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REVIEW

Effectiveness of maxillary protraction using facemask with or without maxillary expansion: a systematic review and meta-analysis

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Abstract
Objectives Class III therapy using a face mask is a common approach for treatment of a deficient maxilla and reverse overbite. Usually, maxillary protraction is combined with transverse palatal expansion using intraoral appliances. The purpose of this study was to systematically review the effectiveness of face mask therapy in combination with concepts of palatal expansion and compression.
Material and methods A systematic review and meta-analysis were performed to identify studies that address class III treatment using a face mask. The search was carried out using common electronic databases as well as hand search. Both screening and study eligibility analysis were performed with consideration of PRISMA and Cochrane Guidelines for systematic reviews. Several terms describing class III face mask treatment were searched. Particular attention was paid to new strategies of enhancing maxillary protraction.
Results The initial search identified 2048 studies. After a thorough selection process, a total of 22 articles met the inclusion criteria. After assessment of the individual quality scoring of each article, eight studies were provided for meta-analysis of the cephalometric parameters. The statistical analysis of treatment changes advocates a positive influence on sagittal maxillary development, which is not primarily influenced by transverse expansion. Dental side effects are more distinct when no expansion was carried out. For the concept of alternating activation/deactivation of the expansion appliance (alt-RAMEC), two articles of high methodological scoring were identified. They indicate an enhancement of face mask treatment.
Conclusions The findings are consistent with results of previous literature studies regarding the efficiency of class III face mask treatment. A further need for more randomized controlled studies was identified especially with regard to the new concept of alternating maxillary expansion and compression, which showed a positive influence on the maxillary protraction based on two studies.
Clinical relevance Class III therapy using extraoral face mask anchorage is effective for maxillary protraction. The recently discussed new protocols potentially improve this treatment.

Keywords Class III treatment · Expansion · Non-expansion · alt-RAMEC · Systematic review · Meta-analysis

Introduction

The therapy of the class III malocclusion spectrum is one of the most complex challenges of orthodontic and orofacial orthopedic treatment [1–3]. Various treatment strategies have been proposed since the end of the nineteenth century, ranging from functional appliances [4, 5], chin cup therapy [6, 7], and face mask therapy [8–12] to surgical correction by means of sagittal split osteotomy and LeFort I osteotomy.

The prevalence of class III malocclusions ranges from 0 to 26.6 % with an average of 7.04 % and a relatively higher prevalence in East Asian populations [13]. With regard to the etiology and underlying skeletal dysmorphia, various

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studies have indicated that both mandibular prognathism and maxillary retroganthism are equally frequent in individuals with class III abnormalities (with a range of 32–63 % of patients showing a retrusive maxilla) [14–16]. Furthermore, in most patients, a combination of the two skeletal aberrations is present. With an increasing number of studies emphasizing the maxillary component of class III skeletal patterns [17, 18] and with the understanding that therapeutic influence on the growing mandible is limited (and implicating unwanted side effects for the temporomandibular joint), the standard therapy for mild to moderate class III discrepancies especially in growing patients is maxillary protraction for correction of a deficient maxilla.

With a systematic review, it is possible to compare research data from multiple sources. If methodologically plausible, meta-analyses can provide consensus of a medical literature topic by equating and combining results of various independent studies [19]. This is interesting especially in dentistry and orthodontics where several specific topics and care standards are based on few scientifically profound studies and evidence-based approaches (e.g., inadequate sample size and opinion articles).

Few systematic literature review studies and even less containing statistical meta-analysis are available on the effects and effectiveness of maxillary protraction therapy using an orthopedic face mask [2, 20–22]. The influence and possible improvement of maxillary protraction by expansion of the maxilla are controversially discussed [23–27]. In a review in 1999, Kim et al. conclude that expansion slightly improves the effect of maxillary protraction and reduces dental change, although they stated that clinical significance is low [20]. The latest review for face mask therapy by Cordasco et al. was published in 2014 [22]. They also partially included the aspect of expansion, stating that no enhancement through palatal expansion was found. Nevertheless, none of the previous systematic studies methodologically included subject headings specifically delineating transverse palatal expansion.

A new interesting approach was introduced by Liou et al. in 2005. They proposed a protocol of alternating activation and deactivation of the maxillary expansion appliance (alt-RAMEC) before class III mechanics application, thus enhancing the therapeutic effect on the hypoplastic maxilla [28]. Inaugurating it in cleft patients, the group additionally suggests an improvement in non-cleft individual treatment [29]. This new concept of opening and weakening the circumaxillary sutures prior to face mask protraction has been a much debated issue among clinicians in the field of orthodontics and has also not been systematically reviewed before.

The primary purpose of this literature review was therefore to evaluate the effectiveness of maxillary protraction using a face mask appliance in class III patients with particular focus on the influence of maxillary expansion. Currently, introduced concepts of alternating transverse expansion and constriction were included for the first time in scientific literature. Application of the technique of meta-analysis statistical testing was carried out if possible in order to increase sample size and provide stronger statistical support.

