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Effects of Maxillary Arch Expansion: A Systematic Review of Systematic Reviews

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ABSTRACT

Purpose: The aim of this overview was to summarize the available systematic reviews (SRs) and meta-analyses (MAs) reporting the effects of maxillary expansion (ME).

Material and Methods: 5 databases were electronically searched up to May 2019. The outcomes of interest were the craniofacial effect of ME; the effect of ME on the transverse dimension of the maxillary and the mandibular arches, the midpalatal suture, the facial soft tissue, the anteroposterior and vertical jaws relationship and the adjacent sutures, the retention period after ME, the root resorption and periodontal problems associated with ME. The quality of the included reviews was assessed using AMSTAR, LRD tool and according to a pre-determined level of evidence.

Results: The initial search yielded 4390 studies and 25 SRs/MAs were included finally. The quality of evidence was high in 4 reviews, while the rest of the reviews ranged from low to moderate.

Conclusions: High quality evidence supported the dento-alveolar effects of slow and rapid ME in growing patients, whereas the amount of skeletal expansion gained was debatable. There was also spontaneous mild increase in the mandibular arch width and the negligible soft tissue changes due to ME. Moderate quality evidence reported negligible vertical changes occurring following RME.

Keywords: Maxillary expansion, Slow maxillary expansion, Rapid maxillary expansion, Implant-supported maxillary expansion, Bone-supported maxillary expansion, Overview, Systematic review

Abbreviations: SR: Systematic Reviews; MA: Meta-Analyses; ME: Maxillary Expansion; RME: Rapid Maxillary Expansion; SME: Slow Maxillary Expansion; SRME: Semi Rapid Maxillary Expansion; MPS: Mid-Palatal Suture; LRD: Level of Research Design Scoring; LQE: Low Quality Evidence; MQE: Moderate Quality Evidence; HQE: High Quality Evidence; RCT: Randomized Controlled Trials; CBCT: Cone Beam Computed Tomography; QDH: Quad Helix; EP: Expansion Plates

INTRODUCTION

Transverse maxillary deficiency or posterior crossbite is clinically identified when the lower teeth occlude in a buccal position relative to the upper teeth [1]. Posterior crossbites could be of skeletal or dental origins [2]. Be it of any type, posterior crossbite is not self-corrected and should be treated once diagnosed to allow optimum coordination of the maxillary and mandibular dental arches, prevent functional shifts and wear of the permanent teeth, prevent dentofacial asymmetry and temporomandibular joint disorder [3,4]. Consequently, maxillary expansion (ME) has gained much popularity in the orthodontic community and became an integral part of many orthodontic treatments [5].

However, upon reviewing the orthodontic literature, one can find various proposed maxillary expanders and expansion protocols [6], yet there is no consensus regarding which appliance design or activation rate benefits our patients the most. ME rate can be rapid, so-called rapid maxillary expansion (RME), with an expansion rate of 0.5 mm per day, or slow, so-called slow maxillary expansion (SME), with an expansion rate of 0.25-0.5 mm per week [7]. A clear

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outcome and thereby specific indications for each expansion rate could not be established, where both RME & SME are reported to increase the skeletal transversal width, but delineated to be lower than the dento-alveolar expansion attained [8].

Additionally, the ideal age for ME is still debatable. Although it is recommended to treat transverse deficiencies relatively early up to the skeletal growth spurt [9], the midpalatal suture (MPS) fusion is poorly correlated with patient age and gender [10], rendering clear cut indications for surgically assisted ME indefinite.

ME effects surpassed the maxilla to include most adjacent structures [11,12]. The maxillo-mandibular intimate articulation empowered ME not only to increase the transverse palatal dimension, but also to influence the sagittal and vertical facial proportions [13], the mandible with its temporomandibular articulatory system [14], the airway spaces [15] and more. Moreover, the advent of bone anchored ME [16] and the recent modalities detecting MPS maturation [10], have expanded the patients age range that can be treated successfully using the basic ME protocols.

In attempt to summarize the massive amount of evolving data, systematic reviews (SRs) and meta-analyses (MAs) are acknowledged [17]. Not surprisingly, the number of SRs exploring the effects of ME has rapidly escalated. However,

their validity is influenced by the methodology [18]. Aiming to recapitulate and critically appraise the best available evidence for both clinicians and researchers, we performed a SR of the published SRs/MAs to provide an overview of all reported ME craniofacial effects [19].

OBJECTIVES

The aims of the current overview were to: (i) Summarize the reported outcomes of ME dentoalveolar and craniofacial treatment effects, (ii) Evaluate the methodological quality of the SRs/MAs, and (iii) Provide a clinical guideline for orthodontists regarding ME protocols, expansion appliances and the suitable age range for ME treatment based on the best available evidence.

METHODS

Protocol registration

This overview followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [20]. The review protocol was registered at PROSPERO (International prospective register of systematic reviews) with registration number: CRD42018103702.

Eligibility criteria

The inclusion and exclusion criteria of the reviews are mentioned in (Table 1).

Category	Inclusion criteria	Exclusion criteria
Participants	a. Patient with constricted maxilla.b. Patients with posterior crossbite.	Studies involving subjects with defects in oral and maxillofacial regions (e.g., cleft lip and palate), dental pathologies (e.g., dental ankylosis), and medical conditions (e.g., diabetes mellitus).
Intervention	Any type of tooth-borne/ tooth tissue-borne/ bone- borne expanders.	 a. Combination of rapid maxillary expansion with other appliances e.g., Facemask, chin cup, etc. b. Surgically assisted rapid maxillary expansion (SARPE).
Outcomes	 a. Primary: Amount of transverse correction (skeletal and dental). b. Secondary: Effect of maxillary expansion on the transverse dimension of the mandible, the vertical and anteroposterior jaws relation, midpalatal suture and facial soft tissues. 	Any other outcome; effect of expansion on root resorption, periodontal health, circummaxillary sutures, nasal airway, TMJ, obstructive sleep apnea etc.
Study design	Systematic reviews and meta-analyses.	a. Primary studies.b. Narrative reviews.c. Commentaries on reviews.
Language restriction	Studies written in English language.	Studies written in other languages.

