Long-term dental and skeletal changes in patients submitted to surgically assisted rapid maxillary expansion: A meta-analysis

Giselle Naback Lemes Vilani, DDS, MS,[a] Claudia Trindade Mattos, DDS, MS,[a]
Antônio Carlos de Oliveira Ruellas, DDS, MS, PhD,[b] and Lucianne Cople Maia, DDS, MS, PhD,[b] Rio de Janeiro, RJ, Brazil
UNIVERSIDAD FEDERAL DO RIO DE JANEIRO

Objective. This meta-analysis evaluated long-term dental and skeletal changes in patients submitted to surgically assisted rapid maxillary expansion.

Methods. A search was performed in electronic databases. Human clinical trials with patients submitted to surgically assisted rapid maxillary expansion with a follow-up of at least 1 year after expansion were selected. A methodological quality scoring process was used. A meta-analysis was performed to compare measurements of skeletal and dental structures.

Results. Three hundred sixty-five titles and abstracts were read. Ultimately 10 studies met the inclusion criteria. The 3 articles ranked as presenting low methodological quality were excluded. Three measurements could be compared and 3 time periods were used to assess changes.

Conclusions. There is moderate evidence to conclude that maxillary alveolar width and intercanine and intermolar width have a long-term significant increase as a result of surgically assisted rapid maxillary expansion. A significant relapse is expected in the intercanine width after expansion. (Oral Surg Oral Med Oral Pathol Oral Radiol 2012;114:689-697)

Rapid maxillary expansion (RME) has been the most effective treatment in orthodontics to correct transverse maxillary discrepancies in growing adolescents and occurs by the opening of the midpalatal suture.[1-3] According to some authors, the ideal period for RME is during the pubertal growth spurt or until the subject is 15 years old.[4-6]

This treatment has not been effective on mature adolescents and adult patients. This limitation can be attributed to several factors related to bone maturation. One of them is the gradual midpalatal suture closure, which prevents the expansion by increasing bone strength,[7,8] although studies in patients with cleft palate showed that this structure was not related to the success of expansion.[9] Another difficulty of the lateral movement of the maxilla is associated with the strong structure of the zygomatic buttress, which was demonstrated to be the principal area of increased facial skeletal resistance to expansion.[10] Because of increased skeletal resistance, RME in adults is related to some deleterious effects that may happen directly to the anchorage teeth and supporting tissues, such as buccal alveolar tipping, periodontal damage, root resorption, buccal bone resorption, tipping and extrusion of the teeth, pain, and palatal necrosis.[10-13]

Surgically assisted rapid maxillary expansion (SARME) proved to be a reliable modality in orthodontic therapy for skeletally mature, nongrowing adolescents and adult patients to allow maxillary expansion.[10] Several surgical techniques for maxillary expansion have been proposed with the aim to release the most resistant areas in the maxilla associated with a more conservative surgical procedure and stable results in treatment.[14] Many authors suggest the use of combined osteotomies in the suture, anterior and lateral maxilla, and particularly at the pterygoid plates so as to achieve a reliable expansion.[10,15-23] Kurt et al.[17] concluded that skeletal and dental width were stable in patients submitted to SARME with and without pterygoid osteotomy, whereas Koudstaal et al.[24] observed different expansion according to the inclusion or not of the pterygoid osteotomy in the surgery. It has been suggested that the long-term stability and relapse rates for both surgery procedures vary.[25]

In relation to the type of distractor or appliance that should be used, whether a bone-borne (BB) or a tooth-borne (TB) anchorage device, there is no consensus in the literature regarding the one that provides the best dental and skeletal results and stability. The TB appliances, like the Hyrax device, distribute stress to the anchorage teeth and to the supporting tissues. This appliance can be easily installed without anesthesia and allows easy hygiene and great comfort, which is one of the reasons why this device is widely accepted by patients.[1] There are some disadvan-

[a]PhD Student, Department of Pediatric Dentistry and Orthodontics, School of Dentistry, Universidad Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brazil.
[b]Professor, Department of Pediatric Dentistry and Orthodontics, School of Dentistry, Universidad Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brazil.
Received for publication Aug 13, 2011; returned for revision Nov 8, 2011; accepted for publication Jan 17, 2012.

2212-4403/$ - see front matter
http://dx.doi.org/10.1016/j.oooo.2012.01.040

Table I. Search strategies in different databases

Database	Keywords
Scirus (MEDLINE/PubMed; science direct; PubMed, Central; Biomed) http://www.scirus.com/srsapp/advanced	"rapid maxillary expansion" OR "rapid palatal expansion" OR "maxillary disjunction" OR "palatal disjunction" OR "palatal expansion technique" AND "maxillary surgery" OR orthognathic OR osteotomy OR surgical
Ovid http://ovidsp.tx.ovid.com	Rapid maxillary expansion OR rapid palatal expansion AND surgery OR orthognathic OR osteotomy
ISI web of knowledge http://apps.isiknowledge.com	Surgical AND expansion AND palatal
PubMed http://www.ncbi.nlm.nih.gov/pubmed	Surgical* AND rapid maxillary expansion AND stabil* Surgical* AND bone-borne OR tooth-borne OR dental anchorage
VHL (LILACS, IBECS, MEDLINE, Scielo) http://regional.bvsalud.org/php/index.php	"palatal expansion technique"(MeSH) AND "orthognathic surgical procedures" (MeSH)
Cochrane Library (systematic reviews; quality analyzed abstracts; CCRCT-Cochrane central Register of controlled trials) http://cochrane.bvsalud.org	Surgical AND expansion AND palatal

