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Review

Dental and skeletal effects of palatal expansion techniques: a systematic review of the current evidence from systematic reviews and meta-analyses

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SUMMARY The aim was to assess the quality and to summarise the findings of the Systematic Reviews (SRs) and Meta-Analyses (MAs) on the dental and skeletal effects of maxillary expansion. Electronic and manual searches have been independently conducted by two investigators, up to February 2015. SRs and MAs on the dentoalveolar and skeletal effects of fixed expanders were included. The methodological quality was assessed using the AMSTAR (A Measurement Tool to Assess Systematic Reviews). The design of the primary studies included in each SR/MA was assessed with the LRD (Level of Research Design scoring). The evidence for each outcome was rated applying a pre-determined scale. Twelve SRs/MAs were included. The AMSTAR scores ranged from 4 to 10. Two SRs/MAs included only RCTs. The current findings from SRs/MAs support with high evidence a significant increase in the short-term of maxillary dentoalveolar transversal dimensions after Rapid Maxillary Expansion (RME). The same effect is reported with moderate evidence after Slow Maxillary Expansion (SME). However, there is moderate evidence of a non-significant difference between the two expansion modalities concerning the short-term dentoalveolar effects. With both RME and SME, significant increase of skeletal transversal dimension in the short-term is reported, and the skeletal expansion is always smaller than the dentoalveolar. Even though dental relapse to some extent is present, long-term results of the dentoalveolar effects show an increase of the transversal dimension, supported by moderate evidence for RME and low evidence for SME. Skeletal long-term effects are reported only with RME, supported by very low evidence.

KEYWORDS: palatal expansion technique, malocclusion, review literature as topic, evidence-based dentistry, adolescent, growth and development

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Background

Posterior Crossbite (PXB) is a reverse position, on the transversal plane, of one or more maxillary teeth of the canine, premolar and molar region, with respect to the corresponding mandibular teeth (1). The prevalence of this malocclusion ranges between 8 and 22% in children in primary/mixed dentition (2, 3). Anatomical and myofunctional alterations as asymmetric condylar positioning, asymmetric mandibular growth, dental discrepancies and dental asymmetries with Class II tendency on the crossbite side, have been related to untreated PXB; (4–7) however, restoration

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of normal growth and function have been reported after the resolution of the crossbite (8, 9).

Maxillary expansion (ME) is one of the treatment options for the correction of skeletal constriction of the upper jaw, with the intent to increase the transverse widths of the maxilla through the opening of the mid-palatal suture (10, 11). ME can be achieved by means of different expansion rates and forces (Rapid Maxillary Expansion–RME or Slow Maxillary Expansion–SME), and with different appliances, and the choice among these options can influence the resulting effects of the treatment, and the relative relapse.

With the rapid spread of the systematic approach to the primary literature, highly debated topics, such as the effect of ME, have been extensively studied in Systematic Reviews (SRs) and Meta-Analyses (MAs), variable in quality and scope (12). Furthermore, MAs in orthodontics are often affected by methodological flaws (13), that in turn can affect the results provided (17).

Hence, when a number of SRs and MAs exist in priority scientific areas, an Overview of reviews is the type of research suggested to summarise and appraise multiple results (12, 14). This work benefits to clinicians who look for evidence on treatments of PXB and highlights potential 'evidence gap', informing reviewers about topic to be prioritised.

Such approach has been previously adopted in the orthodontic field to synthesise the evidence on Class II orthopaedic functional treatment (15), but to the best of our knowledge this is the first SR of SRs on the effects of palatal expansion.

The aims of the present study were to: (i) evaluate the methodological quality of SRs and MAs on dental and skeletal effects of palatal expansion, and (ii) summarise the reported effects of treatment by appraising the evidence on which the results are based.

Methods

Study selection and data collection

Six electronic databases were investigated for the systematic literature search. The survey covered the period from the starting of the databases up to June 2014. The search was later updated up to February 2015. Furthermore, hand-search of orthodontic journals (*European Journal of Orthodontics*, *American Journal of Orthodontics and Dentofacial Orthopedics* and *The Angle Orthodontist*) was performed, starting from the first volume available on the digital archives. An effort of exploration of the grey literature was performed among the abstracts collected on Web of Knowledge and Scopus databases and on the databases of scien-

Table 1. Search strategy for each database and relative results

Database	Search strategy	Results
PubMed www.ncbi.nlm.nih.gov	((((((('Palatal Expansion Technique'[Mesh]) OR (maxillary expansion OR palatal expansion))) AND (('Meta-Analysis' [Publication Type]) OR 'Review' [Publication Type]))) NOT 'Craniofacial Abnormalities'[Mesh]) NOT 'Malocclusion, Angle Class III/therapy'[Mesh]) NOT 'Orthognathic Surgery'[Mesh]) NOT 'Cleft Palate'[Mesh]	119
Web of Knowledge (WOK) https://webofknowledge.com/	TOPIC: (palatal expansion OR maxillary expansion) AND TOPIC: (review OR meta-analysis) NOT TOPIC: (craniofacial syndrom*) NOT TOPIC: (surg*) NOT TOPIC: (angle class III) NOT TOPIC:(cleft palate)	105
Scopus http://www.scopus.com/	(TITLE-ABS-KEY (palatal expansion OR maxillary expansion) AND TITLE-ABS-KEY (review OR meta-analysis) AND NOT TITLE-ABS-KEY (craniofacial syndrom*) AND NOT TITLE-ABS-KEY (surg*) AND NOT TITLE-ABS-KEY (cleft palate) AND NOT TITLE-ABS-KEY (angle class iii))	69
Scientific Electronic Library Online (SciELO) http://www.scielo.org	(palatal expansion OR maxillary expansion) AND (review OR meta-analysis)	2
Latin American and Caribbean Health Sciences (LILACS) http://lilacs.bvsalud.org	(palatal expansion OR maxillary expansion) AND (review OR meta-analysis)	18
Cochrane Library www.cochranelibrary.com	MeSH descriptor: [Palatal Expansion Technique] explode all trees	1

tific congresses (*European Orthodontic Society* and *International Association of Dental Research*). The search strategies applied for each database are shown in Table 1 (see also: Table S1, PubMed search).

The *inclusion criteria* were: (i) SR or MA; (ii) Study assessing dentoalveolar and/or skeletal effects of palatal expansion techniques; (iii) Treatment performed with fixed orthodontic expansion appliances. The *exclusion criteria* were: (i) Dual publication; (ii) Systematic Reviews of SRs; (iii) Treatment performed with surgically assisted rapid maxillary expansion (SARME); (iv) Cleft lip/palate diagnosis or craniofacial syndrome diagnosis; (v) Expansion treatment performed in association with protraction headgear/facemask therapy; (vi) Updated publication; (vii) SR/MA focusing on treatments strategies others than fixed appliances (e.g. grinding/removable appliances).

All titles and abstracts were read and in case of uncertainty after the title-abstract reading the reference was included for full-text reading. The references that seemed to fulfil the inclusion criteria were read in full-text, and only those which completely satisfied all the inclusion criteria were included. Whenever a SR/MA addressed different interventions (e.g. fixed and removable appliances), it was included, discarding the unnecessary data. To identify any further relevant missing paper, the reference lists of the included SRs/MAs were analysed.

Data about Authors, Year of publication, Study design, Total number of subjects, Diagnosis, Intervention, Expansion technique, Outcome, Methods, Quality of the primary studies, Results, Author's conclusions and Author's comments on quality of the studies were extracted from the included SRs/MAs. When relevant data were not available in the publication, the authors were contacted to obtain further information.

Study selection and data extraction were independently run by two operators (R.B. and R.R.). Disagreements between the two examiners were discussed and solved to reach consensual decision. If necessary, a third operator (V.D.) was contacted for the final decision.

Quality assessment of the included SRs and MAs

The methodological quality was assessed using 'A Measurement Tool to Assess Systematic Reviews' (AMSTAR) (16). For each AMSTAR item, 'yes' answers were scored 1 point, and the other answers were scored 0 point. According to the number of criteria met, the methodological quality was rated as 'Low' (total AMSTAR ≤ 3), 'Moderate' (total AMSTAR 4 to 7) or 'High' (total AMSTAR ≥ 8) (17, 18).