Search strategy, Study selection and Data collection

Five databases (PubMed, Cochrane library central, LILACS, ScienceDirect and Web of Science) were electronically searched up to May 2019 using the search strategy "(Maxillary transverse discrepancy OR upper dental arch constriction OR unilateral posterior crossbite OR bilateral posterior crossbite OR maxillary constriction OR narrow maxilla OR orthodontic patients OR retroclined molars OR cross-bite) And (Rapid maxillary expansion OR rapid palatal expansion OR maxillary disjunction OR palatal disjunction OR Palatal Expansion OR RME OR SME OR RPE OR Hyrax OR quad helix OR Haas expander Or jack Screw OR surgically assisted palatal expansion OR surgically facilitated palatal expansion OR SARPE OR surgically assisted rapid palatal expansion OR surgically assisted rapid palatal expansion OR surgically maxillary expansion OR corticotomy)".

Hand-search of the European Journal of Orthodontics, American Journal of Orthodontics and Dentofacial Orthopedics, Orthodontist and Craniofacial Research and The Angle Orthodontist was also performed. Electronic search of the grey literature at ProQuest and PROSPERO was performed, in addition to searching the conference abstracts of scientific congresses (European Orthodontic Society and International Association of Dental Research).

Following exclusion of the internal and external duplicates, all resulting titles then abstracts were scanned, and the reviews that seemed to fulfil the eligibility criteria were read in full-text. SRs/MAs which satisfied all the eligibility criteria were included. The reference lists of the included SRs/ MAs were also investigated. The search and study selection were independently accomplished by two reviewers (A.A. and M.A.). In case of any disagreements, the third reviewer (Y.M.) was consulted for a conclusive decision.

Data items and collection

Data about Authors, Year of publication, Study design, Intervention, Total number of subjects, Outcome, Quality of the primary studies, Results, and Author's conclusions were extracted from the included SRs/MAs.

Methodological quality assessment of the included SRs and MAs

The methodological quality was assessed using 'A Measurement Tool to Assess Systematic Reviews' (AMSTAR) [18]. For each question included in the AMSTAR checklist, 'yes' answers were scored 1 point, and the other answers were scored 0 point. According to the number of criteria met and hence the total score, the methodological quality was rated as 'Low' (total AMSTAR score \leq 3), 'Moderate' (total AMSTAR score \geq 4 - 7) or 'High' (total AMSTAR score \geq 8). The inter-examiner

reliability for the AMSTAR scores was calculated by means of Cohen's k coefficient.

Quality assessment of the body of evidence

The design of the primary studies included in each SR/MA was assessed using the Level of Research Design scoring (LRD) [21-24], a scoring system based on the hierarchy of evidence.

For each SR/MA, the quality of the body of evidence was also appraised according to a pre-determined set of levels of evidence According to the number [8]. of downgrades/scores, the evidence of each review was classified as: very low (>5 downgrades), low (4-5)downgrades), moderate (2-3 downgrades) or high (0-1 downgrade) [8]. Quality of the individual studies was not reassessed, but stated as judged by the authors of the reviews. Finally, the overall quality of the review was assessed by the three reviewers (A.A., M.A., Y.M.) based on the individual AMSTAR [18], LRD [21-24] and body of evidence [8] scores.

RESULTS

Study selection: Search results and study selection are detailed in the PRISMA flow diagram in (Figure 1). A total of 4390 articles were identified through electronic and manual searching. After duplicates removal and screening by title and abstract, 30 studies were considered eligible and full texts were thoroughly inspected. 5 articles [1,8,25-27] were excluded following full-text examination. Harrison and Ashby [1] was excluded as it was updated in a recent review [10] which was included, Bucci [8] was an overview, Pithon [25] studied the combined effect of ME and facemask, Isfeld [26] evaluated technologies and methodologies capable of assessing MPS maturation, Andrade [27] studied the functional changes due to posterior crossbite rather than ME.

Finally, 25 SRs/MAs were included in the qualitative synthesis, and were classified according to their main outcome into 8 groups as shown in (**Table 2**).

15 reviews [5,7,28-38] were primarily concerned with the effect of ME on the transverse dimension of the maxillary arch &/or maxilla, one review [39] was primarily concerned with the effect of ME on the transverse dimension of the mandibular arch, two reviews [13,40] studied the effect of ME on the anteroposterior and vertical jaws relationship, one review [11] studied the effect of ME on the adjacent sutures and orbital structures, two reviews [12,41] studied the effect of ME on facial soft tissue, one review [42] studied the retention period after ME, two reviews [43,44] studied the root resorption associated with ME, and one review [45] studied the periodontal problems associated with ME. The data extracted from each review are shown in (**Table 3**).

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the n	nax	illary	arch &/or n	naxilla.			[34], A	lgharbi [6], Can	navale	[35],	Gid	wan	i [36], k	Crüsi	[37	7] <u>.</u>
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Effec	ct o	of max	illary expan	ision on the anter	opost	erior and	De Rossi [12] Egros [40]											
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Effec	ct o	of max	illary expan	sion on facial sof	ue.	Huang [12], Staderini [41].												
The	Ret	tentior	n period afte	er maxillary expan	nsion.		Costa [42].											
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Table 2. The Systematic reviews and meta-analyses included in the final qualitative synthesis.