tages, however, owing to its anchorage on the premolars and molars. The lateral forces resulting from the expansion movement are transmitted more strongly to these teeth and to the alveolar bone. Additionally, as these teeth crowns are situated far from the center of resistance of the maxilla, a lateral tilt of the maxilla may happen instead of a parallel expansion. Another question raised by the authors is the absence of contact of the Hyrax appliance with the palate, which may allow some bone movement during stabilization of the device. This negative and unwanted result may compromise the stability of treatment after SARME.[15,16,24,26] To solve these problems, the BB appliances are directly installed on the palatal bone and the lateral forces act directly to the bone at the mechanically desired level, which prevents or reduces dental and alveolar tipping.[14]

The purpose of this article was to report the results from a meta-analysis of the scientific literature concerned with the long-term dental and skeletal changes associated with SARME.

MATERIAL AND METHODS

The primary objective of this meta-analysis was to evaluate the long-term effect of SARME to correct maxillary transverse deficiencies on dental and skeletal structures. The secondary objective was to compare the effects of different types of appliances and surgical techniques used.

Electronic searches were performed using the following databases: SCIRUS, OVID, ISI Web of Knowledge, Cochrane Library, VHL (Virtual Health Library), and PubMed. Articles published until June 2011 were included without language restriction.

The terms or keywords used in the literature search were selected with the assistance of a senior librarian specialized in health sciences databases. The search strategy is provided in Table I.

The following criteria were formulated to select articles for inclusion in this review: (1) prospective and retrospective human clinical trials; (2) patients submitted to SARME; (3) measurements in dental casts or posteroanterior (PA) cephalometric radiographs; (4) TB or BB palatal distractor appliance; (5) follow-up of at least 1 year after expansion; (6) no history of another craniofacial surgery. There was no restriction on the persisting malocclusion and/or the origin of malocclusion. Case reports, case series, review articles, editorials or opinion articles, and studies with patients who were syndromic, medically compromised, or had cleft were excluded from this systematic review.

Eligibility of the studies was determined by reading the title and abstracts of the articles identified in each database. All the articles that appeared to fulfill the inclusion criteria were selected and retrieved. Articles that appeared in more than one database were considered only once. The selection process was made by 2 reviewers (C.T.M. and G.N.V.) independently, and then the results were compared. Articles in which the abstracts did not present enough information for their inclusion were also obtained. The reference lists of the selected articles were also searched manually for additional relevant publications that might have been missed in database searches.

Independent methodological quality assessment of the included studies was performed according to a scale compiled by the authors and described in Table II. Most of the criteria were based on the CONSORT statement when applicable to this review. Eight criteria related to study design, study measurements, and statistical analysis were used to identify which studies would be most valuable. The studies were qualified as presenting high, moderate, and low methodological quality when the sum of the points reached was above 6, from 4 to 6, or

Table II. Criteria for assessing quality components in the studies included

Component	*Classification*	*Points*	*Definition*
1. Eligible criteria for participants described	Adequate	1.0	Inclusion/exclusion criteria described
	Inadequate	0.5	No description of inclusion/exclusion criteria, but selection done at least by age and type of surgery
	None	0	No description of criteria for selection
2. Presence of a control group	Yes	1.0	Presence of a control group
	No	0	Absence of a control group
3. Blinding assessment stated	Yes	1.0	Blinding assessment described in measures or statistics
	No	0	No blinding assessment described
4. Statistical treatment performed	Adequate	1.0	Statistical treatment fully described and adequate
	Inadequate	0.5	Statistical treatment not fully described or inadequate
	None	0	No statistical treatment applied
5. Reliability of measures tested	Adequate	1.0	Aleatory measures repeated and statistical test applied
	Inadequate	0.5	Measures repeated and inadequate or no statistical tests applied
	None	0	Measures not repeated
6. Reporting drop-outs	Explained	1.0	Dropouts reported with explanation
	Not explained	0.5	Dropouts reported with no explanation or description of complete or incomplete data retrieved
	None	0	No description of dropouts or data retrieved
7. Follow-up period reported	Yes	1.0	Follow-up period reported
	No	0	No description or unclearness of follow-up period
8. Potential bias and trial limitations addressed	Fully	1.0	Description of potential bias and trial limitations acknowledging them
	Partially	0.5	Description of potential bias and trial limitations without acknowledging them
	None	0	No description of potential bias or trial limitations

lower than 4, respectively (Table II). Any disagreement was discussed and a third reviewer consulted when necessary (L.C.M.).

A meta-analysis was performed to combine comparable results by using the Review Manager software (version 5.0, Copenhagen: Nordic Cochrane Centre, Cochrane Collaboration, 2008). The included studies were compared in relation to different measurements of skeletal and dental structures. Forest plots of continuous data were constructed with the weighted mean differences between specific evaluation periods (initial, after expansion, and follow-up). Heterogeneity was assessed among the included studies. Results with less heterogeneity ($I^2 < 75\%$) were presented with a fixed-effects model, as in a previous meta-analysis.[27] Results were assessed with an inverse variance statistical method.

