0.866$) and six articles were selected by hand searching, for a total of 23 articles included. Regarding stability, TB appliances showed width relapse rates ranging from 4 to 35% in canines, from 1 to 37% in premolars and from 0.2 to 49.5% in molars. In BB appliances, width relapse rates were 1.7-21% in canines, 1.5% in premolars and 4.6-11.5% in molars. In hybrid appliances, the width relapse rate was 14% in premolars, with a 1.8% overexpansion reported in the molar region. In TB and BB appliances, skeletal relapse rates were similar on the nasal floor (11-53% and 41.6%, respectively) and at the level of the maxilla (18% and 16%, respectively). The most common complications were bone resorption in TB appliances (18.14%) and appliance-related complications in BB appliances (17.9%). The risk of bias was high in 19 studies, medium in three studies and low in one study. The TB and BB appliances used in SARME were considered to have a high long-term stability. BB appliances appeared to have fewer relapses than TB appliances due to a more parallel distribution of forces exerted. However, relapse appears to be highly influenced by postorthodontic treatments, where arch-form coordination is achieved in the consolidation period

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with the purpose of overexpansion correction, alignment and final vertical adjustments. Further randomised controlled trials with long-term data and large sample sizes are needed to support evidence-based clinical decision-making and to allow meta-analytic studies of stability outcomes regarding the type of anchorage in SARME.

Keywords: Stability; relapse; complications; SARME; dentofacial deformity; systematic review

Introduction

Transverse maxillary deficiency is common among orthodontic-surgical patients, presenting with unilateral or bilateral cross-bites, narrow palatal vault, dental crowding and other functional problems, such as nasal resistance and impaired respiratory function.[1,2] Surgically assisted rapid maxillary/palatal expansion (SARME/SARPE) is the treatment of choice for many maxillofacial surgeons and orthodontists for adult patients with transverse maxillary deficiency.[3,4]

SARME requires surgical intervention in the bony buttresses by means of corticotomies in order to reduce bone resistance. The most traditional approaches are Le Fort I osteotomy with or without pterygomaxillary disjunction (PMD),[5] mid-palatal suture disjunction under general anaesthesia and the utilisation of an oral palatal distractor with bone-borne (BB), tooth-borne (TB) or hybrid (a combination of BB and TB) appliances.[6,7] In adults, SARME can result in undesirable skeletal side effects or postoperative dentoalveolar complex complications, particularly when a TB appliance is used; nevertheless, TB appliances are commonly used due to easy installation and handling.[8,9] On the other hand, some dental professionals prefer to use BB distraction appliances based on the rationale that they transfer the distraction forces directly to the palatal bone, thus enhancing palatal expansion.

Relapse is defined as the gradual recurrence of the abnormality for which distraction was performed.[10] To date, there is no consensus on the type of distractor anchorage to be used to maximise stability and minimise relapse in SARME procedures with minimal unwanted side effects in the treatment of maxillary atresia.

This review was developed to answer the following two specific questions: (1) Which type of distraction device provides the best stability in the postoperative period? (2) What are the main complications of distraction devices in SARME procedures? Therefore, the present systematic review aimed to evaluate skeletal and dental stability and complications related to TB, BB and hybrid distraction appliances in patients undergoing SARME and to evaluate the quality of information available in the literature.

Methods

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and the approval from the Research Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul, under ethics number SIPESQ:8446.

Studies were identified by searching MEDLINE (via PubMed), EMBASE, Cochrane Library and SciELO electronic databases from inception to January 2020 using the participants, interventions, comparators, outcomes and study design (PICOS) approach. The study sample consisted of patients with transverse maxillary deficiency and dentofacial deformities undergoing SARME. The intervention was SARME with TB appliances. The comparator group consisted of patients with BB and/or hybrid appliances for maxillary expansion. The outcomes were skeletal-dental net expansion, skeletal/dental width relapse and complications of TB/BB devices. All randomised and non-randomised intervention studies and longitudinal observational studies were included. No language or publication date restrictions were imposed. Boolean operators (OR, AND) were used to combine search terms related to anchorage devices' stability and complications.

Search strategy

Main search

A search strategy was developed for PubMed using medical subject headings (MeSH) terms and their entry terms as follows: [("Expansion Technique, Palatal" OR "Expansion Techniques, Palatal" OR "Palatal Expansion Techniques" OR "Technique, Palatal Expansion" OR "Palatal Expansion Technic" OR "Expansion Technic, Palatal" OR "Expansion Technics, Palatal" OR "Palatal Expansion Technics" OR "Technic, Palatal Expansion" OR "Maxillary Expansion" OR "" OR "Expansion, Maxillary") AND (("Recurrences" OR "Recrudescences" OR "Recrudescence" OR "Relapse" OR "Relapses") OR ("Complication, Postoperative" OR "Complications, Postoperative" OR "Postoperative Complication") OR ("associated disease" OR "coexistent conditions" OR "sequels" OR "concomitant disease" OR "sequelae" OR "associated conditions" OR "coexistent disease") AND "((tooth borne)" OR "(bone borne") OR ("hybrid appliance"))]

On EMBASE, the following Emtree terms were used: ('Dentofacial deformity'/exp OR 'dentofacial deformities' OR 'dentofacial deformity' OR 'dentofacial malformation' OR 'orthognathic surgery'/exp OR 'orthognathic surgery' OR 'orthognathic surgical procedures') AND ('palatal

expansion'/exp OR 'palatal expansion' OR 'palatal expansion procedure' OR 'palatal expansion technique') AND ('recurrence risk'/exp OR 'recidivation risk' OR 'recidivism risk' OR 'recurrence rate' OR 'recurrence risk' OR 'relapse rate' OR 'risk recidivism' OR 'risk, recurrence' OR 'complication'/exp OR 'complication' OR 'complications' OR 'stability'/syn).

The following search strategy was used for Cochrane Library: Palatal Expansion (MeSH descriptor) OR (dentofacial deformities) (MeSH descriptor) AND ((Recurrence) OR (Postoperative Complications)) OR ("bone borne" or "tooth Borne")).

On SciELO, the search was based on MeSH terms: ("Palatal expansion technique") AND ("recurrence" OR "Complication, Postoperative" OR "Complication, Intraoperative").

Grey Literature search

Google Scholar was searched using the following key words: ("palatal expansion technique" OR "SARPE" OR "SARME" OR "transpalatal distractor") AND ("bone-borne" OR "tooth borne") AND ("recurrence" OR "relapse" OR "Complication, Postoperative" OR "Complication, Intraoperative" OR "complications").

Hand search

The reference lists of the articles included through the main search were hand-searched for additional studies that had not been identified by the main search.

Study selection

One author (MEMP) conducted the systematic search. Two authors (MEMP and LSM) independently screened the titles and abstracts identified by the initial search and selected studies for full review if they met the following inclusion criteria: (1) intervention studies designed as retrospective or prospective clinical studies involving human subjects (randomised and non-randomised clinical trials, case-control studies and case series with sample size > 10); (2) studies that evaluated SARME stability; and (3) studies that reported postoperative complications resulting from the use of TB, BB or hybrid appliances in patients undergoing SARME. Disagreements between the two authors were resolved by consensus or by consulting a third experienced author for arbitration. Case reports, technical notes, in vitro studies, animal studies, review reports, studies involving syndromic patients and studies with follow-up and/or retention periods < 3 months were excluded. Cohen's kappa coefficient (κ) was used to assess inter-rater agreement in the screening of titles and abstracts.

Eligibility assessment

The same two authors (MEMP and LSM) assessed the selected articles for eligibility. To facilitate full-text reading, a standardised form was developed with the following inclusion criteria: (1) the research topic focuses on the use of TB, BB or hybrid appliances in SARME; (2) the study reports skeletal/dental width relapse; and (3) the study reports a controlled follow-up with cone-beam computed tomography (CBCT), computed tomography (CT), plain radiographs and/or dental study casts. For analysis purposes, surgical complications were categorised as dentoalveolar, skeletal, haemorrhage-related, nerve-related, appliance-related and other surgery-related.

Disagreements between the two authors were resolved by consulting other authors for arbitration. Studies that did not meet the eligibility criteria were excluded and the reason for exclusion was recorded. Cohen's kappa coefficient (κ) was also used to assess inter-rater agreement at this stage.