agravère [31]	SR & MA	nteroposterior, and vertical dental and	Total (n=14), rospective CT (n=14).	(n=3). Hyrax (n=4). -Haas (n=5). Haas vs Hyrax (n=1). Bonded hyrax vs banded	335	ental changes. -Vertical and	nteroposterior ental changes.	-Transverse skeletal	changes. - Vertical and	nteroposterior skeletal	assessiment tool. A secondary level of	radiographs	nowed 3.9 mm ncrease in the	axillary inter-	incisal apex vidth and 2.98	im increase in	the midline diastema.	-Vertical and	ental changes:	-Maxillary	iolar cusp was	skeletal	expansion. -Few vertical	-
Zuccati [32] L	SR	increasing the a width between the maxillarv	Total (n=12 RCTs).	(BAME) and tooth anchored maxillary expanders (TAME) (n=1). -RME vs semi- rapid SRME	Not mentioned in the review.	in the inter-	canine width a measured on d	casts, radiographs,	computed tomography, or	CBCT. a -Stability of the	assessing bias. Low risk of bias (n=3).	Moderate rich and the dentition. Four-	band RME	appeared to be n indicated when	severe anterior	accompanied n	by a tapered	arcn rorm, and two-band RME	is d	recommended in the mixed	dentition when n	rotce produced by the two	types of	appliances was
Zhou [33]	SR & MA	effectiveness of RME and SME for transverse	Total (n=14); 2 RCTs & 12 CCT.	turns), or more per day over a period of 1-3 weeks, and approximate 100 N across the midpalatal	993	widths and mandibular inter-moler	widths. For each	outcome, three	were studied;	changes	assessing bias. Low risk of bias (n=2).	[pooled MD =	2.7 mm, followed by a	non-significant	relapse pooled $MD = -$	0.41mm. The	pooled MID of net change was	2.64mm (95 per	3.08.	Maxillary inter-	premolar width: The exnension	-SME is	superior to	KME IN
Agostino [7]	Cochrane	effects of orthodontic treatment for	Total (n=15 RCTs).	(QDH) versus expansion plate (EP) (n=2). -Early treatment with fixed bonded Hyrax	619	changes in the width between	canines, or both.	-Stability of	correction.	symptoms of	assessing bias. -Low risk of bias (n=2).	plate: The	pooled MLD suggests that	HQD	appliances can achieve 1.15	mm more molar	expansion than expansion	plates.	expansion was	0.19 mm in	favor of QDH	expanding the inter-molar	width in	children with
Liu [34]	SR	suture opening and the long- term skeletal	Prospective C1 (N=3), Prospective CCT (N=2), Retrospective	Haas/ hyrax expanders.	Not mentioned	(mm). -The post-	retention effects of RME.	-The percent of midpalatal	suture opening relative to the	total screw activation.	medium mgu quality (n=2). Medium quality (n=4).	total screw expansion.	Mean	expansion at the inter-molar	midpalatal	from 1.6-4.3	mm, or 22.9-	SCTEW	expansion.	Long-term changes of	midpalatal	the total screw expansion.	-After RME,	the suture
Algharbi [6]	SR	designs and different activation	Total (n=7); 6 RCTs & 1 prospective CCT.	group versus tooth-bone- borne group (hybrid) (n=1). -RME versus SME (n=2). -Banded	273	dentoalveolar effects of	RME appliances in	children and	Secondary	difference in	High level of quality (n=1). Moderate level	mtdpalatal suture width	and the distance	between the apices of the	palatal roots of	molars, which	indicated more	dental tipping in the tooth-	tissue-borne	appliance (Haas).	Banded versus	-Findings of a	dental-tipping between	different
Cannavale [35]	SR & MA	transversal width changes after RME and	Total n=18; Retrospective cohort (N=14), prospective	Hyrax $(N=5)$. Hyrax $(N=7)$ Hyrax or Haas (N=1) Acrylic splint expander (N=5).	758	Inter-canine	width and inter- molar width at	the end of RME treatment and	after long-term follow-up mean	of 9.95 years.	Ottawa Quality Assessment Scale	of treatment	(93%UI 4.28; 5.42 mm).	- RME was	associated with relapse of inter-	molar width of	-0.4/ mm (95%CI -0.79; -	0.15 mm) at the	follow-up	(mean of 9.95	years). - A negative	start of KME and the end of	treatment, and a	relapse of -0.47
Gidwani [36]	SR	in children with posterior crossbite as	ketrospective study(n=2), prospective controlled clinical trial	expansion plate (n=6), Haas, hyrax and QH (n=1), QH and NiTi tandem loop (n=1).	632	The amount of	expansion was measured using	intermolar width between	the two permanent	molars.	Not evaluated.	Intermolar	widdn increase using QH	appliance	ranged between (3.6 & 5.7 mm)	immediately	atter removal of the	appliance,	amount retained	ranged between	(3.4 & 5.1	produced by	QH appliance is equal to or	hetter than
Krüsi [37]	SR & MA	anchored RME versus conventional	Total (n=6); 6 RCTs.	hybrid tooth- bone-borne RME versus conventional (tooth-bome) RME (n=3), both bone-	264	tooth-bone- borne RME and	conventional tooth-borne	RME. Secondary	outcomes: Dental	positional/incli nation changes,	or quanty (n=2), low level of quality (n=2),	Cl - 1.0 to - 0.1mm), (ii)	less inter-first-	premolar width expansion (MD	- 1.8mm; 95%	0.9mm), (iii)	less buccal	inclination of the first	premolar (MD -	5.1; 95% CI - 6.8 to - 3.4).	(iv) less buccal	bone-borne	RME was associated with	less patient
Seif-Eldin [38]	SR	transverse maxillary measurement in	CC1 (n=4) Retrospective study (n=1), prospective CCT with a	The effect of RME in pre and post pubertal subjects (n=2), the effects in pre-pubertal subjects only	377	transverse skeletal measurements	following RME.	Secondary	detect changes in Mavillanu	and mandibular	Non- Randomized Studies).	All studies In both groups,	intermolar	width increase	waas about 9 mm on average.	On the long-	term: in the pre- and post-	pubertal	groups, NMLE therapy	produced a	significant	patients treated by tooth-tissue	borne RME	before the
							Effect of	maxiliary expansion on	the transverse dimension of	the mandibular arch.														