Material and methods

The reviewing protocol and process was based on the PRISMA guidelines for systematic reviews and meta-analyses [30]. The Cochrane principles for systematic reviews of interventions were additionally taken into consideration for elaboration of the review process and format [31]. Therefore, the components of both PRISMA Statements (i.e. checklist and flow diagram) and Cochrane Principles (i.e. question framing, identification, quality assessment, evidence summary, and findings interpretation) were critically applied on the orthodontic topic and expected outcome. These measures were assisted by the Institute of Medical Biostatistics and Epidemiology [32]. The following terms were included in the electronic and hand search: *face mask*, *reverse head gear*, *Delaire*, *protraction head gear*, *maxillary protraction*, *reverse occlusion*, *expansion*, *non-expansion*, *expansion and constriction/compression*, *alt-RAMEC*. The search was carried out from January 1994 to December 2014 within the following databases: *Medline* (*Pubmed*), *Embase*, *Cochrane Database*, *Cochrane Controlled Trials*, *ISI Web of Science*, *EBM Reviews*, *BioMed Central*. Additionally, a hand search of relevant orthodontic journals, including those not listed in "Pubmed," was carried out in the library of the university medical center and the department's library.

In the first identification phase, potential articles with search of the terms listed above were detected. The initial records contained abstracts and titles from all search databases. As listed above, the following criteria were applied for selecting the screened articles: published in English language, human clinical trials, and class III treatment with the help of face mask protraction. Furthermore, duplicate articles were then excluded as first part of the screening phase.

At the end of the screening phase, potentially relevant studies were retrieved for more detailed analysis. Both identification and screening were conducted by two independent examiners (C.J. and M.F.). The results up to this point of the research process were then compared for potential discrepancies. If there was disagreement (of inclusion/non-inclusion) between the examiners, a full text analysis was conducted to resolve intraexaminer differences.

The retrieved studies were then re-evaluated with the help of the full text articles and complementary exclusion criteria (case reports with less than five individuals, cleft patients or other cranial syndromatic abnormalities, skeletal anchorage for maxillary protraction or transverse expansion, and uncommon diagnostic procedures including finite element analysis).

Table 1 Description of the methodological scoring according to Prisma guidelines and the scoring point values

Scoring for	Description	Points
1. Study design	Randomized clinical (controlled) trial	3
	Randomization not well described or controlled prospective study	2
	Uncontrolled prospective study	1
	Retrospective study, or not mentioned	0
2. Sample size	Larger than or equal to 15 subjects or prior estimate of sample size	1
	Less than 15 subjects and no prior estimate of sample size	0
3. Sample description	Description of all items (age, sex, severity of malocclusion, exclusion/inclusion criteria, control group description adequate)	2
	Less than 3 items described	1
	Only 1 item described, or no description	0
4. Error analysis	Error analysis values cited	1
	Not cited or not performed	0
5. Statistical analysis	Adequate	2
	Partially adequate	1
	No tests conducted	0

Again, at this point, the results were compared for interexaminer differences and adjusted after detailed communication if necessary. A third equitable examiner (S.W.) was on demand, if consensus was not achieved. Throughout the screening process, individual-related data of authors and institutions were concealed to the examiners to reduce potential selection bias.

The studies included in the systematic review were scored according to an adapted and modified method of methodological scoring, as introduced by Cozza et al., Chen et al., and Grec et al. [33–35]. For quality assessment, the full text articles were evaluated with consideration of the following aspects: (1) study design (0–3 points possible), (2) sample size (0–1 points possible), (3) sample description (0–2 points possible), and (4) error and statistical analysis (0–1/0–2 points possible). The scoring of the particular study was registered in the methodological quality scoring protocol, with a maximum score of 9 points. The allocation to studies of low, medium, and high quality was conducted on the basis of the following classification: 0–5 points=low priority study, 6–7 points=medium quality study, and 8–9 points=high quality study (Table 1).