The design of the primary studies included in each SR/MA was reported with the Level of Research Design scoring (LRD) (19, 20). This score, based on the hierarchy of evidence, applies the following rates: i) SR, ii) Randomised clinical trial (RCT); iii) Study without randomisation (cohort study, case–control study), iv) Non-controlled study (cross-sectional study, case series, case reports), v) Narrative review or expert opinion.

The AMSTAR scores were independently rated by two investigators (R.B. and R.R.), with no blinding for the authors of the review, and disagreements were solved through discussion. The inter-examiner reliability for the AMSTAR scores was calculated by means of Cohen's k coefficient.

Synthesis of the results and quality of the body evidence

The main outcomes of the included SRs/MAs were summarised according to: timing of the effect (short- or long-term), structure involved (dentoalveolar or skeletal effects), direction of the effect (transversal, vertical or sagittal), expansion modality (SME or RME) and appliance.

For each outcome, the quality of the body evidence was rated according to a pre-determined set of levels of evidence. The criteria to downgrade the evidence were: the way the data were pooled (MA or narrative synthesis), the number of studies/participants, and the quality of the primary studies assessing the outcome. Full explanation of the method is reported in Table 2. The quality of the individual studies was not reassessed, but reported as assessed by the authors of the reviews. Similarly, whenever the quality of the body evidence was already assessed in the SR/MA it was not re-assessed, but reported as stated by the authors.

According to the number of downgrades, the evidence was classified as: *very low* (>5 downgrades), *low* (4–5 downgrades), *moderate* (2–3 downgrades) or *high* (0–1 downgrade). It was assumed that for *high* evidence further research was very unlikely to change our confidence in the estimate of effect; for *moderate* evidence further research was likely to have an important impact on our confidence in the estimate of effect and may change the estimate; for *low* evidence further research

Table 2. Objective criteria for rating the evidence of the reported outcomes

	Type of study	No. of participants	No. of studies	Quality of primary studies
No downgrade	Meta-analysis	>200	>10	If low for <50% of the included studies
1 Downgrade	Qualitative synthesis	100–200	6–10	If low between 50 and 75% of the included studies
2 Downgrades		0–99	1–5	If low for >75% of the included studies

If the 'Quality of primary' study was not reported, we were conservative and assumed as 1 downgrade.
If the 'no. of participants' was not reported, we assumed the same downgrade as for the 'no. of studies'.

was very likely to have an important impact on our confidence in the estimate of effect and was likely to change the estimate; for *very low* evidence any estimate of effect was very uncertain.

Results

Studies selection

Study selection is reported in the PRISMA flow diagram in Fig. 1 (see also: Table S2 for the references of the excluded full-text). The most common exclusion criterion was the absence of a systematic search strategy.

The 12 SRs/MAs included and the data extracted are reported in Table 3 (10, 21–31). Four SRs were integrated with MA (21, 25, 28, 31). The total number of subjects ranged from 89 to 997.

The initial diagnosis revealed a unilateral or bilateral posterior crossbite in two studies (21, 23), general posterior crossbite, transverse discrepancy or constricted arches in four studies (24, 27, 28, 31), while no initial diagnosis was reported in the rest of the studies. The appliances studied were: Hyrax (bonded or banded), Haas (bonded or banded), Quad Helix (QH), Minne-expander, bone-anchored maxillary expander, Nitanium maxillary expander and

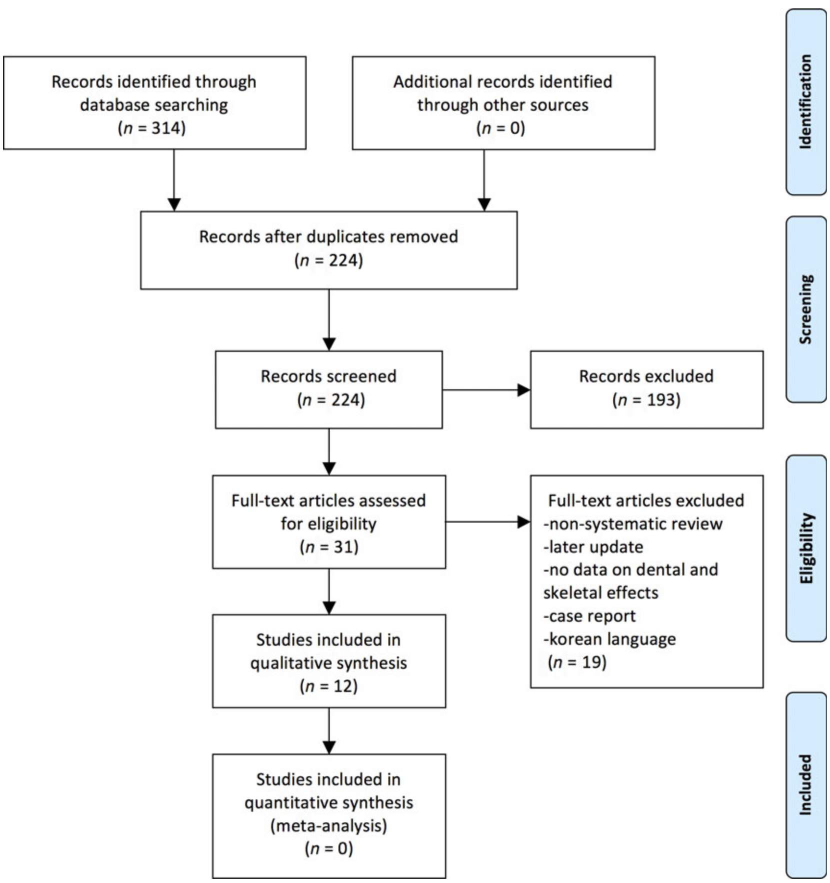

Fig. 1. PRISMA Flow Diagram.

Table 3. Data extracted from the 12 SRs and MAs included

Author, year, reference	Study design, total no of subjects	Diagnosis	Intervention (I) or Appliance (A) and control groups (C)	Expansion Technique	Outcome measures	Methods/ Measurement	Quality of the primary studies	Results	Author's Conclusion (A) and Author's Comments on the Quality of the Papers (Q)
Schiffman & Tuncay, 2001 (21)	Meta-Analysis of 2 RCTs, 2 P CCTs and 2 non-controlled CTs; n. of subjects NR	Unilateral or bilateral posterior crossbite	I1: Hyrax I2: QH C: Absent/AT	SME and RME	Long-term skeletal transversal effects (stability)	NR	Self-produced meta-analytic score: *unclear*	The mean expansion was 6·00 mm ± 1·29. While wearing retention in the short-term (<1 yr.), the 78·5% (4·71 mm) of the original expansion was maintained. While wearing retention in the long-term retention (>1 yr.), the 92% of the original expansion was maintained. Post-retention data show a total loss of 35·5% of the original transverse increase. Studies reporting short-term post-expansion data maintained 75% (3·88 mm), while longer term post-expansion data (>50 months) demonstrated a mean loss of 40% of the expansion (residual expansion 2·4 mm). I1 shows the 50% of relapse, while I2 around 64%.	A: Maxillary expansion stability is minimal. Post-retention data show that the residual expansion is no greater than what has been documented as normal growth. Q: NR
Petren *et al.*, 2003* (22)	Systematic Review of 2 RCTs, 5 P CCTs, 5 R CCTs[†] 695 subjects	Primary and early mixed dentition with posterior crossbite	I1: QH I2: RME (Hyrax/Haas) C: UCG/AT	Unclear	Dental effects (of the early treatment)	Dental cast, posteroanterior radiographs, lateral radiographs, Clinical Examination, Photos	Self-produced checklist: 8 *low quality*, 4 *medium quality*	100% or close to 100% of success rate when using I1 or I2. Spontaneous correction was found to occur in 16% to 50% of the untreated control groups. Highest amount of correction with I1 (Mmw: from 3·3-to 6·4 mm and Mcw from 1·3-to 5·2 mm), followed by I2 (Mmw 5·5 mm, Mcw 3·2 mm). Regarding stability after retention, higher values with I2 (Mmw: 5·4 mm, Mcw: 3·3 mm) followed by I1 (Mmw: from 3·6-to 5·1 mm Mcw: from 2·2- to 3·3 mm)	A: QH and RME are effective in the early mixed dentition at a high success rate. However, there is no scientific evidence available that shows which of the treatment modalities is the most effective. There is limited evidence for stability of crossbite correction at least 3 years post-treatment. Q: Primary studies lack of power because of small sample size, bias, and confounding variables, lack of method error analysis, blinding in measurements, and deficient or lack of statistical methods