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Alves [39]	SR	changes in the mandibular dental arch.	Total (n=6); 3 RCTs & 3 CCT.	The short-term effects (n=4). The long-term effects (n=3). -RME (Acrylic bonded maxillary	431	-Mandibular inter-deciduous molar or inter- premolar distances. -Mandibular inter-first	permanent molar distance. -Arch length.	methodological quality scoring scale developed	Negligible short- and long-	term spontaneous dento-alveolar	changes of approximately	1mm occur in the mandibular	dental arch of patients treated	with either SME or RME.	dento-alveolar changes occur	in the	mandibular dental arch
	Effect of maxillary expansion on the anteroposterior and vertical jaws relationship.																
De Rossi [13]	SR	expansion appliance (BRMEA) on	Number and type of primary studies included.	Intervention.	Total number of participants.	The effects of BRMEA on vertical and sagittal dimensions using linear and	angular cephalometric measurements.	Not evaluated.	backward and downward mandibular	displacement. -BRMEA caused	backward sagittal 	maxıllary displacement while hvrax	caused forward sagittal	maxillary displacement.	absent. There is no	consensus in	the literature regarding the
Feres [40]	SR	sagittal dental or skeletal parameters of	Total (n=4 CCT)	Vertical chin cap (n=1) (out of scope), BRMEA versus Bonded Slow MEA (n=1), Hyrax	152	relationship) or skeletal (cephalometric mandibular parameters) status of Class III	malocclusion, both before and after RME	Randomized Studies (MINORS).	Contradictory results regarding molar	changes following RME treatment	Mandibular skeletal	changes: Most of the selected	studies indicated no	mandıbular shift, nor	supplementary the sagittal	dimension of Class II is still	controversial
	Effect of maxillary expansion on facial soft tissue.																
Huang [12]	SR & MA	facial soft tissue changes that can occur	menuada m me meta-analysis. Cohort (n=6), Retrospective CCT (n=2),	-Hyrax expander (n=11). -Rigid acryli bonded ppliance (n=4).	529	philtrum width. The secondary outcomes: -The nasal tip prominence. -Nasolabial anele.	-Upper lip thickness. -Basic unner lin	CONSORT statement. High quality	-The mouth width (MD: 1.84 mm), and	upper philtrum width (MD: 0 74 mm)	significantly increased.	-The distance from the lower	lips to the E line (MD: 0.75	mm) showed statistically	significant -Most of the	evaluated measurements	showed a mean دام موقور دا
Staderini [41]	SR	influence the nasolabial soft tissue	Total (N=4); RCT (n=3), Case series (n=1).	Bonded RME(n=3), banded and bonded RME (n=1).	140	Nasal width. Mouth width.		Health Care (SBU). The quality of	1.42 mm) m m 2 studies. One study	reported a non- significant change of 0.4	mm. Mouth width:	One study reported statistically	significant increase in	mouth width (1.80 mm).	of view, the	short-term effect of RME	of morphology marine
						The Retention period after	maxiliary expansion.										
Costa [42]	SR	patrents undergoing maxillary	Total (n=6); RCT (n=2), CCT (n=4).	expander (n=1). All authors used the same expander appliance for retention of the expansion,	382	Duration of the retention period after maxillary its relation with posterior	crossbite stability.	studies, and the Downs and Black checklist	and removable retainers used for six months	showed 1.2% and 3.2% relance in the	inter-molar width.	-Relapse in the posterior	crossbite expressed in %	of patients: (0% in the Haas	group for at with either	fixed or removable	appliances seem to be

RCT: Randomized clinical trial; CCT: Controlled clinical trial; CT: Clinical trial; QDH: Quad helix appliance; EP: Expansion plate; RME: Rapid maxillary expansion; SME: Slow maxillary expansion

Quality assessment of the included SRs and MAs (AMSTAR & LRD)

inter-examiner agreement.

The AMSTAR scores of the included reviews are shown in **Table 4.** The AMSTAR scores ranged from 2 to 10 (mean score 5). 3 reviews [13,28,36] were rated as low quality, 8 reviews [7,12,33,37,38,41,44,45] were rated as high quality and the rest were of moderate quality. The Cohen's k coefficient for the AMSTAR was 0.826, indicating excellent

The body of evidence score [8] was calculated individually for each SR/MA in **Table 5**. Concerning the design of the primary studies (LRD score), only three reviews [7,32,37] included randomized controlled trials (RCTs) exclusively, meanwhile twelve reviews [6,11,12,29,33,34,36,39,41,42,44] included RCTs along with other types of studies as controlled clinical trials, prospective

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and retrospective clinical trials. Finally, the remaining reviews were based on non-randomized clinical trials and of evidence for each review are shown in **Table 5**.

Review	1. Was an 'a priori' design provided?	2. Was there duplicate study selection and data extraction?	3. Was a comprehensive literature search performed?	4. Was the status of publication (i.e., grey literature) used as an inclusion criterion?	5. Was a list of studies (included and excluded) provided?	6. Were the characteristics of the included studies provided?	7. Was the scientific quality of the included studies assessed and documented?	8. Was the scientific quality of the included studies used appropriately in formulating conclusions?	9. Were the methods used to combine the findings of studies appropriate?	10. Was the likelihood of publication bias assessed?	11. Was the conflict of interest stated?	Total
Shiffman and Tuncay [28]	Y	N	N	N	N	Y	N	N	CA	N	N	2 low
Petren [29]	Y	Y	Y	Ν	N	Y	CA	Y	NA	Ν	N	5 moderate
Lagravere [5]	Y	Y	Y	Ν	N	Y	N	Y	NA	Ν	N	5 moderate
Lagravere [30]	Y	Y	Y	N	N	Y	N	Y	NA	N	N	5 moderate
Lagravere [26]	Y	Y	Y	N	N	Y	CA	Y	NA	N	N	5 moderate
Lagravere [31]	Y	Y	Y	Y	N	Y	Y	N	CA	N	N	6 moderate
Zuccati [32]	Y	Y	Y	N	N	Y	Y	Y	NA	N	Y	7 moderate
Zhou [33]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	10 high
Agostino [7]	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	10 high
Liu [34]	Y	Y	Y	N	N	Y	CA	Y	N	N	Y	6 moderate
Algharbi [6]	Y	Y	Y	N	Y	Y	N	Y	NA	N	Y	7 moderate
Cannavale [35]	Y	N	Y	N	N	Y	Y	N	Y	Y	N	6 moderate
Gidwani [36]	Y	CA	N	N	N	Y	N	N	NA	N	Y	3 Low
Krüsi [37]	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	9 high
Seif-Eldin [38]	Y	Y	Y	Y	Y	Y	Y	Y	NA	N	N	8 high
Alves [39]	Y	Y	Y	Ν	Ν	Y	Y	Y	NA	N	Y	7 moderate
De Rossi [13]	Y	Y	Y	N	N	Y	N	CA	NA	N	N	4 low
Feres [40]	Y	Y	Y	N	Y	Y	Y	Y	NA	N	N	7 moderate
Huang [12]	Y	Y	Y	N	Y	Y	Y	N	Y	N	Y	8 high
Staderini [41]	Y	Y	Y	Y	Y	Y	Y	N	NA	Ν	Y	8 high
Costa [42]	Y	Y	Y	N	N	Y	Y	Y	NA	N	N	6 moderate

Table 4. Total AMSTAR scores for each included systematic review and meta-analysis.