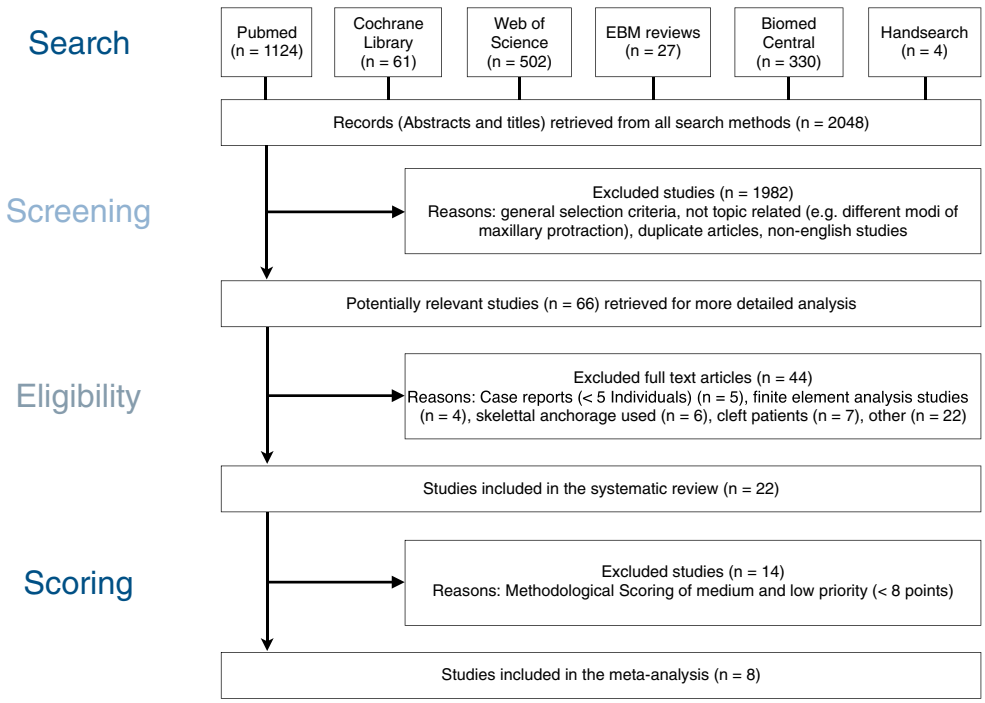


Fig. 1 PRISMA flow diagram showing literature findings and stages of the reviewing process

Table 2 Studies included in the systematic review with year of publication, description of the study, methodological scoring and assessment of priority/quality

Study	Year	Appliance (extraoral)	Expansion	Expansion and constriction	Control	Individuals	Study design (0–3)	Sample size (0–1)	Selection description (0–2)	Method error analysis (0–1)	Statistical analysis (0–2)	Overall scoring	Judged priority/quality
Masucci et al.	2014	Face mask	RME (with acrylic splint)	Yes	21	62	2	1	2	1	2	8	High
Yavuz et al.	2012	Face mask	RME	No	Non-RME group	43	1	1	2	1	2	7	Medium
Chen et al.	2011	Face mask	No (TPA in situ)	No	17	39	3	1	2	1	2	9	High
Masucci et al.	2011	Face mask	RME	No	No	22	3	1	2	1	2	9	High
Kurt et al.	2010	Face mask	RME	No	No	33	1	1	2	1	2	7	Medium
Lee et al.	2010	Face mask (Delaire-type)	No	No	No	49	0	1	2	0	2	5	Low
Mandall et al.	2010	Face mask (Delaire-type)	RME	No	38	35	3	1	2	1	2	9	High
Isci et al.	2010	Face mask (Delaire-type)	RME (Haas-type)	Yes	No	30	3	1	2	1	2	9	High
Tortop et al.	2007	Face mask (Delaire-type)	RME	No	Non RME group	28	1	0	2	1	2	6	Medium
Vaughn et al.	2005	Face mask	RME	No	Non RME group	46	3	1	2	1	2	9	High
Westwood et al.	2003	Face mask	RME	No	22	34	1	1	2	1	2	7	Medium
Saadia et al.	2000	Face mask (Petit-type)	RME (Haas-type)	No	No	112	0	1	2	1	2	6	Medium
Macdonald et al	1999	Face mask	RME	No	No	24	1	1	2	0	2	6	Medium
Baccetti et al.	1998	Face mask (Petit-type)	RME	No	No	46	1	1	2	1	2	7	Medium
da Silva et al.	1998	Face mask (Delaire-type)	RME (Haas-type)	No	No	31	0	1	2	0	1	4	Low
Gallagher et al.	1998	Face mask	RME	No	No	22	0	1	1	0	1	3	Low
Kapust et al.	1997	Face mask	RME	No	No	63	0	1	2	0	1	4	Low
Williams et al.	1997	Face mask	RME	No	No	28	2	1	2	1	2	8	High
Chong et al.	1996	Face mask (Delaire-type)	No	No	No	16	1	1	2	1	2	7	Medium
Ngan et al.	1996	Face mask (Delaire-type)	RME	No	No	20	2	1	2	1	2	8	High
Ngan et al.	1996	Face mask (Delaire-type)	RME (if needed)	No	No	30	0	1	2	1	2	6	Medium
Shanker et al.	1996	Face mask	RME (Haas-type)	No	25	25	1	1	2	1	2	7	Medium

RME rapid maxillary expansion, *TPA* trans palatal arch

Studies with a score of more than 8 points (high-quality studies) were divided in subgroups considering the change of the transverse through expansion (no expansion/expansion/expansion and constriction carried out). All assigned studies were included in the meta-analysis. For each outcome, the mean difference in the treatment groups was compared to a control group with a mean of 0 and a standard error equal to the method error on the corresponding studies. Forest plots were drawn using Review Manager (RevMan) Version 5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). This included the calculation of combined point estimates. Random effect models were used to take into account the heterogeneity. In case of severe heterogeneity (I^2>50 %), results were used for qualitative interpretation. As this is an explorative study, p values were given for descriptive reasons only and should be interpreted with caution and in connection with effect estimates.