Table 3. (continued)

Author, year, reference	Study design, total no of subjects	Diagnosis	Intervention (I) or Appliance (A) and control groups (C)	Expansion Technique	Outcome measures	Methods/ Measurement	Quality of the primary studies	Results	Author's Conclusion (A) and Author's Comments on the Quality of the Papers (Q)
Lagravere *et al.*, 2005 (10)	Systematic Review of 3 R CCTs; 113 subjects	NR	I1: Type of appliance NR C: UCG/fixed appliance	RME	Long-term skeletal transversal, anteroposterior and vertical effects	Posteroanterior radiographs, lateral radiographs	Self-produced checklist:2 *low* (<50% *of checks);* 1 *medium* (>50% *of checks*)	Transverse changes: Statistical increase of latero-nasal width. Statistically significant increase of maxillary width in patients treated before growth peak. Anteroposterior changes: No significant difference Vertical changes: A statistically significant long-term difference was present in the SN-PP (0·88°) and SN-Gn (0·88°) angles when comparing RME vs. C. Mandibular plane reduction (−0·85°) was lower than that reported in C.	A: Long-term stability of transverse skeletal maxillary increase is better in skeletally less mature individuals (pre-pubertal growth peak). Long-term transverse skeletal maxillary increase is approximately 25% of the total appliance adjustment (dental expansion) in pre-pubertal adolescents but not significant for post-pubertal adolescents. RME did not produce significant anteroposterior or vertical changes. Q: Lack of description of a statistical estimation process for the sample size, dropouts, and intra- and inter-examiner reliability. Long-term RCTs are required.
Lagravere *et al.*, 2005 (23)	Systematic Review of 3 R CCTs and 1 P CCT; 412 subjects	Unilateral and bilateral posterior crossbite	I1: Haas (+fixed treatment) C: UCG	RME	Long-term dental effects (Mmw; Mpw; Mcw; mmw; mcw; OVJ; molar extrusion; incisor inclination and OVB).	Dental cast, posteroanterior radiographs, lateral radiographs	NR	I1 increases Mmw (between 4·8-and 2·7-mm), Mpw (between 4·7-and 3·7-mm) and Mcw (between 2·5- and 2·2-mm) and mmw (between 5·4- and 0·7-mm) and mcw (between 1·8- and 0·8-mm) I1 decreases OVJ (0·6 mm), while no statistically significant difference was found for molar extrusion, incisor inclination and OVB when compared with C.	A: Clinically significant long-term maxillary molar width increase can be achieved with I1. Because of crown tipping, the amount of reported long-term width increase varied with the reference point used for measurements. More transverse dental arch changes were found after puberty compared with before puberty. The difference may not be clinical significant (0·8 mm). No anteroposterior or vertical dental changes were associated with RME with Haas expander. Q: Lack of clear statement regarding the retention protocol and different landmarks for measurements.

Table 3. (continued)

Author, year, reference	Study design, total no of subjects	Diagnosis	Intervention (I) or Appliance (A) and control groups (C)	Expansion Technique	Outcome measures	Methods/ Measurement	Quality of the primary studies	Results	Author's Conclusion (A) and Author's Comments on the Quality of the Papers (Q)
Lagravere *et al.*, 2005 (24)	Systematic Review of 1 RCT, 4 P CTs and 4 non-controlled CTs; 89 subjects	Constricted arches	I1: Minne-expander (banded or bonded) I2: QH I3: Nitanium maxillary expander C: absent/AT	SME	Skeletal and dental effects	Dental cast, posteroanterior radiographs, lateral radiographs	NR	I1 increase the transversal width, with a skeletal response from the 28 to the 50% of the total expansion. No difference between bonded and banded I1. I2 can determine a small percentage of skeletal expansion, but the major effect is dentoalveolar. More skeletal effects are obtained in younger patients. I3 effects similar to those of I1.	A: No strong conclusion can be made on dental or skeletal changes after SME. Q: Absence of untreated control group for all of the included studies
Lagravere *et al.*, 2006 (25)	Meta-Analysis of 2 RCTs; 9 P CCTs and 3 non-controlled CTs; 335 subjects	NR	I1: Hyrax (with or without acrylic bite plates) I2: Haas C: Absent/AT	RME	Immediate transversal anteroposterior and vertical dental and skeletal effects	Dental cast, posteroanterior radiographs, lateral radiographs	Self-produced checklist: 14 *low* (<50% *of checks)*	Transverse dental changes. Increase of Mmw (from 6·04- to 6·74-mm), maxillary intermolar mesioapex root width (4·44 mm), maxillary intermolar angulation (approximately 3·10°), Mcw (5·35 mm; when measured from the crown apex). PA cephalometric radiographs showed a 3·9 mm increase in the maxillary interincisal apex width and a 2·98 mm increase in the midline diastema. Non-statistically significant mmw changes. *Vertical and anteroposterior dental changes.* Statistically significant extrusion of the maxillary molar cusp (0·53 mm), increase in overjet (1·29 mm) and change in angulation of the maxillary incisor to sella nasion (SN) plane (0·86 degrees). *Transverse skeletal changes.* Significant increase of nasal cavity width (2·14 mm) and left jugale-right jugale (2·73 mm) *Vertical and anteroposterior skeletal changes.* Statistically significant changes in the mandibular plane (with respect to the palatal plane - 1·65 mm and SN plane - 1·97 mm). No statistically significant changes of the palatal plane.	A: The greatest changes were in the maxillary transverse plane and they were more dental than skeletal. Few vertical and anteroposterior changes were statistically significant, and none was clinically relevant. Q: All the studies had methodological problems regarding sample selection, description and statistical approach.
De Rossi *et al.*, 2008 (26)	Systematic Review of 4 P CCTs; 152 subjects	NR	I1: BRMEA C: AT	RME	Vertical and sagittal skeletal effects	Lateral radiographs	NR	I1 produces downward movement of the maxilla and downward and backward rotation of the mandible, although the vertical effects seem to be smaller than those of the banded appliances.	A: Vertical effects are only partially controlled with bonded devices, there is no consensus in the literature regarding the maxillary sagittal displacement after RME; there is not sufficient evidence to support the use of BRMEA to control the undesirable effects of RME. Q: NR

Table 3. (continued)