AMSTAR SCORE: 'Yes' answer: 1 point, all the other answers: 0 point. Y = Yes; N = No; NA = Not Applicable; CA = Cannot Answer: For each question included in the AMSTAR checklist, 'yes' answers were scored 1 point, and the other answers were scored 0 point. According to the number of criteria met and hence the total score, the methodological quality was rated as 'Low' (total AMSTAR score ≤ 3), 'Moderate' (total AMSTAR score = 4 - 7) or 'High' (total AMSTAR score ≥ 8).

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SR/MA	Type of study (downgrade)	No. of participants (downgrade)	No. of studies (downgrade)	Quality of primary studies (downgrade)	Downgrade Score (level of body evidence)	AMSTAR	LRD	Overall Quality
Schiffman and Tuncay [28]	MA (0)	N=235 (0)	N=6 (1)	Not assessed (2)	(3) moderate evidence	Low	III, IV	Low
Petrén [29]	SR (1)	N=717 (0)	N=12 (0)	Low quality, n=8. Medium Quality, n=4. (2)	(3) moderate evidence	Moderate	II, III, IV	Moderate
Lagravère [5]	SR (1)	N=89 (2)	N=8 (1)	Not assessed (2)	(6) very low	Moderate	IV	Low
Lagravere [30]	SR (1)	N=412 (0)	N=4 (2)	Not assessed (2)	(6) very low	Moderate	III	Low
Lagravere [26]	SR (1)	N=161 (1)	N=3 (2)	A secondary level of evidence was found (2)	(6) Very low	Moderate	Ш	Low
Lagravère [31]	SR & MA (0)	N=335 (0)	N=14 (0)	A secondary level of evidence was found (2)	(2) moderate	Moderate	IV	Moderate
Zuccat[32]	SR (1)	Not mentioned in the review (1)	N=12 (0)	Low risk of bias, (N=3). Moderate risk of bias, (N=1). High risk of bias, (N=8). (1)	(3) moderate	Moderate	I	Moderate
Zhou [33]	SR & MA (0)	N=993 (0)	N=14 (0)	High risk of bias, (N=3). Moderate risk of bias, (N=9). Low risk of bias, (N=2). (1)	(1) high	High	II, III	High
Agostino [7]	SR & MA (0)	N=619 (0)	N=15 (0)	High risk of bias, (N=7). Unclear risk of bias (N=6). Low risk of bias, (N=2). (1)	(1) high	High	I	High

Table 5. Evaluation of the Overall quality of evidence for each included systematic review and meta-analysis.

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Liu [34]	SR (1)	Not mentioned (2)	N=12 (0)	Medium high quality (N=2), Medium quality (N=4), Low quality (N=6). (1)	(4) low	Moderate	II,III,IV	Low
Algharbi [6]	SR (1)	N=273 (0)	N=7 (1)	High level of quality (N=1) Moderate level of quality (N=6) (0)	(2) moderate	Moderate	II, III	Moderate
Cannavale [33]	MA (0)	N=758 (0)	N=18 (0)	Not mentioned (2)	(2) moderate	Moderate	III	Moderate
Gidwani [36]	SR (1)	N=632 (0)	N=9(1)	Not assessed (2)	(4) Low	Low	II	Low
Krüsi [37]	SR & MA (0)	N=264 (0)	N=6 (1)	-Moderate quality (N=2). -Low quality (N=2). -Very low quality (N=2). (1)	(2) Moderate	High	I	High
Seif-Eldin [38]	SR (1)	N= 377 (0)	N=6(1)	All studies were Low quality (2)	(4) Low	High	III	Moderate
Alves [39]	SR (1)	N=431 (0)	N=6 (1)	-High risk of bias (N=3). -Moderate risk of bias (N=1). -Low risk of bias (N=2). (1)	(3) moderate	Moderate	II, III	moderate
De Rossi [13]	SR (1)	N=152 (1)	N=4 (2)	Not assessed (2)	6 very low	Low	III	low
Feres[40]	SR (1)	N=826 (0)	N=7 (1)	High risk of bias (2)	(4) low	Moderate	III, IV	low
Huang [12]	SR & MA (0)	N=529 (0)	N=15 (0)	High quality (N=5), moderate quality (N=9), low-quality study (N=1). (0)	(0) high	High	II, III	high
Staderini [41]	SR (1)	N=140(1)	N=4 (2)	-Moderate quality (N=3). -Low quality	(4) Low	High	П	Moderate

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				(N=1). (0)				
Costa [42]	SR (1)	N=382 (0)	N=6 (1)	High risk of bias (N=4) medium risk of bias (N=1) Low risk of bias (N=1) (2)	(4) low	Moderate	II, III	moderate

Downgrade Score (level of body evidence); very low (>5 downgrades), low (4-5 downgrades), moderate (2-3 downgrades) or high (0-1 downgrade) LRD scoring system; N: number, I: Systematic Review of RCTs; II: Randomized Clinical Trial; III: Study without randomization; IV: non-controlled study, V: Narrative review/expert opinion.

A. Effect of maxillary expansion on the transverse dimension of the maxillary arch &/or maxilla

The age of the patients throughout the studies ranged from 5 to 15 years; hence the following results can be applied to pre-pubertal and pubertal patients only. Short-term effects refer to the effect of treatment immediately post-expansion, while the long-term effect refers to the effect of treatment after a retention period.

Effect of slow maxillary expansion (SME):

Short-term dento-alveolar effects of SME:

- Compared to control, SME increased the maxillary inter-molar and inter-canine widths by 4.45 mm and 2.58 mm, in pre-pubertal and pubertal patients respectively [33], (Level of Research Design scoring (LRD)).

Long-term dento-alveolar effects of SME:

- The inter-molar and inter-canine widths expansion achieved after retention period (3-6 months) using SME were 2.49 mm and 2.27mm, in pre-pubertal and pubertal patients respectively [33], (HQE).