RESULTS

The search results and the number of abstracts selected in all databases are depicted in the flow diagram in Figure 1. The search revealed 524 titles and abstracts. Duplicate publications (159) appearing in more than one database were considered only once. Ultimately, 10 studies met the inclusion criteria and were assessed for eligibility and qualified as described in Table III. None of the studies fulfilled all the requirements in the quality assessment. Seven articles were ranked as moderate and 3 presented low methodological quality. The articles with low methodological quality were excluded.[15,19,28] All studies were clinical trials, 5 prospective[16,17,24,29,31] and 2 retrospective.[18,30] No RCTs were found.

A summary of the methodological characteristics used in these studies, such as sample, age, evaluation method, type of appliance, consolidation time, type of surgery, and mean follow-up, is shown in Table IV.

For the meta-analysis, the studies were divided according to the measurement and the periods of time assessed. Three measurements were compared: maxillary alveolar width, maxillary intercanine width, and maxillary intermolar width. Data from 5 studies[16,17,24,29,31] were used in the meta-analysis. Only studies that used the exact same measurement were compared. Three time periods were used to assess changes: expansion outcome (difference between the after-expansion and the initial measurements), relapse (difference between the last follow-up and the after-expansion measurements), and follow-up outcome (difference between the last follow-up and the initial measurements). Studies where mean differences between different time periods were presented and where data for every period assessed were not available were not included[17,30] in the meta-analysis. A study[24] that presented data for BB appliances and for TB appliances separately had its data analyzed accordingly.

The heterogeneity among the groups assessed in this meta-analysis was very low for every aspect considered

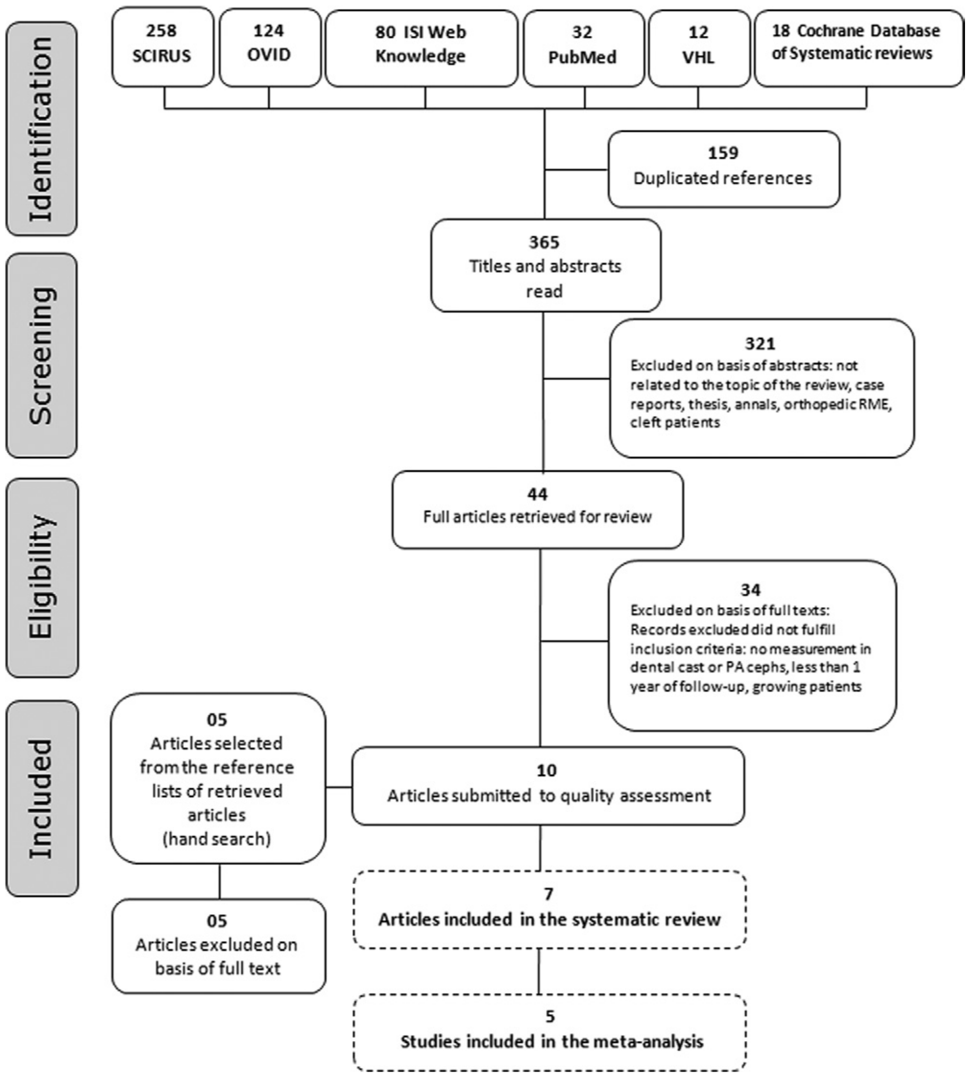


Fig. 1. Flow diagram of literature search.

($I^2 = 0\%$), except for the intermolar width comparison, in which the heterogeneity could be considered moderate ($I^2 = 64\%$).