Author, year, reference	Study design, total no of subjects	Diagnosis	Intervention (I) or Appliance (A) and control groups (C)	Expansion Technique	Outcome measures	Methods/ Measurement	Quality of the primary studies	Results	Author's Conclusion (A) and Author's Comments on the Quality of the Papers (Q)
Zuccati *et al.*, 2011 (27)	Systematic Review of 12 RCTs; n. of subjects NR	Posterior Crossbite	I1: QH C: UCG/AT	NR	Long-term transversal effects (stability)	Dental casts, lateral radiographs, CBCT, CT	Cochrane collaboration tool for assessing risk of bias: *unclear*	I1 shows stable results after 3 years from the treatment.	A: Many treatments appear to be successful in the short term, but challenges remain in the search for better long-term outcomes. Q: small sample size, bias and confounding variables, lack of blinding in measurements, and deficient statistical methods
Zhou *et al.*, 2013 (28)	Meta-Analysis of 2 RCTs and 12 P CCTs; 997 subjects	Transverse discrepancy	I1: RME I2: SME A1: QH, A2: Hyrax A3: Haas A4: Minne-expander C: UCG/AT	RME and SME	Long-term dental effects (post-expansion/ retention and net change): Mmw, Mcw, Mpw and mmw	Dental cast, lateral radiographs	Cochrane collaboration tool for assessing risk of bias: *3 low quality, 9 medium quality, 2 high quality*	*I1vs.Control*: Mmw: Significant increase post-expansion (4·45 mm) and in the net change (2·49 mm). Mcw: Significant increase Post-expansion (2·58 mm) and in the net change (2·27 mm). Mmw: Significant increase Post-expansion (0·49 mm) and in the net change (0·06 mm). *I2vsControl:* Mmw: Significant increase Post-expansion (4·09 mm) followed by a non-significant relapse (−0·40 mm). Significant net change (3·58 mm). Mcw: Significant increase Post-expansion (2·7 mm) followed by a non-significant relapse (−0·41 mm). Significant net change (2·64 mm). Mpw: Significant increase Post-expansion (3·86 mm) followed by a non-significant relapse (−0·16 mm). Significant net change (3·52 mm). mmw: Significant increase Post -expansion (1·19 mm) followed by a significant increase in the retention period (0·65 mm). Significant net change (2·02 mm). I1vs.I2 Mmw no significant changes in the post-expansion and retention period; net change significantly higher in SME. Mcw, Mpw and mmw: no significant difference.	A: SME is effective in expanding maxillary arch, while we cannot determine its effectiveness in mandibular arch expansion. RME is effective in expanding both maxillary and mandibular arches. Furthermore, SME is superior to RME in expanding molar region of maxillary arch. Q: Limited number of high-quality studies, different treatment strategies (expansion only or expansion plus fixed orthodontic treatment), and different measurement landmarks.

Table 3. (continued)

Author, year, reference	Study design, total no of subjects	Diagnosis	Intervention (I) or Appliance (A) and control groups (C)	Expansion Technique	Outcome measures	Methods/ Measurement	Quality of the primary studies	Results	Author's Conclusion (A) and Author's Comments on the Quality of the Papers (Q)
Bazargani *et al.*, 2013 (29)	Systematic Review of 2 RCTs and 8 non-controlled CTs; 256 subjects	NR	I1: Haas I2: Hyrax I3: bone-anchored maxillary expander, I4: tooth-anchored maxillary expander C: Absent/AT	RME	Immediate dental and skeletal effect	3d images from CBCT	Self-produced checklist: *8 low quality, 2 medium quality*	Dental Structures: Buccal tipping of the first molars between 7·5° and 1·0°. Midpalatal suture: The mean posterior expansion ranged from 1·6 to 4·33 mm; the mean anterior expansion ranged from 1·52 to 4·33 mm, corresponding also to 22%– 53% of total screw expansion. Nasal Cavity: Expansion range from 1·2-and 2·73-mm. Circummaxillary Sutures: Overall small changes (0·30- and 0·45-mm). Spheno-occipital synchonrosis: mean expansion of 0·6 mm. Orbital structures: small increase in volume (0·72 mL) and width (1·09 mm) but clinically insignificant.	A: Midpalatal suture amounted to 20%–50% of the total screw expansion. RME produced immediate significant changes in transverse dimensions of the nasal cavity, circummaxillary sutures, spheno-occipital synchondrosis, and aperture width. Q: Frequent shortcomings in study design, sample size and inadequate selection description. The majority of the articles were judged to be of low quality therefore, no evidence-based conclusions could be drawn from these studies.
Lione *et al.*, 2013 (30)	Systematic review of 4 RCTs; 2 P CCTs; 9 R CCTs, 15 non-controlled CTs, 807 subjects in 28 articles‡	NR	I1: Hyrax (bonded or banded) I2: Haas (bonded or banded I3: Bone-anchored expander I4: NiTi expander I5: QH C: absent/UCG/AT	RME	Skeletal transversal and vertical effects	Dental casts, posteroanterior radiographs, lateral radiographs, tridimensional radiographic techniques;	Self-produced checklist: *20 low quality, 8 medium quality, 2 medium-high quality*	Midpalatal suture opening range from 1·1 to 4·8 mm in the anterior region and from 1·2 to 4·3 mm in the posterior region. At the end of the active phase, RME resulted in a slight inferior movement of the maxilla (SN-PNS +0·9 mm; SN-ANS +1·6 mm). This downward movement of the maxilla and premature dental contacts are responsible for the mandible rotation in a downward and backward direction with a mean increase in the following variables: SN-MP, 1·7°; PP-MP, 1·5°; SN-GoGn, 1·1°.	A: RME always opened the midpalatal suture in growing subjects, regardless the type of appliance. The vertical changes were small (less than 2 mm or 2°, and may be not considered clinically relevant) and transitory. Q: The methodology of these investigations was generally of low and medium quality therefore, the findings should be interpreted with caution. Small sample size with no consecutive cases, bias and confounding variables, lack of method error analysis, blinding in measurements, deficiency or lack of statistical methods and absence of power analysis. A very serious limitation of most studies was the lack of an adequate untreated control group.

Table 3. (continued)

Author, year, reference	Study design, total no of subjects	Diagnosis	Intervention (I) or Appliance (A) and control groups (C)	Expansion Technique	Outcome measures	Methods/ Measurement	Quality of the primary studies	Results	Author's Conclusion (A) and Author's Comments on the Quality of the Papers (Q)
Agostino *et al.*, 2014* (31)	Cochrane Meta-Analysis of 15 RCTs; 657 subjects	Posterior crossbite	I1: Hyrax (tooth or tooth-tissue borne) I2: Hass (tooth or tooth-tissue) I3: Bone-anchored maxillary expander I4: Minne Expander (bonded or banded) I5: QH I6: expansion arch C: AT	RME and SME	Comparison between appliances for the correction of crossbite	Dental cast, posteroanterior radiographs, lateral radiographs	Cochrane collaboration tool for assessing risk of bias: *2 low risk of bias, 7 high risk of bias, 6 unclear risk of bias*	No statistical significant differences between RME appliances: -tooth borne and tooth-tissue borne I1 -tooth-tissue borne I2 and tooth borne I1 -tooth borne I1 and I3 -bonded and banded I4 No statistical significant differences between RME and SME, or Semi-Rapid and RME were also reported. No statistical significant differences between SME appliances: -I5 and I6	A: The evidence was of very low quality and was insufficient to allow the conclusion that any one intervention is better than another for any of the outcomes in this review. Q: The sample sizes were consistently small, More randomised controlled trials are required to address the question of what is the best treatment for posterior crossbites. 'Correction of crossbite' needs to be the primary outcome for all studies addressing this research question.

R: retrospective; P: Prospective; CCT: Controlled Clinical Trial; CT: Clinical Trial; RCT Randomised Clinical/Controlled Trials.

UCG: Untreated Control Group; AT: Alternative Treatment; RME: Rapid Maxillary Expansion; SME: Slow Maxillary Expansion; BRMEA: Bonded Rapid Maxillary Expansion Appliance; QH: Quad Helix.

CBCT: Cone-Beam Computer Tomography; CT: Computed Tomography.

NR: Not Reported.

Mmw: Maxillary intermolar width; Mpw: Maxillary interpremolar width; Mcw: Maxillary intercanine width; mmw: mandibular intermolar width; mcw: mandibular intercanine width.

*This paper also reports data about grinding and/or removable appliances that are not pertinent to our review.

†2 RCTs, 2 P CCTs and 1 R CCT only assess the effects of grinding.

‡Two studies reported the number of extracted teeth instead of the number of subjects.

expansion arch. The *short-term* was mainly defined as immediately after treatment, while the definition of *long-term* varied between a minimum of 6 months post-retention (32) and a maximum of 7 years post-retention (28).

Quality assessment of the included SRs and MAs

The Cohen's k coefficient for the AMSTAR was 0·93, indicating excellent inter-examiner agreement.