Short-term skeletal effects of SME:

- 28-50 % of the expansion gained was due to separation of the MPS. Expansion was primarily dento-alveolar and was inversely proportional to the age of the patient. However strong conclusions regarding skeletal changes after SME could not be withdrawn [5], (Low quality evidence (LQE)).

Different types of SME appliances:

- Quadhelix (QDH) appliances can achieve 1.15 mm more molar expansion than expansion plates (EP); fixed QDH appliances may be more successful than removable EP at correcting posterior crossbites and expanding the inter-molar width in children with early mixed dentition aged 8 to 10 years [7], (HQE).
- Treatment with the EP was unsuccessful in one third of the subjects; QDH appliance was superior to the EP in

success rate and treatment time owing to better patient compliance [32], (Moderate quality evidence (MQE)).

- The amount of arch expansion produced by QH appliance is equal to or better than other slow maxillary expanders [36] (LQE).

Effect of rapid maxillary expansion RME:

Short-term dento-alveolar effects of RME:

- RME increased the maxillary inter-molar, interpremolar and inter-canine widths by 4.09 mm, 3.86 mm and 2.7 mm in pre-pubertal and pubertal patients respectively [33], (HQE).
- At the end of RME treatment, there is an inter-molar and inter-canine width expansion of 4.85 mm and 3.73 mm respectively [35], (MQE).
- At younger ages, the amount of anterior expansion is similar to that of the posterior, and it diminishes during growth, becoming half that of the posterior at 15 years of age [35], (MQE).
- The changes in the maxillary transverse plane following RME treatment were caused by more dental than skeletal expansion [31], (MQE).

Long-term dento-alveolar effects of RME: Nonsignificant relapse in the maxillary inter-molar width (-0.40 mm), inter-premolar width (-0.16 mm), and inter-canine width (-0.41mm) occurred in the retention period (3-6 months) [33], (HQE). -The maxillary inter-molar, interpremolar and inter-canine widths expansion gained due to RME treatment after retention period (3-6 months) were 3.58mm, 3.52 mm and 2.64mm respectively [33], (HQE). -There was a maxillary inter-canine width relapse of -0.81 mm between the end of treatment and long-term follow-up after a mean of 9.95 years, with an overall expansion of 2.91 mm. Regarding the inter-molar width, there is a relapse of -0.47 mm between the end of treatment and long-term follow-up of a mean of 9.95 years, with an overall gain of 4.38 mm [35], (MQE). Clinically significant long-term (minimum 1 year post retention) maxillary inter-molar width

increase (3.7-4.8 mm) and inter-canine width increase (2.2-2.5 mm) can be achieved [30], (LQE).

Short-term skeletal effects of RME:

- RME was able to produce transverse skeletal effects on the maxilla by opening the MPS regardless of the palatal expander type. MPS opening during RME amounted to 12-52.5 % of the total screw expansion [34], (LQE). MPS opening during RME amounted to 20-50 % of the total screw expansion [11], (LQE). There was no consistent evidence on whether the MPS opening was parallel or triangular following RME [11,34], (LQE).
- Both bone-anchored and tooth-anchored maxillary expanders showed similar results; the dento-alveolar expansion gained was greater than skeletal expansion, however most of the studies were at high risk of bias therefore do not allow for sound comparison [32], (MQE).

Long-term skeletal effects of RME:

Long-term changes of MPS opening following RME were not significant; the opening of the MPS was stable [34], (LQE). Long-term transverse skeletal ME is approximately 25% of the total appliance adjustment in pre-pubertal patients but non-significant for post-pubertal patients [30], (LQE). Long-term stability of transverse skeletal ME was better in pre-pubertal than pubertal and post-pubertal individuals [30,38], (MQE). The clinical significance of the long-term skeletal ME outcome in post-pubertal individuals is questionable [30], (LQE).

After a retention period post-expansion; bone-borne RME was associated with greater skeletal expansion at the incisal foramen (1.8 mm), greater suture opening at the first premolar (2.3 mm), and greater suture opening at the first molar (2.0 mm) than tooth-borne RME [37], (HQE).

Different types of RME appliances:

- Non-significant differences were observed in the intermolar width expansion gained using tooth-borne Hyrax and tooth-tissue borne Haas, nor using banded and bonded Hyrax. However, the evidence was insufficient to conclude that any one intervention was better than another [7], (HQE). Non-significant differences were observed in the inter-molar width expansion gained using four-point and two-point banded hyrax, nor using tooth-borne and bone-born expander, yet the evidence was of low quality and do not allow for any sound comparison [7,32], (HQE). Dental-tipping effect between different appliances (Banded and bonded Hyrax, Tooth-borne and bone-borne expanders) were contradictory in the studies reviewed and no evidencebased conclusion could be drawn [6], (MQE). No significant differences between Bone-borne and toothborne RME could be identified for buccal tooth tipping, and root resorption [37], (HQE). Hybrid tooth-boneborne RME was associated with less buccal tipping of the first premolar compared to tooth-borne RME postretention, while no significant differences could be found regarding skeletal maxillary width and molar inclination [37], (HQE).

Comparison between different rates of expansion:

RME versus SME

- Both SME and RME are effective in treating posterior cross-bites in the early mixed dentition, however there is no evidence to show which of the treatment modalities was more effective [29], (MQE).
- Both RME & SME appliances are reliable methods for producing significant expansion at the MPS, which treats posterior crossbite effectively on the short-term [6], (MQE).
- The difference in the dental-tipping effect between RME & SME were contradictory in the studies reviewed and no evidence-based conclusion could be drawn [6], (MQE).
- In an age range of 8-14 years, the maxillary inter-molar width gain after the retention period (3-6 months) was significantly larger with SME than RME by 0.75 mm [33], (HQE).
- Non-significant differences were detected regarding post-expansion and post-retention maxillary inter-canine and inter-premolar widths using RME and SME [33], (HQE).
- Stable inter-molar and inter-canine widths were achieved using retention plate for 6 months following RME & SME, however most of the studies appear to be at high risk of bias therefore do not allow for any sound comparison between the stability of RME versus SME [32], (MQE).

RME versus semi-rapid (SRME)

- The evidence is insufficient to allow the conclusion that any intervention rate is better than another [7], (HQE).