Results

Literature findings The primary literature search resulted in 2048 studies from all search sources (Pubmed n=1124, Cochrane Library n=61, Web of Science n=502, EBM reviews n=27, Biomed Central n=330, handsearch n=4). After the screening process, 66 studies were assessed for more detailed analysis with 1982 excluded articles due to conflict with the general selection criteria and duplicate articles. Following full text evaluation, 22 studies [1, 16, 36–55] were included in the systematic review process after exclusion of 44 articles (due to secondary, detailed exclusion criteria). After quality assessment and scoring, a meta-analysis including eight studies was provided [1, 16, 40, 45–47, 52, 55] (Fig. 1). If the independence of a study was unclear or several studies were based on findings derived from the same patient sample, a representative study was selected for meta-analysis on the basis of the highest scoring result (Table 2).

Based on the scoring protocol, a total of 14 studies were rated low (n=4) or medium (n=10) quality/priority. A number of eight studies achieved high-quality scoring results. Of these eight studies in two articles, maxillary protraction was carried out without palatal expansion in the treatment group or a subgroup [1, 52]. Maxillary protraction with palatal expansion was used in seven studies including subgroups [16, 40, 45–47, 52]. Two studies evaluated the effect of face mask treatment with an alternating protocol of expansion and compression [40, 55] (Table 3).

Cephalometric data Comparison of cephalometric variables appeared to be difficult due to high variability of the parameters used. Nevertheless, in most of the studies, the following common measurements and changes were specified: SNA,

Table 3 Studies included in the meta-analysis with modus of transverse treatment and changes in cephalometric parameters

Modus	Study	ΔSNB	σ	ΔSNA	σ	ΔANB	σ	ΔWits	σ	ΔMandibular plane	σ	ΔPalatal plane	σ	ΔUpper incisor angulation	σ	ΔLower incisor angulation	σ	ΔAPoint (vertical)	σ	ΔAPoint (horizontal)	σ	Number
Maxillary protraction	Chen et al., 2011	−1.18	1.94	2.25	1.81	3.42	1.15	n.a.	n.a.	2.46		1.75	−1.04	7.85		0.06		n.a.	n.a.	3.93	2.06	22
	Vaughn et al. 2005 (Subgroup A)	−1.43	0.34	2.51	0.65	3.95	0.65	−3.82	0.80	1.35		0.39	−0.89	2.71		n.a.		−1.28	0.64	3.09	0.55	14
Maxillary protraction with expansion	Masucci et al., 2011	−2.00	3.10	1.90	2.90	0.00	1.40	1.10	2.60	n.a.		n.a.	n.a.	2.40		−0.50		n.a.	n.a.	n.a.	n.a.	26
	Ngan et al., 1996	−1.70	1.20	1.30	1.30	3.00	1.20	4.50	3.30	1.90		1.40	−1.00	3.40		−5.20		n.a.	n.a.	2.30	1.20	30
	Williams et al., 1997	0.00	4.46	0.87	3.00	1.39	2.12	n.a.	n.a.	1.00		3.98	−0.67	5.23		0.48		n.a.	n.a.	n.a.	n.a.	28
	Vaughn et al., 2005 (Subgroup B)	−1.06	0.37	2.77	0.68	3.82	0.70	−3.98	0.75	1.12		0.42	−0.72	0.15		n.a.		−0.99	0.47	3.29	0.58	15
	Mandall et al., 2010	−0.70	1.50	1.40	2.10	2.10	2.30	n.a.	n.a.	1.80		3.20	−0.50	2.90		−4.90		n.a.	n.a.	n.a.	n.a.	35
	Masucci et al., 2014 (Subgroup A)	−0.80	1.40	1.50	1.40	2.30	1.70	1.90	2.10	1.70		0.20	−0.60	n.a.		n.a.		n.a.	n.a.	n.a.	n.a.	31
	Isci et al., 2010 (Subgroup A)	−1.43	0.78	1.87	1.01	3.30	1.33	n.a.	n.a.	2.33		1.85	−0.70	1.53		−0.23		n.a.	n.a.	n.a.	n.a.	15
Maxillary protraction with expansion and compression	Isci et al., 2010 (Subgroup B)	−1.60	0.81	3.10	1.24	4.70	1.49	n.a.	n.a.	2.13		2.10	−1.23	1.13		−1.77		n.a.	n.a.	n.a.	n.a.	15
	Masucci et al., 2014 (Subgroup B)	−1.50	1.60	2.70	1.60	4.00	2.00	3.40	2.40	1.10		1.40	−0.50	1.60		n.a.		n.a.	n.a.	n.a.	n.a.	31

SNB, ANB, Wits, mandibular plane, palatal plane, upper incisor angulation, lower incisor angulation, and horizontal A point evaluation.