The AMSTAR score ranged from 4 to 10 (mean score 6·8). The AMSTAR items for each paper and the total AMSTAR scores are shown in Table 4. None of the papers was rated as *low quality*, whereas seven papers were rated as *moderate quality* and five papers were rated as *high quality.*

Regarding the design of the primary studies, two papers included only studies with randomisation, five papers included RCTs along with other types of studies and five papers included only non-randomised studies. The detailed LRD scores are shown in Table 4.

Synthesis of the results and quality of the body evidence

Short-term effects. The results of the short-term effects are shown in Table 5.

Dentoalveolar transversal effects of SME: Maxillary intermolar width. A significant increase was reported with the QH (22, 24, 28) (*very low* to *moderate* evidence), the Minne-expander (24) (*low* evidence) and the Nitanium maxillary expander (24) (*low* evidence). One study (31), pointed out no significant difference when comparing the bonded with the banded Minne-expander (*very low* evidence). Maxillary intercanine width. A significant increase with the QH (22, 28) was found (*low* evidence). Mandibular intermolar width. There was significant increase with QH (28) (*moderate* evidence).

Dentoalveolar sagittal and vertical effects of SME: No data were reported.

Dentoalveolar transversal effects of RME: Maxillary intermolar width. A significant increase with the Hyrax or Haas appliance (22, 25, 28) was revealed (*very low* to *high* evidence). One study (31), pointed out no significant difference when comparing the banded Hyrax (tooth borne) with the bonded Hyrax (tooth-tissue borne), the tooth-tissue borne Haas with the tooth-borne Hyrax, the tooth-borne Hyrax with the bone-anchored expander and the four-point banded Hyrax with the two-point banded Hyrax (*very low* evidence). Maxillary intercanine width. There was a significant increase with the Hyrax or Haas appliance (22, 25, 28) (*very low* to *high* evidence). Maxillary interpremolar width. A significant increase with the Hyrax or Haas appliance (28) was reported (*high* evidence). Mandibular intermolar width. A non-significant effect was reported in one study (25) (*low* evidence) whereas a significant increase was reported in another study (28) (*high* evidence) with the Hyrax or Haas appliance.

Dentoalveolar sagittal and vertical effects of RME: A significant increase in the distance between the maxillary molar cusp and the Palatal Plane (PP) and significant increase of the Overjet (OVJ) were found with the Hyrax or Haas expanders (25) (*very low* evidence).

Dentoalveolar transversal effects of SME versus RME: There was no significant difference between SME, performed with the Quad-Helix or the Minne-expander, and RME, performed with the Hyrax expander, at maxillary intermolar width (*moderate* evidence), maxillary intercanine width (*moderate* evidence), maxillary interpremolar width (*low* evidence) and mandibular intermolar width (*low* evidence). Regarding maxillary intermolar width, the same result was pointed out, also a more recent MA (31) after treatment with the two-bands expander (*very low* evidence).

Dentoalveolar sagittal and vertical effects of SME versus RME: No data were reported.

Skeletal transversal effects of SME: There was an increase in transversal dimensions with the QH, the Minne-expander or the Nitanium maxillary expander (24) (*very low* evidence).

Skeletal sagittal and vertical effects of SME: No data were reported.

Skeletal transversal effects of RME: With the Haas or Hyrax appliance, an increase in the distance between the left and right jugale points (25) (*low* evidence), an increase in the dimension of the posterior and anterior region of the midpalatal suture (29, 30) (*low* evidence) and an increase in the dimension of the canine region (30) (*low* evidence) were found.

Skeletal sagittal and vertical effects of RME: Upper jaw. Vertical movements with the Hyrax or Haas appliance were reported to be non-significant in one MA (25), (*low* evidence), while a small significant increase was reported in another SR (30) (*very low* evidence). A downward rotation of the maxilla was reported in

Table 4. Quality assessment of the included SRs/MAS. Methodological quality reported as AMSTAR items and total AMSTAR scores and study design of the primary studies included in each SR/MA reported according to the LRD scoring

	Schiffman & Tuncay, 2001 (21)	Petren *et al.*, 2003 (22)	Lagravere *et al.*, 2005 (10)	Lagravere *et al.*, 2005 (23)	Lagravere *et al.*, 2005 (24)	Lagravere *et al.*, 2006 (25)	De Rossi *et al.* 2008 (26)	Zuccati *et al.*, 2011 (27)	Zhou *et al.* 2013 (28)	Bazargani *et al.*, 2013 (29)	Lione *et al.*, 2013 (30)	Agostino *et al.*, 2014 (31)
Was an '*a priori*' design provided?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Was there duplicate study selection and data extraction?	CA	CA	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Was a comprehensive literature search performed?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Was the status of publication (i.e. grey literature) used as an inclusion criterion?	N	N	N	N	N	N	N	N	N	N	N	Y
Was a list of studies (included and excluded) provided?	N	N	Y	Y	N	Y	Y	Y	N	N	N	Y
Were the characteristics of the included studies provided?	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Was the scientific quality of the included studies assessed and documented?	Y	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y
Was the scientific quality of the included studies used appropriately in formulating conclusions?	CA	Y	Y	NA	NA	Y	NA	Y	Y	Y	Y	Y
Were the methods used to combine the findings of studies appropriate?	Y	Y	Y	NA	NA	Y	NA	Y	Y	Y	Y	Y
Was the likelihood of publication bias assessed?	Y	NA	NA	NA	NA	N	NA	NA	Y	NA	NA	N
Was the conflict of interest stated?	N	N	N	N	N	N	N	Y	Y	Y	N	Y
Total AMSTAR score	5	6	8	5	4	8	5	8	9	7	7	10
LRD score	II-III-IV	III*	III	III	II-III-IV	II-III-IV	III	II	II-III	II-IV	III-IV	II

AMSTAR SCORE – 'Yes' answer: 1 point; all the other answers: 0 point. Y = Yes; N = No; NA = Not Applicable; CA = Cannot Answer.
LRD score: I: Systematic Review; II: Randomised Clinical Trial; III: Study without randomisation; IV non-controlled study, V: Narrative review/expert opinion.
*Considering the primary studies assessing the outcomes pertinent to the current review.

Table 5. Results of the expansion procedures in the short-term and levels of evidence for each outcome

Outcome	Appliance	Author, year, reference	Type of synthesis	Effect	No. of. studies	No. of. participants	Quality of primary studies	Level of evidence
Short-term Transversal Dental effects SME								
Maxillary intermolar width	QH	Lagravere *et al.*, 2005 (24)	Narrative	+	3	39	nr	Very low
		Zhou *et al.*, 2013 (28)	MA	4·45	5	132	1 low/4 moderate-high	Moderate
		Petren *et al.*, 2003 (22)	Narrative	3·3–6·4	8	147	5 low/3 moderate	Low
	Minne-Expander	Lagravere *et al.*, 2005 (24)	Narrative	+	5	34	nr	Very low
	Ni-Ti Expander	Lagravere *et al.*, 2005 (24)	Narrative	+	1	16	nr	Very low
Maxillary intercanine width	QH	Zhou *et al.*, 2013 (28)	MA	2·58	4	82	1 low/3 moderate-high	Low
		Petren *et al.*, 2003 (22)	Narrative	1·3–5·2	8	147	5 low/3 moderate	Low
Mandibular intermolar width	QH	Zhou *et al.*, 2013 (28)	MA	0·49	5	132	1 low/4 moderate-high	Moderate
Short-term Transversal Dental effects RME								
Maxillary intermolar width	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	6·04–6·74*	8	166	low (<50% of checks)	Low
		Zhou *et al.*, 2013 (28)	MA	4·09	6	318	1 low/5 moderate-high	High
		Petren *et al.*, 2003 (22)	Narrative	5·5	1	10	Low	Very low
Maxillary intercanine width	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	5·35	6	142	low (<50% of checks)	Low
		Zhou *et al.*, 2013 (28)	MA	2·7	6	318	1 low/5 moderate-high	High
		Petren *et al.*, 2003 (22)	Narrative	3·2	1	10	low	Very low
Maxillary premolar width	Hyrax/Haas	Zhou *et al.*, 2013 (28)	MA	3·86	6	318	1 low/5 moderate-high	High
Mandibular intermolar width	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	0·49(NS)–0·53*	8	166	low (<50% of check)	Low
		Zhou *et al.*, 2013 (28)	MA	1·19	6	318	1 low/5 moderate-high	High
Short-term Vertical Dental effects RME								
Maxillary molar cusp to PP	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	0·53	2	55	low (<50% of check)	Very low
Short-term Sagittal Dental effects RME								
OVJ	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	1·29	2	55	low (<50% of check)	Very low
Short-term Transversal Dental effects RME vs. SME								
Maxillary intermolar width	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	−0·23 (NS)	3	104	1 low/2 moderate-high	Moderate
Maxillary intercanine width	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	0·69 (NS)	3	104	1 low/2 moderate-high	Moderate
Maxillary interpremolar width	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	1·35 (NS)	2	84	2 moderate-high	Low
Mandibular intermolar width	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	−0·68 (NS)	2	84	2 moderate-high	Low
Short-term Transveral Skeletal effects SME								
	QH	Lagravere *et al.*, 2005 (24)	Narrative	+	3	39	nr	Very low
	Minne-Expander	Lagravere *et al.*, 2005 (24)	Narrative	+	5	34	nr	Very low
	Ni-Ti Expander	Lagravere *et al.*, 2005 (24)	Narrative	+	1	16	nr	Very low