Data extraction

The same authors (MEMP and LSM) independently extracted the following data from the included studies for analysis: demographic data, methodological data, stability outcomes of final dental/skeletal width relapse and/or complications. Any discrepancies were resolved by consulting other authors for arbitration.

Risk of bias in individual studies

Methodological quality was assessed with a risk of bias scale used in a previous study by Haas Jr et al[11] to verify the strength of scientific evidence in clinical decision-making. The criteria used by those authors include randomisation of the sample, validation of measurements, statistical analysis, definition of inclusion and exclusion criteria, whether sample loss was reported in the postoperative period, comparative analysis of data between interventions and rater blinding.[11] A study was rated as having low risk of bias when all these items were checked, medium risk when one or two items were missing, and high risk when three or more items were missing.

First, both reviewers (MEMP and LSM) independently rated the quality of evidence. Then, they reported their ratings to each other and any discrepancies were resolved by discussion and consensus between the reviewers.

Results

Search strategy

The last database, grey literature and hand searches were run in January 2020. A flow diagram of each stage of the systematic review is shown in Fig. 1.

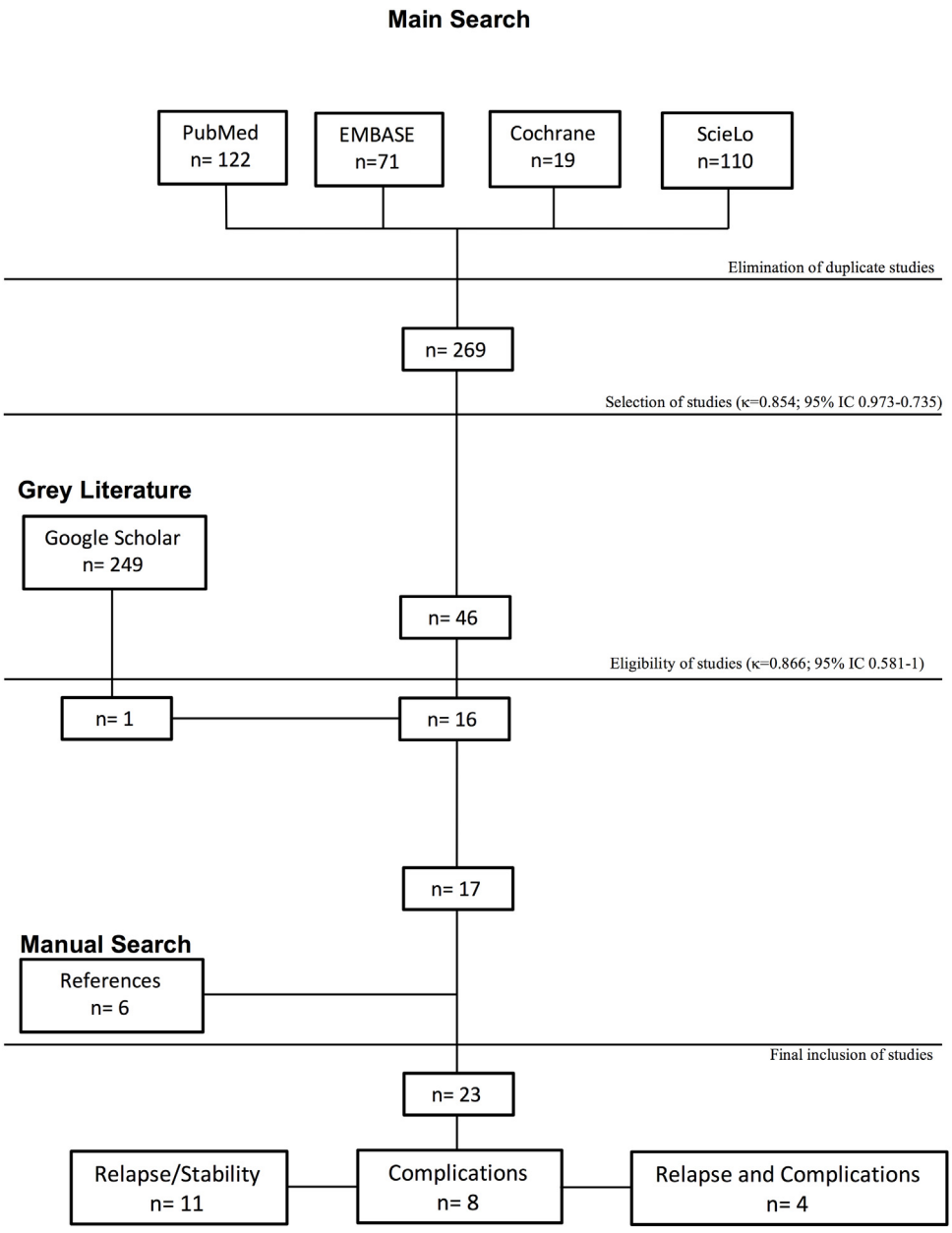


Fig. 1. Flow diagram of the systematic review.

Main search

A total of 122 articles were identified on PubMed, 71 on EMBASE, 19 on Cochrane Library and 110 on SciELO. After removal of duplicates, 269 studies were selected.

Grey literature

A total of 249 articles were identified on Google Scholar, of which one was selected through the eligibility assessment.[12]

Hand search

Six articles[2,13–17] were included in the final sample of the systematic review.

Study selection

After removal of duplicates, 269 articles remained for the screening of titles and abstracts. Of these, 47 were selected for full-text reading. Two corresponding authors were contacted for additional information on the study.[18,19] The inter-rater agreement in the screening of titles and abstracts for full-text reading was $\kappa = 0.854$ (95% confidence interval [CI] 0.973-0.735).

Eligibility of studies

The articles selected for full-text reading were blinded for title, abstract and authorship by a third author with no involve-

ment in the eligibility assessment process (OLHJ). The 46 articles selected by the main search plus the one found through the grey literature search[12] were then read in full by the two blinded authors (MEMP and LSM). Of these, 30 were excluded for the following reasons: 18 studies did not evaluate or report dental and/or skeletal width relapse;[18,20–36] five studies did not have the minimum follow-up period and/or minimum sample size and/or involved syndromic patients;[37–41] three studies did not perform SARME;[42–44] one study was not an intervention study;[45] two studies were not original studies (sample had been used in previous studies);[46,47] and one study did not specify the complications according to the type of anchorage device used.[48] As a result, at the end of the eligibility assessment stage, 17 studies were included in the systematic review. The level of inter-rater agreement in the eligibility assessment of the studies was $\kappa = 0.866$ (95%CI 0.581-1).

Demographic data extraction

The present systematic review included a total of 23 studies, of which 16,8,19,49–62 were identified through the main search, one [12] through the grey literature search and six [2,13–17] through hand searching. The studies were divided according to their outcomes as follows: 11 articles[12,13,15–17,19,50,55,56,58,60] reporting relapse/stability; eight articles[8,49,51–54,61,62] reporting complications; and four articles[2,14,57,59] reporting relapse and complications. The studies were, for the most part, retrospective in nature or non-randomised prospective studies; only two studies[59,60] were randomised controlled trials. The included studies enrolled a total of 649 patients who underwent SARME for transverse maxillary correction. Most patients were women, and mean patient age ranged from 11 years[8] to 59 years.[13] A TB appliance was used in 71.80% (n = 425) of cases, while a BB or hybrid appliance was used in 28.19% (n = 183) of cases (Table 1).

Analysis of stability

Width relapse

Methods used for analysis included measuring dental casts with a calliper,[2,13–17,19,50,56–60] dental scanning with specialised computer software,[55] CBCT,[60] examining dental casts with a three-dimensional reflex microscope[12] and anteroposterior (AP) radiographs.[15,17,19] A total of 295 patients with TB appliances and 45 patients with BB appliances (52.38% of the total sample included in the systematic review) were assessed for postoperative stability.

For maxillary distraction, the studies followed protocols for activation at the time of surgery that ranged from no activation[55] to 3 mm.[16] The latency period ranged from one day[14,16] to seven days.[13,19,57,59] The activation rates ranged from 0.5 to 1 mm per day, and the consolidation period ranged from two months[19] to six months.[14] The mean time required for expansion during the activation period ranged from 1.5 weeks[50] to 3.5 weeks[13] (Table 2).