Figure 2 summarizes the cephalometric changes after protraction using a face mask appliance and no direct maxillary expansion prior to protraction on the basis of two studies. Total SNA angle changes of 2.47°, SNB angle changes of −1.42°, ANB angle changes of 3.72°, mandibular plane angle changes of 1.85°, palatal plane angle changes of −0.91°, and angulation changes of the upper incisor of 5.17°, and A-Point changes of 3.41 mm were found.

Analyzing the skeletal parameters, positive treatment effects with antero-posterior mandibular repositioning and sagittal maxillary forward movement can be seen in patients using a face mask appliance. A slightly clockwise rotation of the mandible and a counterclockwise rotation of the maxillary planum could be noticed. With a metric anterior movement measured in a point of more than 3 mm, the positive effect was emphasized. Noticeable upper incisor proclination was recognized.

Figure 3 shows the effects of face mask treatment with activation of a rapid maxillary expansion appliance on the basis of seven studies. Total SNA angle changes of 1.71°, SNB angle changes of −1.17°, ANB angle changes of 2.28°, mandibular plane angle changes of 1.61°, palatal plane angle changes of −0.71°, angulation changes of the upper incisor of 2.51°, as well as horizontal A point changes of 2.81 mm.

Additionally, the analysis revealed lower incisor angulation changes of −1.99° and Wits appraisal changes of 0.52 mm when expansion was carried out directly prior to facemask treatment.

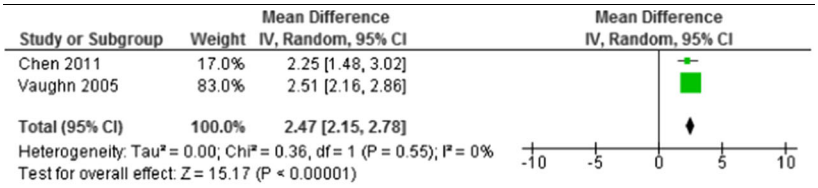
Figure 4 shows the cephalometric changes found in studies using a protocol of alt-RAMEC. Total SNA angle changes of 2.89°, SNB angle changes of −1.57°, ANB angle changes of 4.34°, mandibular plane angle changes of 1.51°, and palatal plane angle changes of −0.86°.

Discussion

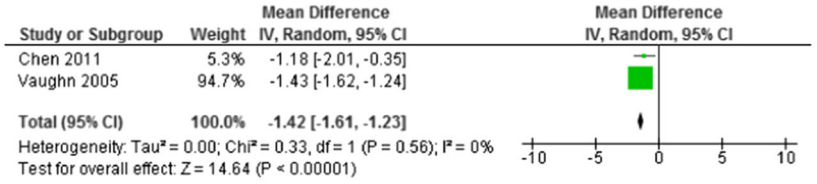
Recent literature So far, only two articles in Anglo-American [20, 21] and two studies in European [2, 22] literature have been published systematically reviewing class III orthopedic treatment using a face mask. In 1999, Kim et al. described the following cephalometric changes on the basis of 14 studies included: mean SNA angle changes of 1.6° in the expansion/1.7° in the non-expansion group, changes of SNB of −1.3°/−1.2, ANB angle changes of 2.9°/2.7°, changes in Wits of 4.9 mm/4.2 mm, and almost similar measurements in dental parameters except for upper incisor angulation with 1.3° in the expansion and 4.1° in the non-expansion groups [20]. The authors conclude a positive effect of face mask treatment with significant improvement of skeletal parameters, and no significant difference between expansion/non-expansion treatment except for reduced dental side effects on upper incisor angulation when additional expansion is carried out. However, in their discussion, they conclude that the use of expansion enhances the protraction effect in terms of treatment time. De Toffel et al. systematically reviewed the topic 10 years later. They describe a 76 % success rate of orthopedic face mask treatment analyzing 19 articles in toto and up to 5 years of follow-up [21]. Nevertheless, no meta-analysis was provided, and their quality assessment revealed a distinctive need for further randomized controlled trials. In 2001, Jäger et al. analyzed 14 studies regarding class III treatment [2]. They confirm the findings of Kim et al. with regard to significant success on the skeletal level by face mask therapy. Not discriminating between expansion/non-expansion treatment, they report SNA angle changes of 1.4°, SNB angle changes of −1.3°, and ANB angle changes of 2.6°. Angulation changes of the upper incisors are specified with 1.6°. The latest study by Cordasco et al. reports SNA changes of 2.1°, SNB changes of −1.54, and ANB changes of 3.66°. Analyzing their subgroups, they report very similar cephalometric changes with regard to expansion and non-expansion protocols when compared to the recent study. All of their findings are based on only three articles included in the meta-analysis [22]. Alt-RAMEC protocols were not included in the literature search. We believe that the present study is the first systematic literature review, which a priori analyzed palatal expansion and expansion/constriction in the initial search process. Recent literature suggests that recognizable changes in skeletal patterns and cephalometric values can be found up to 5 years after face mask treatment. The influence of transverse expansion remains unclear to some extent.