Table 5. (continued)

Outcome	Appliance	Author, year, reference	Type of synthesis	Effect	No. of. studies	No. of. participants	Quality of primary studies	Level of evidence
Short-term Transveral Skeletal effects RME								
Left jugale-right jugale	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	2·73	5	148	low (<50% of check)	Low
Posterior suture	Hyrax/Haas, Acrylic splint, Bone-Anchored ME, Tooth-Anchored ME	Bazargani *et al.*, 2013 (29)	Narrative	1·6 to 4·33	6	108	5 low/1 moderate	Low
	Hyrax/Haas	Lione *et al.*, 2013 (30)	Narrative	1·2 to 4·3	4	107	1 low/2 moderate/ 1 moderate-high	Low
Anterior suture	Hyrax/Haas, Acrylic splint, Bone-Anchored ME, Tooth-Anchored ME	Bazargani *et al.*, 2013 (29)	Narrative	1·52 to 4·33	6	108	5 low/1 moderate	Low
	Hyrax/Haas	Lione *et al.*, 2013 (30)	Narrative	1·1 to 4·8	6	149	3 low/2 moderate/ 1 moderate-high	Low
Intercanine width	Hyrax/Haas	Lione *et al.*, 2013 (30)	Narrative	1·5 to 4·3	3	61	3 moderate	Low
Short-term Vertical Skeletal effects RME								
Lower jaw	BREMA	De Rossi *et al.*,. 2006 (26)	Narrative	Downward rotation	4	nr	nr	Very low
Lower jaw (MP/SN angle)	Hyrax/Haas	Lagravere *et al.*, 2006 (25)	MA	1·97	9	188	low (<50% of checks)	Low
		Lione *et al.*, 2013 (30)	Narrative	1·7	5	122	5 low	Very low
Lower jaw (GoGn/SN angle)	Hyrax/Haas	Lione *et al.*, 2013 (30)	Narrative	1·1	2	107	2 low	Very low
Upper jaw	BRMEA	De Rossi *et al.*,. 2006 (26)	Narrative	Downward rotation	4	nr	nr	Very low
Upper jaw (PP/SN)	Hyrax or Hyrax acrylic or Haas	Lagravere *et al.*, 2006 (25)	MA	0·30 (NS)	9	188	low (<50% of checks)	Low
		Lione *et al.*, 2013 (30)	Narrative	1·7	1	20	1 low	Very low
Short-term Sagittal Skeletal effects RME								
Upper jaw	BRMEA	De Rossi *et al.*,. 2006 (26)	Narrative	Backward movement	4	nr	nr	Very low
Lower jaw	BRMEA	De Rossi *et al.*,. 2006 (26)	Narrative	Unclear	4	nr	nr	Very low

SME: Slow Maxillary Expansion; RME: Rapid Maxillary Expansion; MA: Meta-Analysis; QH: Quad-Helix; CG: control group; AT: alternative treatment; OVJ: Overjet; ME: Maxillary Expander; BRMEA: Bonded Rapid Maxillary Expansion Appliance; PP: Palatal Plane; MP: Mandibular Plane; GoGn: Gonion-Gnation; SN: Sella-Nasion.
*Measured on postero-anterior radiographs or dental cast.

one SR (26) with bonded expansion appliances, whereas unclear results were provided regarding skeletal sagittal movement (very low evidence). Lower jaw. With the Hyrax or Haas expander, a downward rotation of the mandible was reported in all the studies, based on different landmarks (25, 30) (*very low* to *low* evidence). Downward rotation and backward movement of the lower jaw are reported also with bonded expansion appliances (26) (*very low* evidence).

Skeletal transversal, sagittal and vertical effects of SME versus RME: No data were reported.

Long-term effects. The results of the long-term effects are shown in Table 6.

Dentoalveolar transversal effects of SME: Maxillary intermolar width. Roughly 95% of the initial expansion amount obtained with QH was maintained during the retention phase (*low* evidence) (21). After the retention phase, a residual expansion was reported (21, 22, 28) (*low* evidence). Maxillary intercanine width. With the QH a residual expansion post-retention was reported), (28). Mandibular intermolar width. With the QH, a very small amount of residual expansion was reported (28) (l*ow* evidence).

Dentoalveolar sagittal and vertical effects of SME: No long-term data were reported.

Dentoalveolar transversal effects of RME: Maxillary intermolar width. During the retention phase, approximately 85% of the initial expansion amount was maintained after RME with the Hyrax (*low* evidence) (21). Residual expansion after the retention phase was reported with the QH (27) (*low* evidence), and with the Hyrax or the Haas or the Haas in association with a fixed edgewise orthodontic appliance (*very low* to *moderate* evidence)(22, 23, 28). Maxillary intercanine width. A residual expansion after the retention phase was reported with the QH (27) (*low* evidence), the Haas or Hyrax (28) (*very low* to *moderate* evidence), and the Haas expander in association with a fixed edgewise orthodontic appliances (23) (*low* evidence). Maxillary interpremolar width. A residual expansion with the Hyrax or Haas (28) (*moderate* evidence) and the Haas expander in association with a fixed edgewise orthodontic appliances (23) (*low* evidence) was revealed. Mandibular intermolar width. A residual expansion with Hyrax or Haas (28) (*moderate* evidence) and the Haas expander in association with a fixed edgewise orthodontic appliances (23) (*low* evidence) was found. Mandibular intercanine width. There was a residual expansion with Haas appliance in association with a edgewise fixed appliance (23) (*low* evidence).

Dentoalveolar sagittal and vertical effects of RME: A slight reduction of the OVJ and an insignificant molar extrusion with the Haas expander in association with an edgewise fixed appliance (23) were found (*very low* evidence).

Dentoalveolar transversal effects of SME versus. RME: There was no significant difference between SME, performed with the QH or the Minne-expander, and RME, performed with the Hyrax at maxillary intercanine width (*low* evidence) and maxillary interpremolar width (*low* evidence) (28). Regarding the maxillary intermolar width, slightly more favourable results for SME were reported (*low* evidence) (28).

*Dentoalveolar sagittal and vertical effects of SME versus RME***:** No data were reported.

Skeletal transversal, sagittal and vertical effects of SME: No data were reported.

Skeletal transversal effects of RME: A residual expansion in the early maturation group and non-significant values in the late maturation group were reported, without information on the appliance (low evidence)(10).

Skeletal sagittal and vertical effects of RME: Non-significant sagittal changes at both upper and lower jaws were found, except for a significant more retruded position of the A point (*very low* evidence) (10). A slight downward rotation of both upper and lower jaws was found (*very low* evidence) (10). No information on the appliance was reported.