The comparison of the maxillary alveolar width (Figures 2-4) was assessed from the distance between the right and left intersection of the alveolar process and the maxillary molars (Ma-Ma) on the posteroanterior cephalometric radiographs. The expansion outcome was a highly significant increase ($P < .00001$) in the alveolar width (mean 3.33 mm), followed by a relapse (mean 0.01 mm) not statistically significant ($P = .99$). The long-term outcome was a highly significant increase ($P < .00001$) in the alveolar width (mean 3.30 mm).

The comparison of the intercanine width (Figures 5-7) was assessed from the distance between the maxillary cusp tips of the canines measured on the dental casts. The expansion outcome was a highly significant increase ($P < .00001$) in the intercanine width (mean 5.62 mm), followed by a statistically significant ($P = .02$) relapse (mean 1.50 mm). The long-term outcome was a highly significant increase ($P < .00001$) in the alveolar width (mean 3.55 mm).

The comparison of the intermolar width was only possible in the long-term outcome (Figure 8), once the 2 studies assessed,[29,31] which used the exact same measure (the distance between the maxillary first molars mesiopalatal cusp tips) did not present data in the after-expansion period. The long-term outcome was a highly significant increase ($P < .00001$) in the intermolar width (mean 3.71).

The secondary objective of this meta-analysis could not be fulfilled. A comparison between different surgery techniques was not possible, as there were not enough studies of each kind. The comparison between different types of appliances was presented in only one

Table III. Quality assessment of the studies included

Article	Type of study	Eligible criteria for participants described	Presence of a control group	Blinding assessment stated	Statistical treatment performed	Reliability of measures tested	Reporting dropouts	Follow-up period reported	Potential bias and trial limitations addressed	Total points	Research quality or methodological soundness
Kurt et al. 2010[17]	PS	1	1	0	1	1	0	1	1	**6**	Moderate
Koudstaal et al. 2009[24]	PS	1	0	1	1	1	0	1	1	**6**	Moderate
Magnusson et al. 2009[18]	RS	1	1	1	1	1	0	1	0	**6**	Moderate
Sokucu et al. 2009[31]	PS	1	0	1	1	1	0	1	0	**5**	Moderate
Anttila et al. 2004[30]	RS	1	0	0	1	1	0	1	1	**5**	Moderate
Byloff and Mossaz 2004[16]	PS	1	0	0	1	1	0	1	1	**5**	Moderate
Berger et al. 1998[29]	PS	1	0	0	1	1	0	1	1	**5**	Moderate
Stromberg and Holm 1995[28]	RS	1	0	0	0	0	0	1	0	**2**	Low
Bays and Greco 1992[19]	RS	1	0	0	0	0	0	1	0	**2**	Low
Pogrel 1992[15]	RS	0	0	0	0	0	0	1	0	**1**	Low

Type of study: *PS*, prospective study; *RS*, retrospective study.
Research quality or methodological soundness: high, >6 points; moderate, 4 to 6 points; low, <4 points.

study[24] and its authors have already extensively discussed their results.

DISCUSSION

In the comparisons used in this systematic review with meta-analysis, no control group was used because there are no randomized controlled clinical trials in the literature. Rather, individuals were compared with themselves in different periods.

A previous systematic review was published by Lagravère et al.[32] in 2006, and another by Tiago and Gurgel[33] was published in 2011, evaluating skeletal and dental changes after SARME, but the authors included only patients using TB appliances. Another systematic review[26] studied the effects of BB SARME but the authors did not evaluate the long-term results, only the immediate effects. Our proposal was to compare the effects and the stability of the treatment using TB and BB appliances. In addition, no meta-analysis had yet been published comparing dental and skeletal effects of SARME.

Many authors accept patient age as a determining factor in choosing between the orthopedic or surgically assisted maxillary expansion, like Timms and Vero,[34] who accepted 25 years as an upper limit for applying orthopedic expansion. Other authors[24] consider that skeletally mature patients must be submitted to SARME and, in these authors' study, a hand-wrist radiograph was taken, in case of doubt, to determine the stage of skeletal maturation, using the Greulich-Pyle analysis. Treatment of maxillary atresia in adults without combination of orthognathic surgery can lead to several undesirable effects, such as excessive pain, discomfort, gingival recession, and inclination and extrusion of the anchorage teeth, in addition to loss of bone support.[21] Some studies in this systematic review[17,18,24,30] included young patients in their samples, but in a fully matured stage.

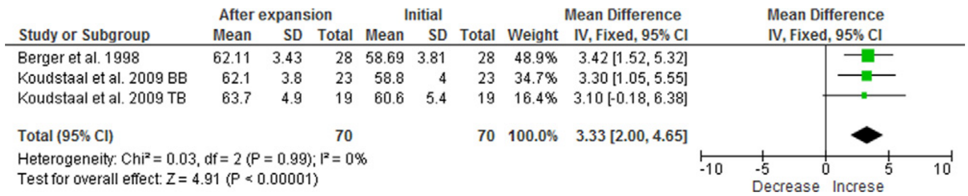
The authors have identified and included 7 pertinent studies with moderate research quality in the review. Five of these studies presented data that could be included in the meta-analysis. No comparison could be made for the interpremolar width, for the maxillary width, or for angulation of molars, either for lack of adequate studies presenting these measurements or for presentation of data in mean difference between time periods. The quality of evidence in this meta-analysis should then be considered moderate, which indicates the need for studies well designed methodologically.