Fig. 2 Forest plots for meta-analysis of the cephalometric parameters: ▶ maxillary protraction using orthopedic face mask (with subdivision for each cephalometric variable *2.1–2.7*)

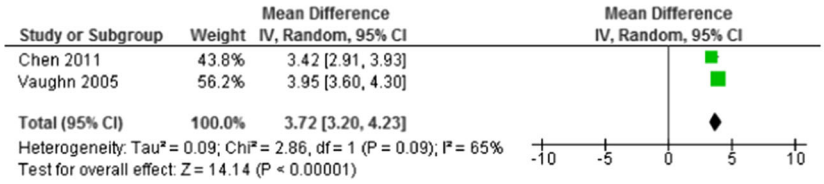
Results of the present study In accordance with the results of Kim et al., the recent analysis confirms the slightly higher SNA change and a relatively similar SNB change for face mask treatment with or without expansion. For all measurements, no relevant differences between the various cephalometric parameters of non-expansion and expansion groups were identified. Overall, this study reveals somewhat higher results for changes in SNA, SNB, and ANB for studies without expansion. To qualify this statement, it has to be mentioned that only two studies were included in this group, and in one group, expansion for crossbite treatment was carried out in few of the individuals, however a fair amount prior to face mask treatment, thus qualifying this study for the non-expansion studies. The current meta-analysis reveals a caudo-posterior (clockwise) development of the mandible plane of



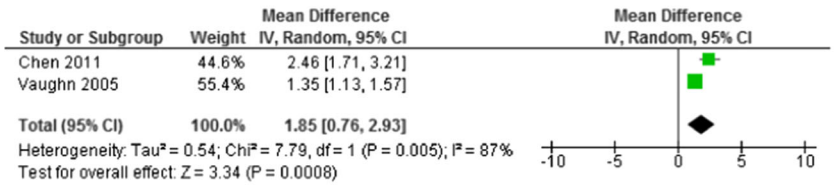
2.1: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: SNA.



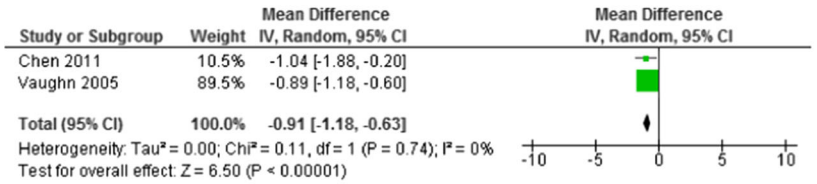
2.2: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: SNB.



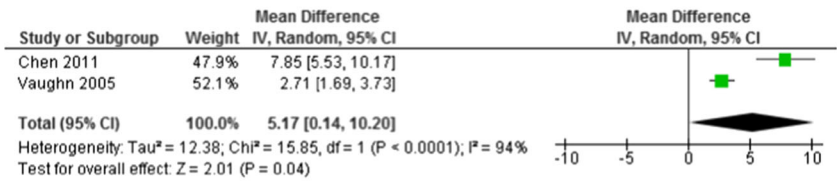
2.3: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: ANB.



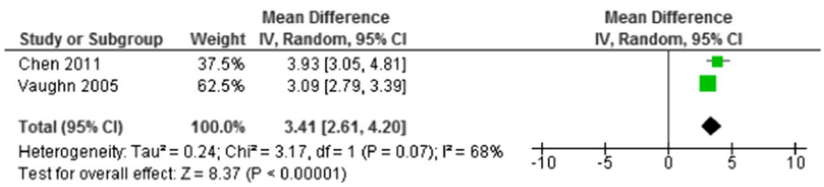
2.4: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: Mandibular plane.



2.5: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: Palatal plane.



2.6: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: Upper incisor angulation.



2.7: Forest plot of comparison: Maxillary protraction (only) vs. no intervention, outcome: A-Point (horizontal).