Width expansion and relapse of TB appliances

In patients undergoing SARME with TB appliances, canine expansion ranged from 3.24 ± 2.97 mm[16] to 8.20 ± 3.08 mm,[12] while canine width relapse ranged from -0.20 ± 2.1 mm[13] to -2.83 ± 1.9 mm.[19] Expansion in the premolar region ranged from 5.82 mm^2 to 9.8 ± 2.7 mm,[55] while width relapse in the premolar region ranged from -0.04 ± 0.20 mm to -2.02 ± 2.37 mm.[15] Also, a width gain of 1.1 ± 2.5 mm was reported.[59]

Maxillary expansion measurements in the molar region ranged from 5.4 ± 4.55 mm[55] to 9.6 mm,[17] while width relapse measurements ranged from -0.02 ± 1.1 mm[12] (first molar) to -3.64 ± 1.98 mm[19] (second molar). Width gains from 0.6%[55] to 6%[58] were reported in the molar region (Table 3) (Graph 1).

The skeletal width relapse due to TB appliances was reported in 5 studies.[15,17,19,59,60] Expansion measurements ranged from 1.82 ± 1.61 mm[19] to 2.6 ± 1.8 mm[59] on the nasal floor and from 1.02 ± 2.1 mm[60] to 7.7 mm[17] at the level of the maxilla. Relapse measurements ranged from 0.22 ± 1.46 mm[19] to -1.4 ± 1.4 mm[59] on the nasal floor and from 0.1 ± 0.21 mm[60] to -0.24 ± 2.7 mm[15] at the level of the maxilla (Table 3) (Graph 3).

Width expansion and relapse of BB and hybrid appliances

In patients undergoing SARME with BB appliances, canine expansion ranged from 6.0 ± 3.4 mm[59] to 8.8 mm,[57] while canine relapse ranged from -0.15 mm[57] to -1.3 ± 3.2 mm.[59] In the premolar region, expansion was 7.0 ± 3.1 mm[59] and relapse was -0.1 ± 2.5 mm.[59] In the molar region, expansion ranged from 5.3 ± 3.4 mm[59] to 8.3 mm[57] and width relapse ranged from -0.35 mm[57] to -0.6 ± 1.5 mm[59] (Graph 2).

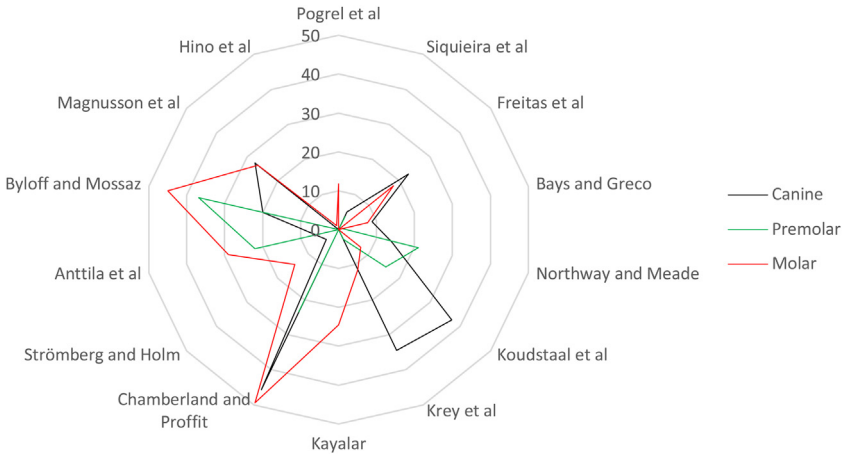
Mean skeletal expansion due to BB appliances was 3.1 ± 2.4 mm[8] at the level of the maxilla and 2.4 ± 1.9 mm[8] on the nasal floor. The mean relapse measurement was -0.5 ± 0.8 mm[8] at the level of the maxilla and -1.0 ± 0.9 mm[8] on the nasal floor (Table 3) (Graph 4).

In patients with hybrid appliances,[60] mean total expansion was 4.74 ± 0.79 mm[60] and relapse was -0.7 ± 0.48 mm[60] in the premolar region. In the molar region, mean total expansion was 6.13 ± 1.62 mm[60] and relapse was 0.11 ± 1.95 mm,[60] representing a width gain of 1.79%. Skeletal changes due to hybrid appliances were 3.75 ± 1.15 mm[60] in the anterior maxilla and 1.93 ± 2.92 mm[60] in the posterior maxilla. Relapse was 0.27 ± 0.94 mm[60] in the anterior maxilla (representing a 7.2% width gain due to skeletal treatment changes) and -0.3 ± 1 mm[60] in the posterior maxilla (representing a 15.54% loss due to skeletal treatment changes) (Table 3) (Graph 4).

Table 1
Demographic data for the studies included.

Author	Year published	Type of study	Sample size per type of anchorage	Age, years (Range)	Gender and no.	Follow-up period (months)
Pogrel M.A et al [A]	1992	RCS	TB-h: 12	16-32	F: 8; M :4	6-12
Siqueira D. et al [A]	2015	RCS	TB-h: 18	23.3(18-35)	F: 12; M: 6	6
Freitas R.R et al [A]	2008	PCS	TB-h: 20	24.5(20-45)	F: 15; M:5	12
Gerlach, K. [A]	2003	PCS	BB-t: 10	25.8(12-37)	F: 9; M:1	6
Northway & Meade[A]	1997	PCS	TB-h: 16	25.97(17.0-35.3)	F: 10; M: 6	>12
Koudstaal M.J et al [A,B]	2009	RCT	TB-h: 21	25(16-44)	M: 13/ F:8	12
			BB-t/r: 25	33(16-50)	M: 10/ F:15	
Krey K.F et al [A]	2008	PCS	TB-h: 31	>18	NS	3
Kayalar E. et al [A,B]	2015	RCT	TB-h: 10	19.3	M:6 / F: 4	6
			BB-h: 10	19.2	M:3 / F: 7	
Chamberland & Proffit. [A]	2011	PCS	TB-s: 38; 30(at follow-up)	(15-54)	M: 19; F:19	15.2 ± 5.1
Bays & Greco [A,B]	1992	PCS	TB:19	30.2(21.2-39.2)	M: 3; F:17	24 ± 15.6
Strömberg C et al [A]	1995	PCS	TB: 20	36.3 (18-59)	M: 11; F: 9	36(7-96)
Anttila A et al [A]	2004	RCS	TB: 20; 15 (at follow-up)	30.6 (16.2-44.2)	M:6; F: 14	70.8 (37.2-138)
Hino C et al [A]	2008	PCS	TB-h: 19	27.5 (18-37)	NS	4
			TB-Hs: 19	29 (19-39)	M: 9/ F: 10	
Magnusson A et al [A]	2009	PCS	TB-h: 31	25.9 (15.7-48.9)	M: 17; F: 14	76.8 ± 39.6
Byloff & Mossaz[A]	2004	PCS	TB-h: 14	27.2 (18.6-41.8)	M: 11; F: 3	12
Laudemann K et al [B]	2010	RCT	TB:16	>13/<55	NS	20+-1.34
			BB: 18			
Dergin G [B]	2015	RCS	TB:60	17-26	M: 37; F: 23	3
Verquin M et al [B]	2017	RCS	TB: 55	13-47(22)	M: 20; F: 35	1
Neyt N. et al [B]	2002	RCS	BB: 57	18(11-43)	M: 25; F: 32	6
Ramieri G.A et al [B]	2005		BB:29	26.4	M: 8; F:21	12
Günbay T. et al [B]	2008	PCS	BB: 10	22.3(18-26)	M: 6; F:4	2-3
Landes C.A et al [B]	2009	RCS	TB: 26	(13-50)	NS	
		PCS	BB: 24			
Gauthier C. et al [B]	2011	PCS	TB: 14	23.0 (16.4-39.7)	M: 5; F: 9	6

RCT: randomised clinical trial; PCS: prospective clinical study; RCS: retrospective clinical study; TB-h: Tooth-Borne Hyrax; BB-t: Bone-Borne TPD (Transpalatal Distractor); BB-t/r: Bone-borne TPD/RPD(Rotterdam Palatal Distractor); BB-h: Hybrid Bone-borne; TB-s: Tooth-Borne Superscrew Super-Spring. TB-Hs: tooth-borne Haas; F: Feminine; M: Masculine; NS: not specified; (A): Stability analysis; (B): Complication analysis. NR: not reported; NI: not informed; NE: not evaluated



Graph 1. Distribution of dental width relapse percentages of TB appliances in the systematic review.
Siqueira et al. reported a molar width gain of 1% (not represented graphically).
Northway & Meade reported a molar width gain of 6% (not represented graphically).
Kayalar et al reported a premolar gain of 2.6% (not represented graphically).