Skeletal transverse, sagittal and vertical effects of SME versus RME: No data were reported.

Discussion

The present SR aimed to summarise the current evidence from SRs and MAs on dental and skeletal effects produced by different palatal expansion modalities. In particular, the focus of the present study concerned the quality and the main findings of the SRs/MAs addressing this issue.

Quality assessment of the included SRs and MAs

SRs and MAs are generally considered the cornerstone of the evidence-based health care. Nevertheless, as

Table 6. Results of the expansion procedures in the long-term and level of evidence for each outcome

Outcome	Appliance	Author, year, reference	Type of synthesis	Effect	No. of. studies	No. of. participants	Quality of primary studies	Level of evidence
Long-term Transversal Dental effects SME								
Maxillary intermolar width (with retention)	QH	Schiffman&Tuncay, 2001 (21)	MA	(Initial 5·6) 5·5	2	27	2 moderate	Low
Maxillary intermolar width (post- retention)	QH	Zhou *et al.*, 2013 (28)	MA	(initial 4·45) 2·49	2	53	2 moderate-high	Low
		Petren *et al.*, 2003 (22)	Narrative	(initial 3·3–5·4) 3·6–5·1	8	147	5 low; 3 moderate	Low
		Schiffman & Tuncay, 2001 (21)	MA	(Initial 5·6) 4·09	2	27	2 moderate	Low
Maxillary intercanine width (post-retention)	QH	Zhou *et al.*, 2013 (28)	MA	2·27	2	53	2 moderate-high	Low
		Petren *et al.*, 2003 (22)	Narrative	2·2–3·3	8	147	5 low; 3 moderate	Low
Mandibular intermolar width	QH	Zhou *et al.*, 2013 (28)	MA	0·06	2	53	2 moderate-high	Low
Long-term Transversal Dental effects RME								
Maxillary intermolar width (with retention)	Hyrax	Schiffman & Tuncay, 2001 (21)	MA	(initial 6·0) 4·4	3	39	3 moderate-high	Low
Maxillary intermolar width (post-retention)	QH	Zuccati *et al.*, 2013 (27)	Narrative	3·4–4·6	4	nr	4 moderate-high	Low
	Haas/Hyrax	Zhou *et al.*, 2013 (28)	MA	3·58	3	190	3 moderate-high	Moderate
		Petren *et al.*, 2003 (22)	Narrative	5·4	1	10	1 low	Very low
	Haas (+fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	4·0–4·5*	2	133	nr	Low
	Hyrax	Schiffman&Tuncay, 2001 (21)	MA	(Initial 6·0) 3·56	3	39	3 moderate-high	Low
Maxillary intercanine width (post-retention)	QH	Zuccati *et al.*, 2013 (27)	Narrative	1·4–3·2	4	nr	4 moderate-high	Low
	Haas/Hyrax	Zhou *et al.*, 2013 (28)	MA	2·64	3	190	3 moderate-high	Moderate
		Petren *et al.*, 2003 (22)	Narrative	3·3	1	10	1 low	Very low
	Haas (+fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	2·3–2·5*	2	133	NR	Low
Maxillary interpremolar width (post-retention)	Haas/Hyrax	Zhou *et al.*, 2013 (28)	MA	3·52	3	190	3 moderate-high	Moderate
	Haas (+fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	4·2–4·7*	2	133	NR	Low
Mandibular intermolar width (post-retention)	Haas/Hyrax	Zhou *et al.*, 2013 (28)	MA	2·02	3	190	3 moderate-high	Moderate
	Haas (+fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	0·7–2·5*	2	133	NR	Low
Mandibular intercanine width (post-retention)	Haas (+fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	0·8–1·5*	2	133	NR	Low
Long-term Sagittal Dental effects RME								
OVJ (post-retention)	Haas (+ fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	−0·6	1	25	NR	Very low
Long-term Vertical Dental effects RME								
Molar extrusion	Haas (+ fixed edgewise)	Lagravere *et al.*, 2005 (23)	Narrative	NS	1	25	NR	Very low
Long-term Transversal Dental effects SME vs. RME								
Maxillary intermolar width (post-retention)	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	−0·75 (larger in SME)	2	44	2 moderate-high	Low
Maxillary intercanine width (post-retention)	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	1·45 (NS)	2	44	2 moderate-high	Low

Table 6. (continued)

Outcome	Appliance	Author, year, reference	Type of synthesis	Effect	No. of. studies	No. of. participants	Quality of primary studies	Level of evidence
Maxillary interpremolar width (post-retention)	Minne-expander/ QH vs. Hyrax	Zhou *et al.*, 2013 (28)	MA	1·06 (NS)	2	44	2 moderate-high	Low
Long-term Transversal Skeletal effects RME								
Maxillary width	Unclear	Lagravere *et al.*, 2005 (10)	Narrative	Early maturation group 3 mm; late maturation group 0·9 (NS)	1	42	1 moderate (60% of checks)	Low
Long-term Sagittal Skeletal effects RME								
A-point	Unclear	Lagravere *et al.*, 2005 (10)	Narrative	−1·05°	1	25	1 low (45% of checks)	Very low
Other variables (upper and lower jaw)	Unclear	Lagravere *et al.*, 2005 (10)	Narrative	NS	1	25	1 low (45% of checks)	Very low
Long-term Vertical Skeletal effects RME								
Lower jaw - MP/SN	Unclear	Lagravere *et al.*, 2005 (10)	Narrative	−0·85°	1	25	1 low (45% of checks)	Very low
Upper jaw - SN/PP	Unclear	Lagravere *et al.*, 2005 (10)	Narrative	0·8°	1	25	1 low (45% of checks)	Very low
Upper jaw - SN/GoGn	Unclear	Lagravere *et al.*, 2005 (10)	Narrative	0·8°	1	25	1 low (45% of checks)	Very low

SME: Slow Maxillary Expansion; RME: Rapid Maxillary Expansion; MA: Meta-Analysis; QH: Quad-Helix; CG: control group; AT: alternative treatment; OVJ: Overjet; ME: Maxillary Expander; BRMEA: Bonded Rapid Maxillary Expansion Appliance; PP: Palatal Plane; MP: Mandibular Plane; GoGn: Gonion-Gnation; SN: Sella-Nasion.
*Measured from the lingual gingival margin or from the centroid.

with all other publications, the value of a SR depends on the methodological quality, and it is crucial for the readers to critically appraise the findings with appropriate instruments. The AMSTAR is a valid, reliable and largely used tool for the assessment of the methodological quality of SRs and MAs (32, 33).

In our study, the only AMSTAR item that presented a Yes answer for all the included SRs/MAs was the *item 1* (*'Was an 'a priori' design provided?'*). It refers to the existence of a registered protocol, or pre-determined *a priori* published research objectives, but since databases for protocol registration (e.g. PROSPERO-International Prospective Register of Systematic Review (41)) have been recently introduced, in our study we took into consideration the chronological limitation and attributed an affirmative answer whenever the research question and inclusion criteria seemed to have been clearly established before conducting of the review. Such an approach should prevent the review method from being influenced by reviewers' expectations.

Frequent items to lose points in the AMSTAR total score included: *item 4* (*'Was the status of publication, i.e. grey literature, used as an inclusion criterion?'*), *item 10* (*'Was the likelihood of publication bias assessed?'*), and *item 11* (*'Was the conflict of interest stated?'*). In the interpretation of the AMSTAR score, it has to be taken into account that the items have a different weight in the overall quality (34). For instance, not reporting the conflict of interest has a lower impact than introducing a publication bias. Publication bias is a major threat to the validity of any type of review, so whenever a meta-analysis is not possible, including data from unpublished trials appear to be one obvious way to avoid this issue (14) and must be critically improved.

The other item that was unchecked in half of the papers was *item 5 ('Was a list of studies, included and excluded, provided?')*, due to the frequent lack of the references of the excluded papers.