Effect of primary teeth grinding:

- Grinding of the interferences as treatment in the primary dentition can be proposed [29], (MQE).

Effect of maxillary expansion on the transverse dimension of the mandibular arch

- The mandibular inter-molar width expansion gained due to SME immediately after treatment and retention period (3-6 months) were 0.49 mm and 0.06 mm in prepubertal and pubertal patients respectively [34], (HQE).
- The mandibular inter-molar width expansion gained due

to RME immediately after treatment and the retention period (3-6 months) were 1.19 mm and 2.02 mm in prepubertal and pubertal patients respectively [34], (HQE).

- Non-significant differences were detected regarding post-expansion and post-retention mandibular intermolar width using RME and SME [34], (HQE).
- Negligible short- and long-term spontaneous dentoalveolar changes of approximately 1mm occur in the mandibular arch of patients treated with either SME or RME in the mixed and early permanent dentition [40], (MQE).
- Less mandibular inter-molar and inter-canine width expansion was achieved in adults compared with adolescents treated with RME [30], (LQE).

Effect of maxillary expansion on the anteroposterior and vertical jaws relationship

- Anteroposterior and vertical dento-alveolar changes following RME:
- Immediately following RME, few vertical and anteroposterior dental changes were statistically significant, and none were clinically significant [32], (MQE).
- Regarding the effect of RME on Class II molar malocclusions, contradictory results regarding molar relationship changes following RME treatment [41], (LQE).
- No long-term anteroposterior or vertical dental changes were associated with RME [30], (LQE).
- Anteroposterior and vertical skeletal changes following RME:
- Immediately following RME treatment, few vertical skeletal changes were statistically significant, and none were clinically significant [32], (MQE).
- The effect of RME on the sagittal dimension of Class II is still controversial and has not been proved yet [41], (LQE).
- RME did not produce significant long-term anteroposterior or vertical skeletal changes in the position of the maxilla and mandible [31], (LQE).

- Different types of RME appliances:

- Bonded RME appliance caused less downward and backward displacement of the mandible than the banded appliances, but these alterations were not completely absent. There was not sufficient evidence to support the use of bonded RME appliances to control the undesirable vertical effects of RME [13], (LQE).
- B. Effect of maxillary expansion on the adjacent Sutures and orbital structures:

- All participants were pre-pubertal and pubertal patients (6-14.5 years).
- RME produced immediate significant changes in transverse dimensions of the circummaxillary sutures, spheno-occipital synchondrosis, and aperture width.
 Structures articulating directly with the maxilla (zygomaticomaxillary and frontomaxillary) had larger displacement than those located further away. However, the majority of the articles were judged to be of low quality, therefore no evidence-based conclusions could be drawn [11], (LQE).

C. Effect of maxillary expansion on facial soft tissue:

- All subjects were in the facial skull growth phase (8-14 years).
- RME significantly increased nasal width, mouth width, upper philtrum width, and distance from the lower lip to the E line after the retention phase. No significant changes were detected in the height of the lower face, nose, or lips. However, most of the evaluated measurements showed a mean change of <1 mm, which indicated limited clinical or esthetic relevance [12], (HQE).
- RME appliances produce slight clinically nonsignificant nasolabial soft tissue changes. In addition, the aesthetic impact provided by RME appliances may be considered as not clinically significant [42], (MQE).

D. The Retention period after maxillary expansion:

 24 h/ day of retention using the expansion appliance fixed in place or removable palatal plate for six months seemed enough to avoid relapse in the short-term [43], (MQE).

E. Root resorption associated with maxillary expansion:

- CBCT radiography displayed significant root volume loss associated with RME. However, when considering volume loss percentages, no statistical significance was found [44], (LQE).
- RME caused root resorption of posterior teeth with the first molars being the most affected as assessed by CBCT. Root resorption was similar in anchored and unanchored teeth [45], (MQE).

F. Periodontal problems associated with maxillary expansion:

- RME caused thinning of the alveolar buccal bone and reduction of the marginal bone level of anchored teeth less than 1 mm [54], (HQE).
- SME protocol seemed to cause more severe alveolar bone loss, bone dehiscence and periodontal impairment than RME [6, 54], (HQE).

DISCUSSION

Conducting overviews is the next rational step that should be taken in attempt to summarize and critically appraise the massive amount of evolving evidence. It can also serve as guidelines for both clinicians and researchers [47]. The current overview presented and evaluated the available evidence concerned with ME treatment effects, providing a comprehensive analysis of all reported short- and long-term outcomes of the different ME protocols. Unlike the previous ME overview conducted by Bucci [8], the aim of the present study was to report and criticize all the available three dimensional dental and craniofacial effects of ME, besides the direct effect of ME on the transverse maxillary dimension.

Quality of the evidence

It was of utmost importance to critically appraise and evaluate the included reviews with appropriate tools. The methodological quality of the included reviews was assessed with AMSTAR [18], a recent valid and reliable quality tool. 8 reviews [7,12,34,38,39,42,45,46] out of 25 were rated as high quality. Most of the studies lost points for not performing a grey literature search and not mentioning a list of excluded studies (Questions 4 and 5). Nevertheless, AMSTAR score evaluates whether a SR was conducted in appropriate way, without considering the design of the individual articles included in the SR. To overcome this shortcoming, the Level of Research Design Scoring (LRD) was also implemented, a score system based on the design of the primary studies according to the hierarchy of evidence [21-24]. Only three reviews [7,33,38] included randomized controlled trials (RCTs) exclusively, while the majority of SRs were based on non-randomized controlled clinical trials and clinical trials. The body of evidence was also evaluated individually for each review according to a scoring system adopted previously [8]. The overall quality of evidence was judged based on the individual AMSTAR, LRD and body of evidence scores, to be able to manipulate the scientific quality of the included reviews in formulating conclusions.

The highest overall quality was the Cochrane review conducted by Agostino [7]. This result is in agreement with what previously reported that Cochrane SRs present less shortcomings and superior methodological quality than other peer-reviewed SRs [48]. Krüsi [37] was also rated as a highquality systematic review and meta-analysis owing to the high AMSTAR and LRD scores. Huang [12] and Zhou [34] were also judged as high-quality reviews, however the primary studies included were not solely based on RCTs. The remaining reviews were judged as moderate and lowquality evidence, all representing future research points to be able to reach solid guidelines and clinical recommendations.