Table 2
Relapse measurements methods and maxillary expansion protocols of the included studies.

Author and year	Type of measurement method	Methodology for width measurement	Maxillary Expansion Protocols	Average time needed for expansion (weeks)
Pogrel M.A et al, 1992	Caliper on Dental casts	It was measured on molar region with a caliper.	ETOS: 1 mm. AR: twice daily, until desired expansion achieved.	1.5-3.5
Siqueira D. et al 2015	Dental cast scanning (D-250, 3Shape)	Dental casts were scanned with a 3D scanner (D-250, 3Shape, Copenhagen, Denmark). Linear measurements were taken by means of Geomagic Studio 5^{TM} (Research Triangle Park, USA)	ETOS: No activation. LP:3 days. Twice daily activations until desired correction, no OC. CP: 3 months.	NS
Freitas R.R et al 2008	Starret digital millimetric caliper model 727	The measurements were made in millimeters, with a Starret digital millimetric caliper model 727	ETOS: NS. 2.0 mm (10 activations) at TOS. LP: 2 days 4 daily (0.4 mm morning-0.4 mm afternoon) activations(0.8 mm) until planned expansion. CP: 6 months.	2
Gerlach, K.et al, 2003	Plaster casts and caliper	Dental casts for width measurements of ICD, ADA and PDA.	ETOS: NS. LP: 7days. AR: 0.4 mm/day with two screw turns per day. CP: 3 months. Distraction until cross-bite completely corrected	3
Northway & Meade. 1997	Dial caliper with dental casts	Transverse width of canines' cusp tips or most labial surface and the mesiolingual cusp tips and buccal groove of first molars	NS	NS
Koudstaal M.J et al 2009	Dental casts, Plane radiographs and dicom-data program Easy-ViewWeb (2005, PhilipsMedi-cal systems, Best, Netherlands).	Measurements of dental casts with an electronic digital caliper (kraftixx®, art. 0906-90) with an accuracy of 0.02 mm. Landmarks: cusp of canine, tip of buccal cusp of premolar and tip of disto-buccal cusp of first molar to measure arc width. Skeletal widening was measured with PA cephalograms.	ETOS: NS. LP: 1week. AR: 1 mm/day, until desired expansion was obtained. CP: 3months.	NS
Krey K.F et al 2008	3-dimensional reflex microscope on dental casts	Casts measured with a reflex microscope. The x-, y- and z- coordinates are monitored continuously by linear encoders and can be stored on command in the computer (C3D software, Reflex Measurement Ltd., London, UK)	ETOS: eight quarters: 1.92 mm. AR: 2 daily activations,0.48 mm daily.. LP: NS. CP: 3 months.	NS
Kayalar E. et al 2015	CBCT	On scanned CBCT images, measurements were made at the width between the buccal cusp tips of the first premolars and first molars. Scanora 3D; Soredex, Tuusulu, Finland). Subsequent scans were taken with a voxel size of 0.25 mm, at 12.5 mA, with a field of view (FOV) of 14.5 cm, and following a low-dose protocol with 90 kVp instead of the standard CT setting of 120 kVp. Measurements were made using Mimics 16.0 (Materialise, Belgium)	ETOS: 1 mm. AR: 2 turns per day, 0.25 mm per turn. LP: NS. CP: 6months.	2

Table 2 (*Continued*)

Author and year	Type of measurement method	Methodology for width measurement	Maxillary Expansion Protocols	Average time needed for expansion (weeks)
Chamberland & Proffit. 2011	Dental casts and plane posteroanterior radiographs, measurement of dental casts with a digital caliper	Inter-canine width was measured in the cusp tip, Inter-premolar width was measured in the mesial fossa, inter-molar was measured in the central fossa	ETOS: NS. LP: 7 days. 0.25, twice daily. CP: 2months.	2-3
Bays & Greco, 1992	Caliper on dental casts	From occlusal pit to occlusal pit in posterior teeth and for the canine, the height of contour of the most distobuccal surface.	ETOS: 1.5-2.0 mm. LP: 5 days. AR: Quarter turns per day until desired expansion is achieved. CP: NS. No OC needed.	NS
Strömberg C et al, 1995	Caliper on dental casts	Shortest distance at the gingival margin between the first upper molars and between the canines.	ETOS: NS. LP: 7days. AR: 0.25 mm per day until desired expansion.	3.5
Anttila A et al, 2004	Digital sliding caliper	Measurements from dental canine cusps, palatal premolar cusps and the mesiopalatal cusps of the molars	LP: 1 day. ETOS: 3-6 turns until minor diastema between central incisors. AR: 0.5 mm/day (two turns daily). CP: 6 months.	3(2-7)
Magnusson A et al, 2009	Dental models	Direct measurements were made with a digital caliper (model Mitutoyo 500-171, Kanawaga, Japan) to the nearest 0.01 mm. Two Reference points were taken at the cusp tips of the canines and the most prominent cervical point of the palatal ridge, and on the first molars, it was measured between the mesiobuccal cusp tips and between the most cervical point of the palatal fissure	ETOS: 3 mm (12 turns). LP: one day. AR: one turn twice a day, 0.5 mm/day. An overexpansion of half a cusp width bilaterally was achieved.	NS
Byloff & Mossaz, 2004	Models, occlusal radiographs, PA radiographs,	Using a dial caliper, measuring to 1/1000 mm, it was measured the distances between canine cusp tips, the premolars and molars (occlusal crown center) on dental casts. On PA radiographs, a midline reference point was determined on the line connecting each orbit at the intersection between the greater wing of sphenoid and the inner cortex of the orbit at the landmark described as latero-orbitale. From the midline, two perpendicular lines were drawn 5 mm above the inserted pin and were measured to monitor skeletal expansion.	ETOS: four quarter turns (1 mm). LP: 3 days. AR: one quarter turn per day until necessary amount of expansion.	3-5
Hino C et al, 2008	Dental casts and PA x-rays.	On PA radiographs and plaster orthodontic models, linear measurements were obtained with a digital caliper (Mitutoyo) of 0.01 mm precision.	ETOS: 1.6 mm. LP: 4 days. AR: 2 quarter turns per day. (twice a day), corresponding 0.4 mm of daily expansion, until necessary expansion, but it was over-expanded 2 mm at molar region. RP: 4 months.	NS

ETOS: Expansion at Time of surgery; LP: Latency period; AR: Activation rate; OC: Over-correction; RP/CP: Consolidation period; BB: Bone- Borne; TB: Tooth-Borne; TPD: Transpalatal Distractor; ICD: inter-canine dental width; ADA: anterior dental width; PDA: posterior dental width; NS: not specified; PA: Posterior-anterior; CBCT: cone beam computer tomography. FOV: Field of view.

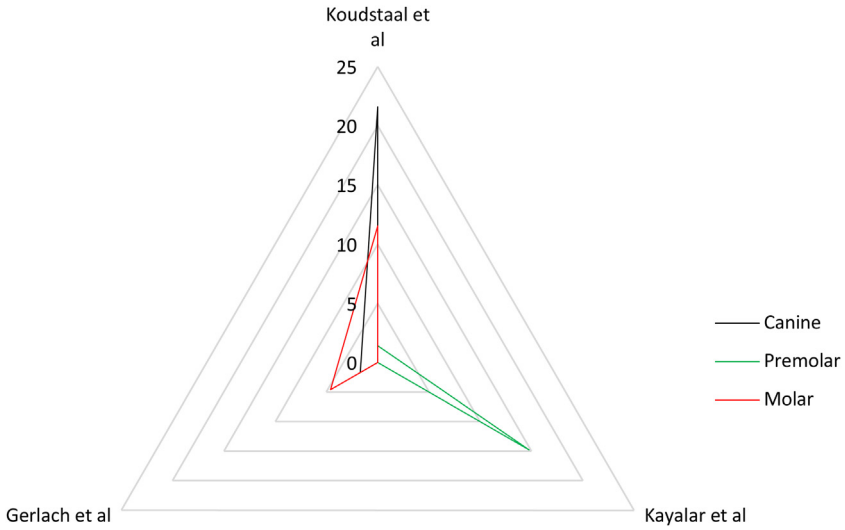
Table 3
Analysis of width stability/relapse as the outcome of the included articles.