1.84° (non-expansion) respectively 1.6° (expansion) and a counterclockwise direction of the palatal plane of −0.91 respectively −0.7°. Both findings contribute to the positive effect of face mask treatment with regard to the vertical improvement, especially in brachyfacial class III patients. It has to be emphasized that not only the enhancement of the sagittal movability of the skeletal components is crucial for expansion but also the dentoalveolar transversal deficit indicated by posterior crossbite and narrow upper dental arch. Furthermore, it can be concluded that inclination of the upper incisors shows significant proclination after protraction. Dental changes occur in higher severity when there was no expansion. This might be explained with the flattening of the anterior part of the dental arch during posterior expansion. Furthermore, it has to be stated that statistical heterogeneity for various variables is high which makes validity less conclusive; however, the recent findings corroborate clinical realities and are in line with the findings of Cordasco et al. [22].

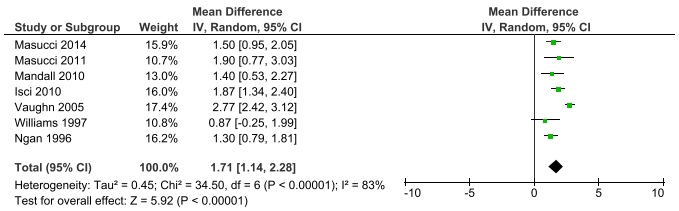
Alternating expansion and constriction On the basis of research in cleft patients with additional class III malocclusion, Liou et al. introduced the concept of alternating expansion and compression of the maxilla in 2005 for enhancing class III therapy in growing patients. In contrast to the commonly used expansion appliances (such as Haas/Hyrax expanders [56], fan-type expanders [57, 58], etc.), they use a double-hinged expander for the transverse expansion proposing a more sufficient expansion in the anterior region [59]. They also use a ß-titanium maxillary protraction spring as class III mechanic. After 7 weeks of alternating activation and deactivation of the expansion appliance, the class III therapy is started. Using the protraction spring, Liou reports a 5.8 mm protraction of A-point. Although the used appliances are somewhat different than the frequently used devices (posterior Haas-type expander/facemask), according to Tsai et al., no significant difference in maxillary protraction is found even when using a face mask in combination with the alt-RAMEC protocol (5.2 mm A-point protraction) [60]. In the discussion of this new strategy and in consideration of the weakening effect on the circumaxillary sutures, it has to be stated that evidence on effectiveness and side effects (osteoarthrosis, pseudoarticulation of the sutures, and dental side effects) is rather minimal. In pursuit of minimizing unwanted dental side effects, animal studies have shown that the factor of sutural disarticulation (for example, through direct skeletal anchorage) is potentially capable of reducing significant dental tipping [61, 62].

The recent extensive literature research resulted in two articles of high quality to be in line with the inclusion criteria dealing with the alt-RAMEC protocol [40, 55]. These trials analyze the effect of alternating activation/deactivation of the expansion appliance in addition to face mask treatment, in comparison to an expansion-only group. They report significant change of ANB angle of 4.34° in the activation/deactivation group with an also remarkable change in SNA angle of 2.89° when compared to the expansion-only group. Furthermore, a significantly higher amount of A-point movement of 4.13 mm was detected in one of the studies [40] when compared to the standard protocol (2.33 mm). These findings reflect a good correlation of the data detected in the studies mentioned above as part of this systematic review (A-point movement of 2.81 mm for expansion studies). Nevertheless, it has to be emphasized that there is a critical absence of well-designed studies regarding this interesting approach.

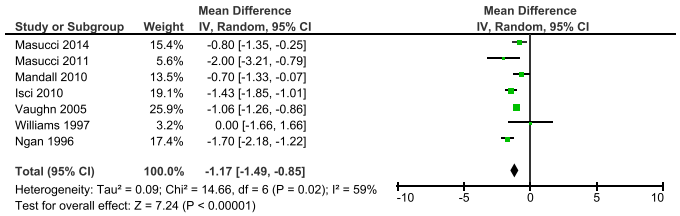
Fig. 3 Forest plots for meta-analysis of the cephalometric parameters: ▶ maxillary protraction using orthopedic face mask and transverse rapid maxillary expansion (with subdivision for each cephalometric variable, *3.1–3.7*)

Apart from enhancing maxillary protraction by disarticulating the maxillary sutures using the abovementioned protocols, skeletal anchorage is another recently proposed option for improving class III therapy [63]. Various temporary skeletal anchorage devices (TADs), such as bone anchors [64] and miniscrews [65], have been combined with class III mechanics in a few studies. For skeletal anchorage combined with the alt-RAMEC protocol, one case report can be found in the literature [66].