Overall completeness and applicability of evidence

The age range of participants in all SRs/MAs were between 6-14 years, which is considered pre-pubertal and pubertal

age. There is insufficient evidence on ME for post-pubertal patients. Although, treatment of posterior crossbite is recommended early up to the peak of pubertal growth, there is significant variation in the timing of skeletal maturation among individuals [9]. Moreover, MPS fusion is poorly correlated with age [10]. Accordingly, it was recommended that clinicians and researchers use proper diagnostic tools to individually assess MPS maturation to identify each patient's ideal expansion treatment option and timing [10]. Prematurely referring a patient to surgically assisted ME, will expose him to a significant burden of treatment including increased pain, recovery time and expenses.

Summary of main results

HQE supported the short- and long-term dento-alveolar effects of SME [5] and RME [34,36] in growing patients, where both protocols successfully increased the inter-molar and inter-canine widths. Upon comparing both ME protocols, HQE supported that the maxillary inter-molar width expansion after a brief retention period was slightly greater using SME than RME by about 0.75mm [34]. However, this modest difference limits its clinical applicability.

The amount of skeletal expansion gained due to maxillary expanders was debatable. Only LQE supported the short-term skeletal effects of RME & SME protocols, which was assumed to be no more than 20-50 % of the total expansion gained [5,11,35]. Moreover, there was no evidence to detect the long-term skeletal effects of SME [5], while LQE supported the long-term stability of the MPS opening following RME [35], which was better retained in less skeletally mature individuals [31].

One of the aims of the current study was to formulate clinically useful recommendations regarding the best ME appliance and protocol for every dentition stage. Unfortunately, the evidence was insufficient to allow the conclusion that any ME rate (RME, SRME, SME) nor ME appliance is superior than another [6,7,33].

HQE also supported the spontaneous mild increase in the mandibular inter-molar width due to ME, however no significant differences were detected between RME and SME protocols [40].

Despite being accused of increasing the vertical dimension and pushing the maxilla forward [49,50], MQE supported the negligible vertical and anteroposterior changes occurring following RME on the short- and long-term [13,41].

Regarding soft tissue changes following ME, HQE pointed out negligible changes with limited clinical consequence [12,42]. The latter finding expands the indication of ME; it can be safely utilized with no significant profile changes.

MQE concluded that 24 h/day of retention for six months with either fixed or removable appliances are recommended

to avoid relapse [43], unlike the traditional 3 months expansion which was long suggested [51].

Because of the considerable force needed to break the MPS during RME, and yet most of the treatment effect is dentoalveolar rather than skeletal expansion, it may be thought that RME may have detrimental effects on the teeth and their supporting tissues. Fortunately, MQE pointed out that nonsignificant root resorption occurred in the posterior teeth following RME when compared to the total root volume [44,45]. However, ME caused mild thinning of alveolar buccal bone and reduction of the marginal bone level of anchored teeth, attributed to the buccal tipping of the posterior teeth [46].

CONCLUSIONS

Implications for practice

Based on high quality evidence, the following could be concluded:

- 1. Both RME and SME can effectively increase the maxillary inter-molar and inter-canine widths on the short- and long-term in pre-pubertal and pubertal patients.
- 2. The maxillary inter-molar width gain after a retention period of 3-6 months was significantly larger in SME than in RME protocols by 0.75 mm pre-pubertal and pubertal patients. Regarding the maxillary inter-canine and inter-premolar widths, non-significant differences were detected.
- 3. Fixed quad-helix appliances may be more successful than removable expansion plates at correcting posterior crossbites in children at early mixed dentition.
- 4. In pre-pubertal and pubertal patients, mandibular intermolar width expansion of approximately 1mm was gained due to SME and RME immediately after treatment and retention period (3-6 months), with nonsignificant differences detected between both protocols.
- 5. RME increased nasal width, mouth width and upper philtrum width, and decreased lower lip thickness by <1 mm after the retention phase in pre-pubertal and pubertal patients, which indicated limited clinical significance.

Based on moderate quality evidence, the following could be concluded:

- 1. The maxillary transverse width increase following RME treatment was mainly dento-alveolar.
- 2. At the end of the RME treatment, the inter-molar and inter-canine widths could be increased by 4.85 mm and 3.73 mm respectively. Upon long-term follow-up (mean of 9.95 years), an overall gain of 4.38 mm and 2.91 mm were detected.

- 3. At younger ages, the amount of anterior expansion due to RME is similar to that of the posterior, and it diminishes with growth, becoming half that of the posterior opening at 15 years of age.
- 4. On the short-term, clinically insignificant vertical and anteroposterior, dental and skeletal changes occur following RME protocol.
- 5. Six months of full-time retention with either fixed or removable appliances seem to be enough to avoid relapse.
- 6. RME side effects include root resorption of posterior teeth, affecting both anchored and unanchored teeth equally. Besides, RME causes thinning of alveolar buccal bone and reduction of the marginal bone level of anchored teeth less than 1 mm.
- 7. SME protocol seemed to cause more severe alveolar bone loss than RME.
- 8. Low level laser therapy seemed to improve the opening of the MPS and stimulate the repair process during the retention phase after RME, however did not increase the amount of expansion significantly.
- 9. Grinding away of interferences as treatment for crossbite in the primary dentition can be proposed.

Based on low quality evidence, the following could be concluded:

- 1. 28-50 % of the total expansion gained immediately following SME was due to skeletal response (MPS separation). Expansion was primarily dento-alveolar and inversely proportional to the age of the patient.
- 2. MPS separation immediately following RME treatment constituted 20-50 % of the total expansion gained. There was no consistent evidence on whether the MPS opening was parallel or triangular.
- 3. Long-term stability of the skeletal maxillary width increase following RME was stable, and was better retained in pre-pubertal than pubertal & post-pubertal individuals.
- 4. CBCT radiography displayed significant root resorption associated with RME. However, when considering volume loss percentages, it was non-significant.

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CONFLICTS OF INTEREST

The authors hereby declare that there are no conflicts of interest.

ETHICS APPROVAL

None.

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