Author and year	Type of anchorage and *n*	Method of analysis	Dental width relapse (mm), SD, (%) from TxC			Skeletal width relapse (mm), SD, (%) from TxC		Dental treatment changes (mm), SD			Skeletal treatment changes(mm),SD	
			Canine	Premolar	Molar	Nasal floor	Maxilla level	Canine	Premolar	Molar	Nasal floor	Maxilla level
Pogrel M.A et al, 1992[50]	TB-h: 12	Dental casts and caliper.	NE	NE	−0.88 ± 0.48 (11.73%)	NE	NE	NE	NE	7.50	NE	NE
Siqueira D. et al, 2015[55]	TB-h: 18	Dental cast scanning (D-250, 3Shape)	−0.29 ± 0.16 [5%] [a]	−0.35 ± 0.28 [3.7%] [a] (1st premolar) -0.04 ± 3.12 (0.5%) *[a] (2nd premolar)	0.06 ± 0.45 (0.6%) [a] (1st molar) -0.03 ± 4.62 (0.55%)[a] (2nd molar)	NE	NE	5.87 ± 2.40	9.8 ± 2.7 (1st premolar) 9.49 ± 3.14 (2nd premolar)	9.26 ± 4.19 (1st molar) 5.4 ± 4.55 (2nd molar)	NE	NE
Freitas R.R et al, 2008[56]	TB-h: 20	Starret digital millimetric caliper model 727	−1.69 ± 0.31 [23%] [b]	NE	−1.48 ± 0.2 (18%) [b]	NE	NE	7.22 ± 3.0	NE	8.06 ± 3.06	NE	NE
Gerlach and Zahl, 2003[57]	BB-t: 10	Plaster casts and caliper	−0.15 (1.7%) [a]	NE	−0.35 (4.6%) [a]	NE	NE	8.8	NE	8.3	NE	NE
Northway and Meade, 1997[58]	TB-h: 16	Dial caliper with dental casts	−0.47 ± 0.6 [14%] [b]	NE	0.14 ± 1.1 [6%] [b]	NE	NE	3.45 ± 2.1	NE	5.5 ± 2.9	NE	NS
Koudstaal M.J et al, 2009[59]	TB-h: 21 BB-t/r: 25	Dental casts, Plane radiographs	TB: -2.2 ± 3.8* (37.2%) [b] BB: -1.3 ± 3.2* [21.6] [b]	TB: 1.1 ± 2.5 [15.49%] [b] BB: -0.1 ± 2.5* [1.42%] [b]	TB: -0.5 ± 1.8 [7.35%] [b] BB: -0,6 ± 1.5 [11.53%] [b]	TB: -1.4 ± 1.4*[b] (53,84%) BB: -1.0 ± 0.9*[b] (41,6%)	TB: -0.4 ± 1.3[b] (12.90%) BB: -0.5 ± 0.8*[b] (16%)	TB: 5.9 ± 3.6* BB: 6.0 ± 3.4*	TB: 7.1 ± 3.5* BB: 7.0 ± 3.1*	TB: 6.8 ± 2.9* BB: 5.3 ± 3.4*	TB: 2.6 ± 1.8* BB: 2.4 ± 1.9*	TB: 3.1 ± 2.0* BB: 3.1 ± 2.4*
Krey K.F et al, 2008[12]	TB-h: 31	3-dimensional reflex microscope on dental casts	−2.83 [34.51%][c]*	−0,04 ± 0.20[c]* [0,48%] (1st premolar) - 0.23 ± 0.07[c]* [2.8%] (2nd premolar)	−0,02 ± 0.19[c]* [0,23%] (1st molar) - 0.68 ± 0.05[c]* [11.5%] (2nd molar)	NE	NE	8.20 ± 3.08*	8.22 ± 2.77* (1st premolar) 8.20 ± 4.22* (2 premolar)	8.37 ± 3.49* (1st molar) 5.87 ± 5.07* (2nd molar)	NE	NE
Kayalar E. et al, 2015[60]	TB-h: 10 HB-h: 10	CBCT	NE	TB: 0.16 ± 1.33 [2.6%][c] (1st premolar) HB: -0.7 ± 0.48* [14.76%][c] (1st premolar)	TB: -0.32 ± 1.31 [24.49%][c] (1st molar) HB: 0.11 ± 1.95 [1.79%][c] (1st molar)	NE	TB: AM -0,25 ± 1.9 (5.45%) PM 0.1 ± 0.21 (9.80%) HB: AM 0.27 ± 0.94 (7.2%) PM -0.3 ± 1 (15.54%)	NE	TB: 6.13 ± 1.47* (1st premolar) HB: 4.74 ± 0.79 (1st premolar)	TB: 7.12 ± 1.75* (1st molar) HB: 6.13 ± 1.62 (1st molar)	NE	TB: AM 4.58 ± 1.8* PM 1.02 ± 2.1 HB: AM 3.75 ± 1.15* PM 1.93 ± 2.92

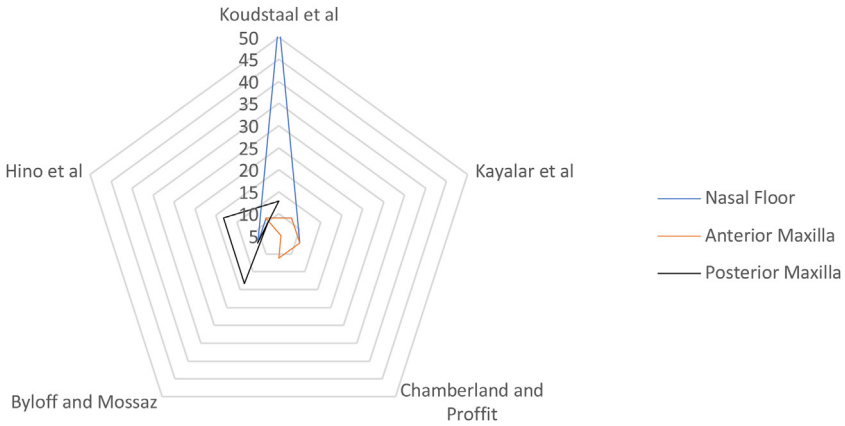
Table 3 (*Continued*)

Author and year	Type of anchorage and *n*	Method of analysis	Dental width relapse (mm), SD, (%) from TxC			Skeletal width relapse (mm), SD, (%) from TxC		Dental treatment changes (mm), SD			Skeletal treatment changes(mm),SD	
			Canine	Premolar	Molar	Nasal floor	Maxilla level	Canine	Premolar	Molar	Nasal floor	Maxilla level
Chamberland and Proffit, 2011[19]	TB-s: 30	Dental casts and plane radiographs	-2.60 ± 1.9^{b}* [45.7%]	-1.787 ± 2.239^{b} [23.47%] (1st premolar) -1.65 ± 2.4^{b} [21.04%] (2nd premolar)	$-1.832 \pm 1.834^{b,}$* [24.11%] (1st molar) -3.64 ± 1.98^{b}* [49.45%] (2nd molar)	0.223 ± 1.462& (11.1%)	-0.035 ± 1.556& (1%)	5.69 ± 2.03*&	7.61 ± 1.86* (1st premolar) 7.86 ± 1.86* (2nd premolar)	7.60 ± 1.57* (1st molar) 7.36 ± 1.85* (2 ns molar)	1.82 ± 1.61*&	3.58 ± 1.63*&
Bays and Greco,1992[2]	TB: 19	Dental casts	-0.39 ± 0.79^{b} [8.8%]	0.064 ± 1.0 [1%] [b]	-0.45 ± 0.69^{b} [7.7%]	NE	NE	4.89	5.82	6.23	NE	NE
Strömberg and Holm, 1995[13]	TB: 20	Dental casts	-0.2 ± 2.1^{b} [4.08%]	NE	-1.2 ± 1.3^{b} [14.45%]	NE	NE	5.0 ± 2.2	NE	8.3 ± 2.6	NE	NE
Anttila A et al, 2004[14]	TB: 15 (12 at follow-up for stability)	Dental casts	-0.5^{b} [6%]	-0.7^{b} [12%] (1st premolar) -1.5 [22%] (2nd premolar)	-1.3*[b] [21%] (1st molar) -1.4*[b] [29%] (2nd molar)	NE	NE	NS	NS	NS	NE	NE
Byloff and Mossaz, 2004[15]	TB-h:14	Dental casts and PA radiographs	-0.94 ± 2.3^{b} [20%]	-2.02 ± 2.37^{b} [36.86%] (1st premolar) -1.38 ± 2.7^{b} [20.14%] (2nd premolar)	-2.62 ± 1.8^{b} [45.01%] (1st molar) -1.48 ± 0.98^{b} [36.81%] (2nd molar)	NE	-0.24 ± 2.7 (18.32%)	5.19 ± 2.28	8.08 ± 1.78 (1st premolar) $8,26 \pm 2.48$ (2nd premolar)	8.73 ± 2.49 (1st molar) 5.48 ± 2.53 (2nd molar)	NE	1.31 ± 3.03
Magnusson A et al, 2009[16]	TB-h: 31	Dental casts	-0.89 ± 2.95^{b} [27.46%]	NE	-1.54 ± 3.63^{b} [26.55%]	NE	NE	3.24 ± 2.97*	NE	5.80 ± 3.73*	NE	NE
Hino C et al, 2008[17]	TB-h: 19 TB-Hs: 19	Dental casts and PA x-rays.	NE	NE	TB-h: -0.1*[c] [1.12%] TB-Hs: 0.0[c] [0%]	NE	TB-h: -1.4 (18.18%)[c] TB-Hs: -0.80 (10.38%)[c]	NE	NE	TB-h: 8.9 TB-Hs: 9.6	NE	TB-h: 7.70 TB-Hs: 7.7