The measurements compared were obtained either from dental casts or from PA cephalometric radiographs. Despite the limitations of using PA radiographs, such as the difficulty in reproducing the position of the head or in identifying the anatomical structures,[20] several studies have used them to assess changes in transverse dimension. Different methods to

Table IV. Overview of studies included

Author, year of publication	*Origin*	*Sample*	*Age range (mean) years*	*Evaluation (DC, PAC)*	*Type of appliance (TB or BB)*	*Time of bone consolidation after expansion/other treatment*	*Type of surgery*	*Mean follow-up*
Kurt et al. 2010[17]	Turkey	10 (3/7) 10 (4/6) (Control Group)	19.01 (16.25-25.58) 15.27 (13.42-17.00)	PAC	Tooth-borne (occlusal-coverage) Tooth-borne (hyrax)	• 3 mo • Fixed orthodontic treatment • Transpalatal arch	SARME • With and without pterygoid Disjunction	3 y
Koudstaal et al. 2009[24]	Netherlands	46	16 years or more (fully matured aged)	DC PAC	Tooth-borne[21] (hyrax) Bone-borne[25]	• 3 mo • Fixed orthodontic Treatment	SARME • Without pterygoid disjunction	1 y
Magnusson et al. 2009[18]	Sweden	31 (14/17)	25.9 (15.7-48.9)	DC	Tooth-borne (hyrax)	• 3 mo • Transpalatal arch • Fixed orthodontic treatment	SARME • With pterygoid disjunction	6.4 y
Sokucu et al. 2009[31]	Turkey	13 (9/4)	18.5 ± 2.3	DC	Tooth-borne (occlusal coverage)	• 6 mo • Transpalatal arch • Fixed orthodontic treatment • Hawley plate (1 year)	SARME • With pterygoid disjunction	2 y
Anttila et al. 2004[30]	Finland	20 (14/6)	30.6 (16.2-44.2)	DC	Tooth-borne (19-hyrax) Tissue-borne (1 -Haas)	• 6 mo (3-11 mo) - Fixed orthodontic treatment	SARME • With pterygoid disjunction	5.9 y (3.1-11.5 y)
Byloff and Mossaz 2004[16]	Switzerland	14 (3/14)	27 y 2 mo (18.6-41.8)	DC PAC	Tooth-borne (hyrax)	• 3 mo • Removable retainer for 3 mo • Fixed orthodontic treatment	SARME • With pterygoid disjunction	1 y
Berger et al. 1998[29]	USA	28 (16/12)	19.25	DC PAC	Tooth-borne (hyrax)	• 2-3 mo • Transpalatal arch • Fixed orthodontic treatment	Le Fort I without down fracture	1 y

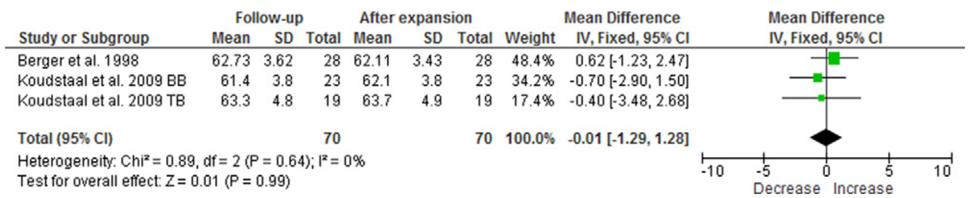
DC, dental casts; PAC, posteroanterior cephalometric radiograph; TB, tooth-borne; BB, bone-borne; SARME, surgically assisted rapid maxillary expansion.



Study or Subgroup	After expansion Mean	SD	Total	Initial Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Berger et al. 1998	62.11	3.43	28	58.69	3.81	28	48.9%	3.42 [1.52, 5.32]
Koudstaal et al. 2009 BB	62.1	3.8	23	58.8	4	23	34.7%	3.30 [1.05, 5.55]
Koudstaal et al. 2009 TB	63.7	4.9	19	60.6	5.4	19	16.4%	3.10 [-0.18, 6.38]
Total (95% CI)			**70**			**70**	**100.0%**	**3.33 [2.00, 4.65]**

Heterogeneity: Chi² = 0.03, df = 2 (P = 0.99); I² = 0%
Test for overall effect: Z = 4.91 (P < 0.00001)

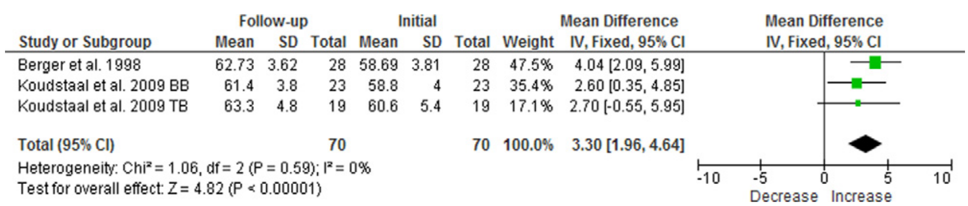
Fig. 2. Expansion outcome of alveolar width (Ma-Ma) measured on the PA cephalometric radiograph in millimeters.