The paper with the highest AMSTAR scores was a Cochrane MA (31). This result is in accordance with previous studies that report the quality of Cochrane SRs being better than that of non-Cochrane reviews (35–37). These findings underline the importance of several levels of peer-review and standardised guidelines to improve the quality of the literature. Furthermore, the Cochrane SR was the only updated paper, showing that more efforts should be made to keep non-Cochrane reviews constantly updated.

To gain a wider perspective on the overall quality of the included SRs/MAs, the LRD score was used to report the design of the primary studies. This instrument was previously adopted in SRs of SRs (15, 34), but its major limitation is the weak definition of *controlled studies* (LRD III), as it generally includes both untreated control groups and alternative treatment groups.

According to our findings, four SRs/MAs included also non-controlled studies: this choice dramatically reduces the strength of the conclusions, but it still underlines important weaknesses in the primary literature on specific topics.

In seven SRs the literature search resulted in the inclusion of RCTs, but only two of these reviews were entirely focused on randomised studies. From the total number of 20 RCTs included across the SRs analysed, five RCTs overlapped in three SRs/MAs and six RCTs overlapped in two SRs/MAs. This is due to the different inclusion criteria and outcomes of the studies.

Synthesis of the results and quality of the body evidence

After pooling the data from the included SRs/MAs, it was impossible to perform a MA due to the high heterogeneity of methodologies and endpoints. The main factors that affected the comparability of the results were: the heterogeneity in the expansion protocol (appliance and rate of screw activation), the variability in the materials (radiographs or dental cast), landmarks and measurements, the lack of clarity of the endpoints and the unclearness in the initial diagnosis.

Weakness and variability in the definition of *long-term* was a further factor limiting the validity of the results of the current SR of SRs. The time range considered in the included SRs varied from more than 6 months up to more than 5 years after retention period, determining considerable inconsistencies in the reported outcomes.

The major limit of the current SR of SRs was the use of a scale of statements to assess of the quality of the body evidence that had not been previously tested or validated, but was proposed as modified from existent tools adopted in recent Cochrane overviews of SRs (17, 18, 38). The proposed tool resembles the concepts of study limitation, publication bias, imprecision, inconsistency and indirectness required for the

GRADE levels of evidence (39), and provides a transparent, objective and reproducible assessment. The cut-offs were established by reaching consensus among the authors of the review. We were unable to adopt the GRADE, as suggested by the Cochrane Collaboration, since frequently raw data from primary studies were unavailable to provide the Summary of Findings table.

High evidence: According to the findings of the current study, the highest evidence was provided regarding the dentoalveolar short-term transversal effects of RME.

In the included review, frequently data from Hyrax and Haas appliance were combined. Even if pooling data from different appliances provides better evidence regarding the expansion modality (RME) as more data are collected, it must be taken into account that it can limit the applicability of the results since the appliances might differ in biomechanics and provide different effects.

The greatest expansion effect was obtained on the molars, with progressively reduced expansion in the anterior part of the arch. This can be explained by the design of the appliances that exert their force directly on the posterior teeth.

Even though the expansion force was not applied on the inferior teeth, mandibular intermolar width was found to be increased of 1·19 mm after treatment with Hyrax or Haas expander, supporting the hypothesis of spontaneous adaptation of the occlusion (40).

Moderate evidence: Different from what was pointed out with RME, the effect of SME on the lower molars was found to be small and clinically not relevant (0·49 mm), thus indicating a lesser spontaneous adaptation of the lower dentition, probably due to the different speed in movement.

Focusing on the amount of expansion achieved with the two expansion modalities, the findings of the current review could provide the general impression that the short-term results obtained with RME are better than those achieved with SME. However, the direct comparison of the two techniques pointed out with moderate evidence that no statistical significant difference exists. Therefore, the choice between the two activation modalities is still determined by the clinicians' expertise.

Long-term dental effects of RME with the Haas or Hyrax expander are supported by moderate evidence, and relapse to some extent was found after the retention phase. Interestingly, Zhou and co-workers (28) assessed also the dental changes during the retention phase, pointing out no significant differences during the retention period. Despite the primary role of retention in the maintenance of the treatment result, the studies assessing long-term dental effects frequently lack a clear statement of the retention protocol. It is strongly suggested for future studies to standardise and adequately report the retention techniques and the follow-up periods, in order to properly assess the amount of relapse. Furthermore, without orthodontic intervention, natural dental arch width and arch perimeter loss from late adolescence to the fifth/sixth decade of life might occur (41). Therefore, a clear description of a later phase of fixed orthodontics, should be reported in future studies.

Low evidence: The skeletal effects of RME have been extensively investigated, reporting that this technique always produces immediate transverse skeletal changes on the maxilla regardless the type of palatal expander. However, the differences in landmarks and measurements adopted prevented the pooling of data from numerous studies; therefore the best level of evidence found for this outcome was *low*.

Interestingly, two SRs (23, 30)suggested that RME was able to induce significantly more favourable skeletal changes when it was performed before the pubertal growth peak. Therefore, treatment timing might must to be taken into account for future clinical studies on this outcome.

Long-term dental effects of SME are also reported with a *low* level of evidence due to the small number of primary studies and small sample size. Limitations to these findings are similar to those pointed out for RME: lack of retention protocol, lack of defined follow-up period and absence of a description of the fixed orthodontic treatment phase.

Very low evidence: Short-term skeletal effects of the SME are reported in only one SR, with a *very low* level of evidence. In particular, an increase in maxillary dimension was pointed out with no details on the amount of the increase or on the landmark considered.

Concerning immediate vertical and sagittal skeletal changes after RME treatments, *very low* evidence of a more backward and downward position of the mandible and a downward position of the maxilla was reported. It has been argued that the movement of the maxilla during the expansion period can cause premature dental contacts, which can be responsible for the mandible rotation. This is supported by the lesser downward and backward displacement of the mandible found with bonded appliances, probably due to the absence of occlusal interference, even though these movements are not completely eliminated (26). However, the evidence substantiating this outcome is still too limited to support the use of bonded appliances in patients with vertical growth patterns.

Long-term transversal skeletal effects of RME were studied in only one SR, and the reported evidence is generally *very low* due to the scarcity of valid primary literature. Interestingly, as for the dentoalveolar effects, one SR reported higher stability in transverse skeletal maxillary increase in the group treated before the pubertal peak than in the group treated after the pubertal peak (10), but this finding needs to be further investigated.

Only one MA (31) assessed the differences in the effectiveness of several expansion appliances, reporting *very low* evidence of non-significant results. In our opinion, this seems to be a crucial point in the evidence-based decision-making that should be further investigated in order to provide the best treatment option.

Conclusions

1. The quality of the SRs and MAs on the effects of palatal expansion ranged between moderate and high (from 4 to 10);
2. Two studies (one MA and one SR) included only RCTs (LRD II), and the only included Cochrane SR reported the highest AMSTAR and LRD scores;
3. Palatal expansion is an effective procedure in the resolution of dental posterior crossbite since it always produces an increase in transverse dimension in the short-term. The overall evidence supporting these outcomes is lower for SME than for RME, due to the lesser quality and lower number of primary studies.
4. An increase of the skeletal transversal width is always present, but reported to be lower than dentoalveolar expansion. More research is needed to confirm this finding with RME, and even more with SME.
5. Dentoalveolar long-term expansion data are supported by *moderate* evidence for RME and *low* evidence for SME. However, these results are still unclear due to the variability in retention protocol, follow-up periods and the absence of untreated control groups.
6. Skeletal long-term expansion data are poor for RME and supported by *very low* evidence. The same outcome is not reported for SME.

Important gaps in the evidence provided by SRs and MAs on palatal expansion concern the short- and long-term comparisons of the skeletal effects of RME versus SME, the long-term assessment of the skeletal effects of SME, and the evaluation of vertical and sagittal dental and skeletal short- and long-term effects of SME.

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Disclosure

The authors of this manuscript declare that they have no conflict of interest.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Table S1 PubMed search strategy.

Table S2 References excluded and reason for the exclusion.