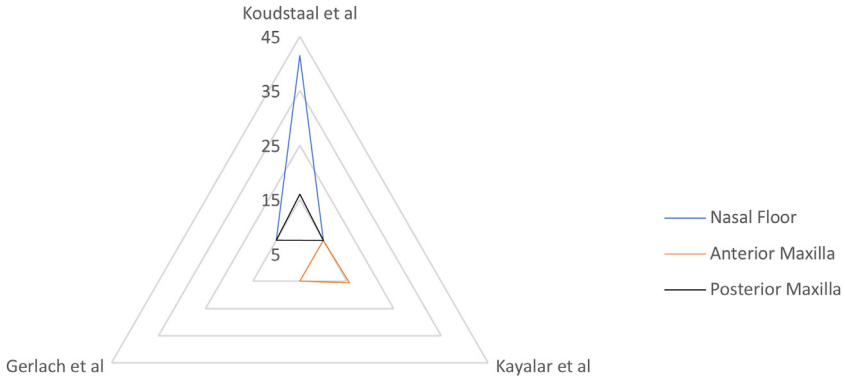
[a]6-month follow-up; [b]≥12-month follow-up; [c]6 < x ≥ 3month follow-up. Negative Values: Loss of width; Positive Values: Gain of width; CBCT: Cone Beam Computed Tomography; PA x ray: posterior-anterior radiograph; NS: Not specified (*): Statistically significant; TB-h: Tooth-Borne Hyrax; TB-Hs: tooth-borne Haas; BB-t: Bone-Borne TPD (Transpalatal Distractor); BB-t/r: Bone-borne TPD/RPD(Rotterdam Palatal Distractor); BB-h: Hybrid Bone-borne ; TxC: treatment change. AM: anterior maxilla; PM: posterior maxilla. PA: Posterior-anterior. (&): data consulted to the author. NE: not evaluated; NS: not specified.



Graph 2. Distribution of dental width relapse percentages of BB appliances in the systematic review. Kayalar et al. reported a molar gain of width of 1.79% (not represented graphically).



Graph 3. Distribution of skeletal width relapse percentages of TB appliances in the systematic review. Chamberland & Proffit, reported a width gain of the nasal floor gain of 11%.



Graph 4. Distribution of skeletal width relapse percentages of BB appliances in the systematic review. Kayalar et al compared a TB vs HB device.

Table 4
Type of anchorage and complication data for the studies included.

Author and year	Type of anchorage and *n*	I					II	III	IV	V	VI						Total
		Tooth Discoloration /Absence of thermal sensitivity	Bone Resorption	Root Exposure or root blunting	Loss of Attachment/> probing/ gingival recession	Tooth Mobility	Asymmetric Expansion	Nasal Bleeding	Nerve Damage	Appliance related	Pain	Infections	Hematoma	Oro-nasal fistula	Lacrimation	Other	
Gerlach K et al 2003	BB: 10			1										1			2
Koudstaal M.J et al, 2009	TB:21	1															1
	BB: 25						2										2
Bays & Greco, 1992	TB: 19							1									1
Anttila et al, 2004	TB: 15		1	1						1						1(palatal irritation)	4
Laudemann et al, 2010	TB: 16				16												16
	BB: 18				18 [a]												18
Dergin et al, 2015	TB: 60							12			15				5	1 (Tinnitus)	33
Verquin et al, 2017	TB: 55	1		2		2	3	5	16	3	4		2			1 (Iatrogenic gastric bleeding) 4 (Nausea and vomiting)	43
Neyt et al 2002	BB: 57							1	1	19		2	3			3 (Palatal ulceration)	29
Ramiere et al, 2005[c]	BB: 29				1	2				10						9 (palatal ulceration) 4(unfavorable fracture line	26
Günbay et al, 2008	BB: 10					2	1	2		2	3					1 (Wound dehiscence)	11
Landes et al, 2009	TB: 26		26[b]														26
	BB: 24		24														24
Gauthier et al, 2011	TB: 14		14		11	6											31
N patients with complications as outcomes of the systematic review	TB: 226	2 (0.88%)	41 (18.14%)	3 (1.32%)	27 (11.94%)	8 (3.5%)	3 (1.32%)	18 (7.96%)	16(7.07%)	4 (1.76%)	19 (8.04%)	0	2 (0.88)	0	5 (2.21%)	7 (3.09%)	155 (68.58%)
	BB: 173	0	24 (13.87%)	1(0.57%)	19 (10.9%)	4 (2.31%)	3 (1.73%)	3 (1.73%)	1 (0.57%)	31 (17.91%)	3 (1.73%)	2 (1.15%)	3 (1.73%)	1 (0.57%)	0	17 (9.82%)	112 (64.73%)

The classification of complications is organized by: I. Dentoalveolar, II. Skeletal, III. Hemorrhage related, IV. Nerve related V. Appliance-related VI. Other.

[a] Greater overall attachment loss was observed in BB devices.

[b] Greater vestibular resorption occurred in the 1st and 2nd premolars in TB appliances.

Analysis of TB/BB Surgical Complications

Twelve studies[2,8,14,49,52–54,57,59,61,62] were assessed for outcomes of SARME procedures with TB and/or BB appliances, including a total of 399 patients (61.4% of the total sample included in the systematic review). Of these, 226 patients received TB appliances (56.6%) and 173 patients received BB appliances (43.3%). For analysis purposes, complications were categorised as dento-alveolar, skeletal, haemorrhage-related, nerve-related, appliance-related and other (Table 4).

The most common complications were bone resorption[14,53,54] in TB appliances (18.14% of all TB complications) and appliance-related complications[8,51,52] in BB appliances (17.91% of all BB complications) (Graph 3). Two complications were most commonly reported: appliance-related complications, accounting for 1.76%[14,49] of all TB complications and 17.91%[8,51,52] of all BB complications; and nasal bleeding, accounting for 7.96% of all TB complications[2,49,62] and 1.73% of all BB complications.[8,52] The least common complication was tinnitus, reported only in one study[62] (Fig. 2).

In BB appliances, no cases of tooth discoloration or lacrimation were reported. In TB appliances, no cases of infection or oro-nasal fistula were reported. Gauthier et al[54] reported the highest rate of patients with complications: 31 events in 14 patients analysed with TB appliances, resulting in a mean of 2.2 complications per patient. These complications included bone resorption, tooth mobility and gingival recession and/or loss of attachment. Koudstaal et al[59] reported the lowest prevalence of patients with complications, with one complication in 21 patients (4.76%) who received TB appliances and two complications in 25 patients (8%) who received BB appliances.

Assessment of methodological quality

The risk of bias was considered high in 19 studies,[2,8,12–17,19,49–52,54–58,62] medium in three studies,[53,59,61] in which the criteria for quality assessment related to sample randomisation, comparison between treatments and blind assessment were missing, and low in one study[60] (Table 5).