Study or Subgroup	Follow-up Mean	SD	Total	After expansion Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Berger et al. 1998	62.73	3.62	28	62.11	3.43	28	48.4%	0.62 [-1.23, 2.47]
Koudstaal et al. 2009 BB	61.4	3.8	23	62.1	3.8	23	34.2%	-0.70 [-2.90, 1.50]
Koudstaal et al. 2009 TB	63.3	4.8	19	63.7	4.9	19	17.4%	-0.40 [-3.48, 2.68]
Total (95% CI)			**70**			**70**	**100.0%**	**-0.01 [-1.29, 1.28]**

Heterogeneity: Chi² = 0.89, df = 2 (P = 0.64); I² = 0%
Test for overall effect: Z = 0.01 (P = 0.99)

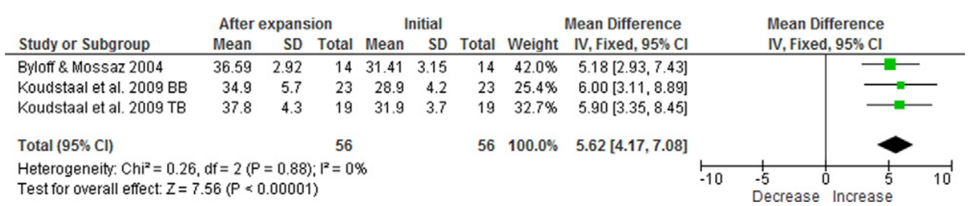
Fig. 3. Relapse of alveolar width (Ma-Ma) measured on the PA cephalometric radiograph in millimeters.



Study or Subgroup	Follow-up Mean	SD	Total	Initial Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Berger et al. 1998	62.73	3.62	28	58.69	3.81	28	47.5%	4.04 [2.09, 5.99]
Koudstaal et al. 2009 BB	61.4	3.8	23	58.8	4	23	35.4%	2.60 [0.35, 4.85]
Koudstaal et al. 2009 TB	63.3	4.8	19	60.6	5.4	19	17.1%	2.70 [-0.55, 5.95]
Total (95% CI)			**70**			**70**	**100.0%**	**3.30 [1.96, 4.64]**

Heterogeneity: Chi² = 1.06, df = 2 (P = 0.59); I² = 0%
Test for overall effect: Z = 4.82 (P < 0.00001)

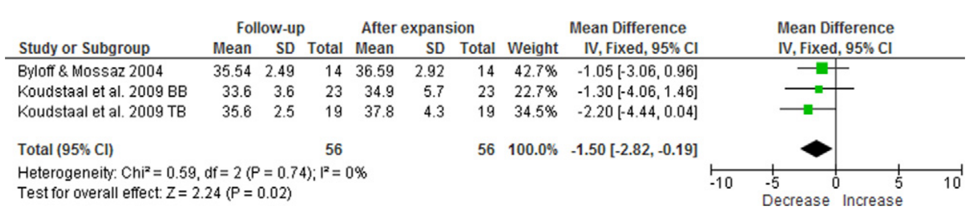
Fig. 4. Follow-up outcome of alveolar width (Ma-Ma) measured on the PA cephalometric radiograph in millimeters.



Study or Subgroup	After expansion Mean	SD	Total	Initial Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Byloff & Mossaz 2004	36.59	2.92	14	31.41	3.15	14	42.0%	5.18 [2.93, 7.43]
Koudstaal et al. 2009 BB	34.9	5.7	23	28.9	4.2	23	25.4%	6.00 [3.11, 8.89]
Koudstaal et al. 2009 TB	37.8	4.3	19	31.9	3.7	19	32.7%	5.90 [3.35, 8.45]
Total (95% CI)			**56**			**56**	**100.0%**	**5.62 [4.17, 7.08]**

Heterogeneity: Chi² = 0.26, df = 2 (P = 0.88); I² = 0%
Test for overall effect: Z = 7.56 (P < 0.00001)

Fig. 5. Expansion outcome of intercanine width (cuspal tips) measured on dental casts in millimeters.



Study or Subgroup	Follow-up Mean	SD	Total	After expansion Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Byloff & Mossaz 2004	35.54	2.49	14	36.59	2.92	14	42.7%	-1.05 [-3.06, 0.96]
Koudstaal et al. 2009 BB	33.6	3.6	23	34.9	5.7	23	22.7%	-1.30 [-4.06, 1.46]
Koudstaal et al. 2009 TB	35.6	2.5	19	37.8	4.3	19	34.5%	-2.20 [-4.44, 0.04]
Total (95% CI)			**56**			**56**	**100.0%**	**-1.50 [-2.82, -0.19]**

Heterogeneity: Chi² = 0.59, df = 2 (P = 0.74); I² = 0%
Test for overall effect: Z = 2.24 (P = 0.02)

Fig. 6. Relapse of intercanine width (cuspal tips) measured on dental casts in millimeters.

test the intra- or interobserver reliability of the measurements were applied in all studies selected in this systematic review. Additionally, Tausche et al.,[35] in their 3-dimensional evaluation of SARME, did not find different results in intermolar distance when comparing the computed tomography (CT) with PA radiographs and cast models. However, as 3-dimensional assessment is currently available through CT, this examination tool is gradually substituting both dental casts and PA radiographs for the assessments mentioned in this review.