Discussion

Transverse skeletal expansion is considered the least stable and predictable treatment in patients with maxillary atresia.[63] Segmental maxillary and conventional Le Fort I osteotomies are used to correct transverse deformities in mature patients, with SARME being one of the most stable and commonly used procedures.[6]

The use of TB and BB appliances has been introduced in SARME to achieve maxillary expansion[64,65]. Several studies have evaluated the stability, technique, expansion protocols and complications of these appliances,[2,21,49–51,57–59] and a recently published systematic review and meta-analysis has investigated which appliance provides more skeletal and dental expansion.[66] However, there is still no consensus on which appliance has the best outcomes in terms of less dental and skeletal relapse and fewer complications in the postoperative period.[59]

A comprehensive search strategy[67] was used in this systematic review, prioritising sensitivity over specificity by using the highest level of evidence available. Following the purpose of the study, and since "SARME stability", "tooth-borne stability" and "bone-borne stability" are not listed as MeSH or Emtree terms, a combination of "palatal expansion technique", "recurrence", "complication, postoperative" and their appropriate entry terms were further combined with "tooth-borne", "bone-borne" and "hybrid appliance" in an attempt to mitigate the effects of specificity and retrieve the largest number of articles from the four databases used in the main search. The same strategy was used for the grey literature search in order to increase sensitivity for the primary outcomes. A total of 47 studies were selected for full-text reading, 46 from the main search and one study[12] from the grey literature. There was an excellent level of agreement between the reviewers (MEMP and LSM) according to the Landis and Koch classification[68] in the selection and eligibility screening of the studies, with $\kappa = 0.854$ (95%CI 0.973-0.735) and $\kappa = 0.866$ (95%CI 0.581-1), respectively. This increased the reproducibility of the study.

After thorough analysis during the eligibility assessment process, 23 studies were included in the final sample,[2,8,12–17,19,49–62] including six studies[2,13–17] selected by hand searching. The studies considered to have the best methodological quality were those by Kayalar et al 2016[60] (low risk of bias) and Koudstaal et al 2009[59] (medium risk of bias) for the analysis of the stability of TB vs BB/hybrid appliances, since both were randomised controlled trials. Other two studies[53,61] also had a medium risk of bias, but there was no randomisation of the sample.

Two studies were discarded during the eligibility assessment process for not being original studies.[46,47] It is worth noting, however, that both studies met the methodological design criteria for inclusion in this systematic review. De Gijt et al 2017[47] evaluated 17 of the original 42 patients from the study conducted by Koudstaal et al 2009,[59] with the main purpose of analysing the long-term dental and skeletal effects of TB and BB appliances in this part of the sample. The study was excluded from the present systematic review because the number (of patients) who responded was too small to compare the two types of distractor (TB vs BB), and because the original study presented a more complete data set. The study by Chamberland and Proffit 2008[46] was excluded because, despite having been published as the first original study, the most recent study published by the authors in 2011[19] has further longitudinal data for the analysis of short-term and long-term stability, in addition to a larger sample size.

After data extraction and analysis, the selected studies that included relapse as an outcome were divided into two

Table 5
Quality assessment of included studies.

Quality criteria for relapse studies	Pogrel ma et al, 1992	Siqueira D. et al 2015	Freitas R.R et al 2008	Gerlach, K. 2003	NorthwaY & Meade 1997	Koudstaal M.J et al 2009	Krey K.F et al 2008	Kayalar E. et al 2015	Chamberland & Proffit 2011	Bays & Greco 1992	Strömberg C et al, 1995	Anttila et al, 2004	Hino C.,et al 2008	Magnusson A et al, 2009	Byloff&Mossaz, 2004
Sample randomization	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No
Comparison between treatments+	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No
Blind assessment	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No
Validation of measurements	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Statistical Analysis	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Defined Inclusion and exclusion criteria	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Report of follow-up	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Risk of Bias Assessment	High	High	High	High	High	Medium	High	Low	High	High	High	High	High	High	High

Quality criteria for complication studies	**Laudemann et al, 2010**	**Dergin et al, 2015**	**Verquin et al, 2017**	**Neyt et a, 2002**	**Ramiere et al, 2005**	**Günbay et al, 2008**	**Landes et al, 2009**	**Gauthier et al, 2011**
Sample randomization	No	No	No	No	No	No	No	No
Comparison between treatments+	Yes	No	No	No	No	No	Yes	No
Blind assessment	Yes	No	No	No	No	No	Yes	No
Validation of measurements	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Statistical Analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Defined Inclusion and exclusion criteria	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Report of follow-up	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Risk of Bias Assessment	Medium	High	High	High	High	High	Medium	High

+Comparison between the BB device and HB device on SARME procedures. Bias risk potential estimation: High: 0 to 4 yes – Medium: 5 to 6 yes – Low: 7 yes.

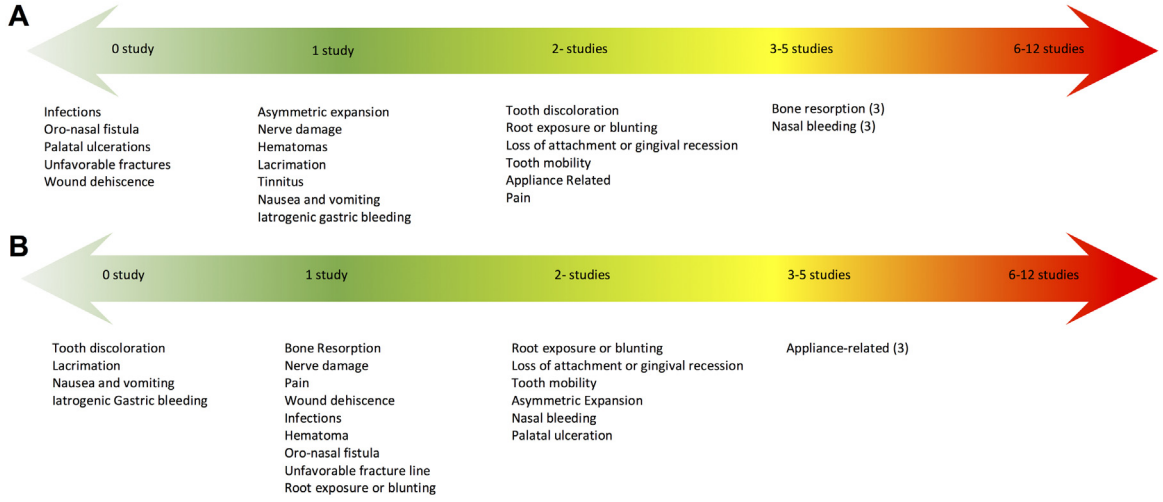


Fig. 2. **(A)** Complications most often reported in TB appliances. **(B)** Complications most often reported in BB appliances.

postoperative main groups for TB and/or BB appliances: dental/skeletal width relapse and dental/skeletal width expansion (treatment changes). The analysis of these outcomes served to establish the width stability in maxillary expansion for each distraction appliance.

In TB appliances, in general, molars (first or second molars) showed greater relapse[2,13–16,19] than canines, with relapse rates of up to 35% in canines and 45% in molars. However, in studies[12,55,56,59] where relapses occurred more often in the canine region than in the molar region, one plausible explanation is that treatment changes in dental width were proportionally greater, that is, the greater the expansion achieved, the greater the degree of relapse observed, even though some authors reported no association between expansion degree and relapse rate.[19,56] It is also reasonable to associate greater canine relapses in TB appliances with the surgical technique used.[12,56] When PMD is not performed, the associated forces exerted on the palatal mucoperiosteum and surrounding bucco-oral muscles may increase resistance in the posterior regions, leading to less molar width expansion and, consequently, less molar width relapse in the consolidation period.[16] However, some authors have demonstrated that PMD is not necessary to achieve expansion of the maxilla.[50,58] Overall, skeletal changes seem to be a determining factor when considering maxillary width relapse in studies analysing TB appliances, since dental relapses are associated with dental tipping and lateral rotation of the maxillary halves.[15,59] Expansion of the maxillary halves appears to increase as the retention period increases, as demonstrated in several studies.[15,19] The rate of maxillary skeletal width relapse reached up to 73%[15] in the maxilla and 53%[59] on the nasal floor (when reported), indicating that one possible factor for maxillary relapse lies in the fact that TB appliances do not have the rigidity required to withstand the exerted forces, thus causing dental tipping.