A difficulty in this meta-analysis was the different ways each author made the measurements to assess skeletal changes and interpremolar and intermolar width. This variability made it impossible to compare all selected studies, which could have made the evidence in this meta-analysis stronger. Another limitation in the studies included in this meta-analysis is the different time adopted by the authors for retention of the expansion and the length of follow-up time after the expansion was completed. Moreover, in most studies in this meta-analysis, the patients underwent orthodontic

Study or Subgroup	Follow-up Mean	SD	Total	Initial Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Berger et al. 1998	34.61	2.68	28	30.89	2.56	28	32.7%	3.72 [2.35, 5.09]
Byloff & Mossaz 2004	35.54	2.49	14	31.41	3.15	14	13.9%	4.13 [2.03, 6.23]
Koudstaal et al. 2009 BB	33.6	3.6	23	28.9	4.2	23	12.1%	4.70 [2.44, 6.96]
Koudstaal et al. 2009 TB	35.6	2.5	19	31.9	3.7	19	15.3%	3.70 [1.69, 5.71]
Magnusson et al. 2009	32.85	3.08	31	30.45	3.11	31	26.0%	2.40 [0.86, 3.94]
Total (95% CI)			115			115	100.0%	3.55 [2.76, 4.33]

Heterogeneity: Chi² = 3.51, df = 4 (P = 0.48); I² = 0%
Test for overall effect: Z = 8.86 (P < 0.00001)

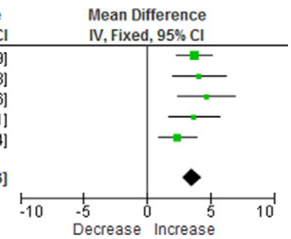


Fig. 7. Follow-up outcome of intercanine width (cusp tips) measured on dental casts in millimeters.

Study or Subgroup	Follow-up Mean	SD	Total	Initial Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Berger et al. 1998	41.79	2.86	28	37.02	3.45	28	44.3%	4.77 [3.11, 6.43]
Sokucu et al. 2009	40.9	1.37	14	38.03	2.47	14	55.7%	2.87 [1.39, 4.35]
Total (95% CI)			42			42	100.0%	3.71 [2.61, 4.82]

Heterogeneity: Chi² = 2.80, df = 1 (P = 0.09); I² = 64%
Test for overall effect: Z = 6.59 (P < 0.00001)

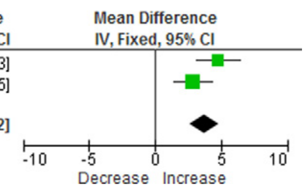


Fig. 8. Follow-up outcome of intermolar width (mesiopalatal cusp tips) measured on dental casts in millimeters.

treatment after the expansion, which probably influenced the outcome. The activation protocol, the appliance used for retention, and the surgical technique also differed among the studies. These confounding factors may have influenced the results from each study. In relation to the parameters included in the meta-analysis, however, their influence probably did not affect the results, as the heterogeneity among the studies was not high.

The results from this meta-analysis showed a significant long-term increase in the maxillary alveolar width, and in the intercanine and intermolar width in patients submitted to SARME. The alveolar width showed no relapse from just after the expansion until the last follow-up assessment. Although the intercanine width showed a significant relapse of 1.5 mm, its increase from the initial phase to the follow-up evaluation was highly significant. It may be inferred from these results that the alveolar width changes remain stable and that some relapse is expected in the intercanine width, thus some overcorrection may be advisable.

Future research is expected to produce studies with a high-quality methodological level, featuring randomized controlled clinical trials, 3-dimensional analysis, control of confounding factors, and a longer follow-up out of retention.

CONCLUSIONS

Based on the results from this meta-analysis, there is moderate evidence to conclude that maxillary alveolar width, and intercanine and intermolar width have a long-term significant increase as a result of SARME. A significant relapse is expected in the intercanine width after expansion.

REFERENCES

1. McNamara JA, Baccetti T, Franchi L, Herberger TA. Rapid maxillary expansion followed by fixed appliances: a long-term evaluation of changes in arch dimensions. Angle Orthod 2003;73:344-53.
2. Chung CH, Font B. Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. Am J Orthod Dentofacial Orthop 2004;126:569-75.
3. Lagravere MO, Major PW, Flores-Mir C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. Angle Orthod 2005;75:1046-52.
4. Bishara SE, Staley RN. Maxillary expansion: clinical implications. Am J Orthod Dentofacial Orthop 1987;91:3-14.
5. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. Am J Orthod 1970;57:219-55.
6. Melsen B. Palatal growth studied on human autopsy material. A histologic microradiographic study. Am J Orthod 1975;68:42-54.
7. Lines PA. Adults rapid maxillary expansion with corticotomy. Am J Orthod 1975;67:44-56.
8. Bell RA. A review of maxillary expansion in relation to rate of expansion and patient's age. Am J Orthod 1982;81:32-7.
9. Isaacson RJ, Murphy TD. Some effects of rapid maxillary expansion in cleft lip and palate patients. Angle Orthod 1964;34:143-54.
10. Bell WH, Epker BN. Surgical-orthodontic expansion of the maxilla. Am J Orthod 1976;54:517-28.
11. Işeri H, Ozsoy S. Semirapid maxillary expansion—a study of long-term transverse effects in older adolescents and adults. Angle Orthod 2004;74:71-8.
12. Zimring JF, Isaacson RJ. Forces produced by rapid maxillary expansion. 3. Forces present during retention. Angle Orthod 1996;35:178-86.
13. Handelman CS, Wang L, BeGole EA, Haas AJ. Non-surgical rapid maxillary expansion in adults: report of 47 cases using the Haas expander. Angle Orthod 2000;70:129-44.
14. Mommaerts MY. Transpalatal distraction as a method of maxillary expansion. Br J Oral Maxillofac Surg 1999;37:268-72.
15. Pogrel MA, Kaban LB, Vargervik K, Baumrind S. Surgically assisted rapid maxillary expansion in adults. Int J Adult Orthodon Orthognath Surg 1992;7:37-41.
16. Byloff FK, Mossaz CF. Skeletal and dental changes following