In BB appliances, relapse was analysed only in two included studies: one randomised controlled trial[59] and one prospective clinical study.[57] One study[60] used a hybrid appliance and, therefore, cannot be equally compared. BB appliances showed width relapse rates ranging from 1.7 to 21.6% in the canine region and from 4.6 to 11.5% in the molar region, rates lower than those reported for TB appliances. Lower relapse rates may be explained by a more parallel distribution of forces exerted by the distractor on the maxillary halves, reducing segmental and dental tipping. The difference between studies in the width relapse of BB appliances may be related to the type of surgical technique used, the location/direction of the screw expander[57,60] and patient age.

Perhaps the rationale to explain why the canine region has more relapses than the posterior region is that BB appliances are localised more posteriorly in the palatal vault, thus creating greater resistance of the maxillary halves to relapse. Another plausible explanation is the alignment of the maxillary dental arch in the consolidation period, as observed in several studies[15,19,56,57,59] in the TB and BB groups. During consolidation, relapse varies regardless of the type of appliance used, and the stability of SARME procedures should be analysed after proper arch-form co-ordination and/or final AP or vertical relationships have been achieved.[19]

Skeletal width in BB appliances was evaluated only by Koudstaal et al 2009,[59] with a mean nasal floor relapse of 41.6% and a mean maxillary level relapse of 16%. A pattern of increased relapse was found in a cranial to caudal direction on the vertical axis, suggesting that a less rigid distraction device could lead to greater relapse. It is also important to note that greater expansions were achieved at more caudal levels, whereas minor expansions were observed on the nasal floor (upper level)[15,46,59] for both TB and BB appliances. During expansion of the maxillary halves, differences in patterns ranging from V-shaped to parallel widening have been reported in the literature[52,53,57] for TB and BB appliances. In the present review, a parallel pattern expansion on the dental arch on AP view was observed in TB and BB appliances.[46,57,59]

Overall, the outcomes of dental width stability in the literature were consistent with lower relapse rates in patients receiving BB rather than TB appliances for the canine, premolar and molar regions[15,16,19,55,57,59]. In studies reporting greater relapse in the canine region than in the molar region, retention periods appear to have played an important role, because arch-form coordination and postoperative adjustments made evident a dental pseudo-relapse.[19,56] Moreover, patients with an indication for SARME often have canines in an infra-labioversion position and these teeth tend to be aligned in arch-form during the postoperative period, thereby taking a more lingual position.[55]

Both appliances provided good long-term stability, ranking high in the hierarchy of stability[46,63] in accordance with SARME procedures. A maxillary outward pattern of expansion was reported in the studies[56,59] for TB and BB appliances, showing that the increase in segmental maxillary tipping during the retention period, in conjunction with the small amount of relapse in TB and BB appliances, does not influence relapse in SARME procedures.[59]

Surgical complications were also analysed in this systematic review. The studies evaluating this outcome[2,8,14,49,52–54,57,59,61,62] enrolled a total of 399 patients, of whom 56.6% received TB appliances and 43.4% received BB appliances. Overall, 267 patients had some complication: 68.5% of patients in the TB group and 64.7% in the BB group.

For better data analysis, each reported complication was grouped according to type (dento-alveolar, skeletal, haemorrhage-related, nerve-related, appliance-related and other). Bone resorption (dento-alveolar) was the most common complication in TB appliances, followed by loss of attachment/gingival recession, pain and nasal bleeding.[14,49,54,59] Because TB appliances have a direct effect on dento-alveolar tissues, it seems obvious that the most common complications would affect the periodontium. A study investigating the periodontal effects of SARME using TB appliances found statistically significant changes at six-month follow-up when patients were evaluated radiographically.[54] Another study reported a high prevalence of bone resorption in TB and BB appliances,[53] with the greatest vestibular bone resorption in patients aged over 20 years with TB appliances who underwent SARME without PMD. The problems encountered in comparing bone loss in two studies[53,54] reporting bone loss measurements, were that the sites for measuring bone loss were different (at the buccal alveolar crest in the study of Gauthier et al[54] and from the buccal tooth apex to external rim of the buccoalveolar bone in the study of Landes et al[53]) and were also performed at different times during treatment, therefore interpretation bias was possible. However, bigger buccal bone resorption occurred in TB appliances in the first and second premolars compared to BB appliances;[53] and also a decrease in the buccal alveolar crest bone at 6 months postoperatively[54] was found for TB appliances with higher losses in premolars and molars. These findings may be related to the fact that, in TB appliances, the periodontium of the anchorage teeth is directly damaged.[49,53,57] Appliance-related complications (18%) were the most common complications in BB appliances, followed by bone resorption (13.87%).[8,51,53] As dictated in the surgical technique for BB distraction,[64] additional incisions are needed in the palatal vault for insertion of the appliance, thus contemplating all the possible postoperative complications that result from the utilisation of osteosynthesis screws and poor hardware adaptation.[8,51,52] In addition, Laudemann et al 2010[61] pointed out that the periodontal complications resulting from BB appliances occur due to greater forces transmitted to the palatal halves, but at the price of more overall attachment loss.

In general, care must be taken in pre-operative evaluations of expansion procedures to ensure that good attached gingiva remains mainly in the anchorage teeth or in teeth near the different osteotomies in SARME[51]. The lack of teeth may benefit the choice of BB appliances.[49,51,53,57,59,61]

The criteria for methodological quality assessment of the studies included in the present systematic review have been used in previous systematic reviews.[11,67]. Only one randomised clinical trial met the criterion of outcome assessor blinding[60] and only three studies met the criteria for medium risk of bias,[53,59,61] of which two[53,61] did not include sample randomisation and one[59] did not include blind assessment of the outcome. The remaining 19 included studies[2,8,12–17,19,49–52,54–58,62] had a high risk of bias. The studies reporting stability/complications[2,12–17,19,50,55,60] as an outcome were more robust than those reporting only complications.[8,49,51,54,61,62] Therefore, a meta-analysis was not possible due to the heterogeneity of the variables found in the two randomised clinical trials of stability,[59,60] since one compared TB vs BB appliances and the other compared TB vs hybrid appliances. However, by using a search strategy that encompasses the literature on relapse/stability and complications in TB, BB and hybrid devices, this systematic review was able to analyse the outcomes of the 23 included articles.[2,8,12–17,19,49,62] To the authors' knowledge, there is one systematic review[69] that evaluated relapse in TB and BB appliances in SARME; nevertheless, those authors included in the final review a randomised controlled trial[21] that reported as one of its limitations not assessing relapse and long-term stability. In order to review most of the literature on relapse associated with TB and BB appliances, in the present study, the authors did not limit the inclusion criteria to study design, thus including original and intervention studies with prospective and retrospective designs.

In conclusion, based on the results of this systematic review, the outcomes of TB and BB appliances provide excellent stability in SARME procedures, with no relevant clinically differences between the two appliances in the postoperative periods, since the differences of width relapse appeared to be corrected in the consolidation periods. However, overall, higher relapse was observed in TB appliances; therefore, BB appliances have had increased width stability. There is a consensus that initial anterior gap aperture

must be obtained in order to support an eventual maxillary expansion.[19,56,59] The different variables in the studies of TB and BB appliances regarding expansion protocols, variations in surgical techniques and patient age should be considered for proper treatment planning and clinical decision-making. It is imperative that the surgeon works in an interdisciplinary and articulated manner with the orthodontist, as SARME is a procedure that involves both parties. Regarding relapse in TB and BB appliances, several dental movements occur during the retention period, which may last from three to six months, resulting in relapse mainly due to postorthodontic movements with the purpose of overexpansion correction, arch-form co-ordination and final vertical adjustments.[16,46,59] Therefore, long-term stability after SARME will depend also on the orthodontist's ability to obtain a stable and functional occlusion.[56]

Given the quality of evidence of the included studies, it is imperative that evaluations be conducted through randomised controlled trials, as this is the most suitable study design for SARME. Randomised controlled trials are ideal for the evaluation of skeletal and dental relapse, because they generate the best scientific evidence and provide more homogeneous data, which can be meta-analysed.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

The reference approval number is SIPESQ:8446 of the Research Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul. Patient permission not applicable.

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