surgically assisted rapid palatal expansion. Eur J Orthod 2004;26:403-9.
17. Kurt G, Altug-Ataç AT, Ataç MS, Karasu HA. Stability of surgically assisted rapid maxillary expansion and orthopedic maxillary expansion after 3 years' follow-up. Angle Orthod 2010;80:425-31.
18. Magnusson A, Bjerklin B, Nilsson P, Marcusson A. Surgically assisted rapid maxillary expansion: long-term stability. Eur J Orthod 2009;31:142-9.
19. Bays RA, Greco JM. Surgically assisted rapid palatal expansion: an outpatient technique with long-term stability. J Oral Maxillofac Surg 1992;50:110-13.
20. Athanasiou AE, Miethke R, Van Der Meij AJ. Random errors in localization of landmarks in postero-anterior cephalograms. Br J Orthod 1999;26:273-83.
21. Northway WM, Meade JB. Surgically assisted rapid maxillary expansion: a comparison of technique, response, and stability. Angle Orthod 1997;67:309-20.
22. Chamberland S, Proffit WR. Closer look at the stability of surgically assisted rapid palatal expansion. J Oral Maxillofac Surg 2008;66:1895-900.
23. Chamberland S, Proffit WR. Short-term and long-term stability of surgically assisted rapid palatal expansion revisited. Am J Orthod Dentofac Orthop 2011;139:815-22.
24. Koudstaal MJ, Wolvius EB, Schulten AJ, Hop WC, van der Wal KG. Stability, tipping and relapse of bone-borne versus tooth-borne surgically assisted rapid maxillary expansion: a prospective randomized patient trial. Int J Oral Maxillofac Surg 2009;38:308-15.
25. Marchetti C, Pironi M, Bianchi A, Musci A. Surgically assisted rapid palatal expansion vs. segmental Le Fort I osteotomy: transverse stability over a 2-year period. J Craniomaxillofac Surg 2009;37:74-8.
26. Verstraaten J, Kuijpers-Jagtman AM, Mommaerts MY, Bergé SJ, Nada RM, Schols JG, Eurocran Distraction Osteogenesis Group. A systematic review of the effects of bone-borne surgical assisted rapid maxillary expansion. J Craniomaxillofac Surg 2010;38:166-74.
27. Mattos CT, Vilani GN, Sant'Anna EF, Ruellas AC, Maia LC. Effects of orthognathic surgery on oropharyngeal airway: a meta-analysis. Int J Oral Maxillofac Surg 2011;40:1347-56.
28. Strömberg C, Holm J. Surgically assisted, rapid maxillary expansion in adults. A retrospective long-term follow-up study. J Craniomaxillofac Surg 1995;23:222-7.
29. Berger JL, Pangrazio-Kulbersh V, Borgula T, Kaczynski R. Stability of orthopedic and surgically assisted rapid palatal expansion over time. Am J Orthod Dentofacial Orthop 1998;114:638-45.
30. Anttila A, Finne K, Keski-Nisula K, Somppi M, Panula K, Peltomäki T. Feasibility and long-term stability of surgically assisted rapid maxillary expansion with lateral osteotomy. Eur J Orthod 2004;26:391-5.
31. Sokucu O, Kosger HH, Bicakci AA, Babacan H. Stability in dental changes in RME and SARME: a 2-year follow-up. Angle Orthod 2009;79:207-13.
32. Lagravère MO, Major PW, Flores-Mir C. Dental and skeletal changes following surgically assisted rapid maxillary expansion. Int J Oral Maxillofac Surg 2006;35:481-7.
33. Tiago CM, Gurgel JA. Expansão rápida da maxilla assistida cirurgicamente: revisão sistemática sobre as alterações dentárias, esqueléticas e estabilidade. Ortod SPO 2011;44:13-21.
34. Timms DJ, Vero D. The relationship of rapid maxillary expansion to surgery with special reference to midpalatal synostosis. Br J Oral Surg 1981;19:180-96.
35. Tausche E, Hansen L, Hietschold V, Lagravère MO, Harzer W. Three-dimensional evaluation of surgically assisted implant bone-borne rapid maxillary expansion: a pilot study. Am J Orthod Dentofacial Orthop 2007;131:S92-9.

Reprint requests:

Lucianne Cople Maia, DDS, MS, PhD
Avenida Professor Rodopho Paulo Rocco, 325
Ilha do Fundão
Department of Pediatric Dentistry and Orthodontics
School of Dentistry
Federal University of Rio de Janeiro
Rio de Janeiro, RJ, Brazil CEP 21941-913
rorefa@terra.com.br