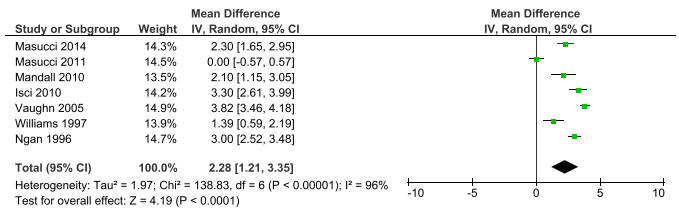
In summary The recent study reveals certain inhomogeneities with regard to study quality, cephalometric variables used, and the included age groups of the reviewed articles, thus making it rather difficult to correctly analyze and combine their findings. This does not only concern the clinical setup of the studies but also the differing statistical methods (for example, the use of standard deviation vs. standard error, missing information on control group definitions, etc.). Out of 22 reviewed articles, only 8 were of acceptable quality to be included into the meta-analysis. A critical lack of randomized controlled trials and/or prospective setups comparing expansion/non-expansion and alternating expansion/compression in combination with face mask maxillary protraction has to be mentioned. In recent years, few articles show promising study designs, which might be adapted for future trials [45, 52]. On the other hand, the methodological application of the face mask appliance was relatively similar with regard to force level, wear time, and treatment duration throughout the reviewed studies. Nevertheless, although a statistical combination of studies with these constant clinical variables might seem possible, it must be taken into consideration that additional uncontrolled factors (e.g., individual growth differences and dropout of participants) reduce comparability and thus the possibility for meta-analysis testing. Furthermore, it has to be emphasized that even if meta-analysis is carried



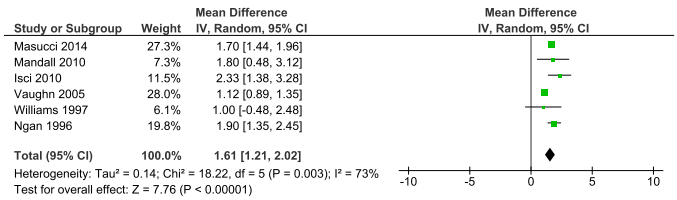
3.1: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention , outcome: SNA.



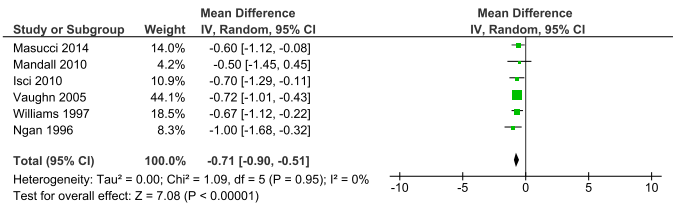
3.2: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention, outcome: SNB.



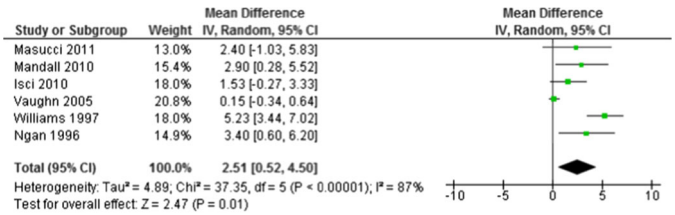
3.3: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention, outcome: ANB.



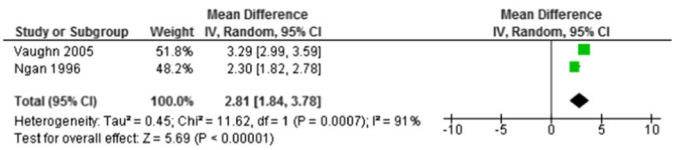
3.4: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention, outcome: Mandibular plane.



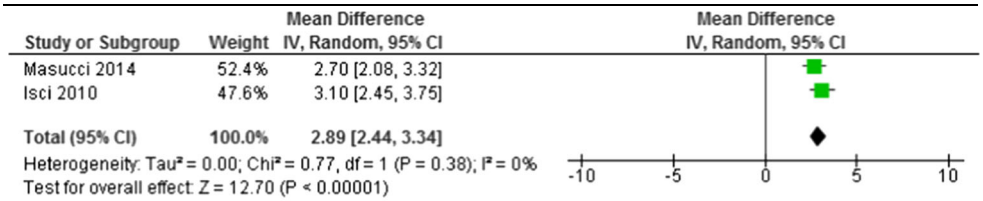
3.5: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention, outcome: Palatal plane.



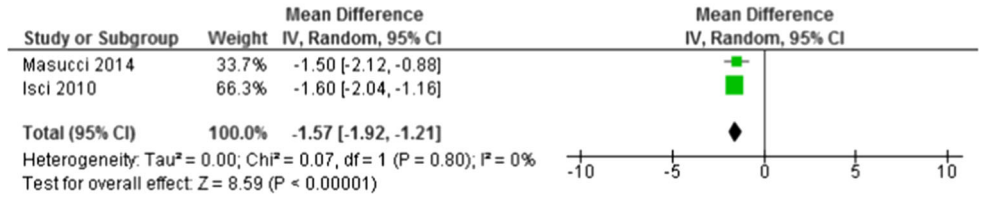
3.6: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention, outcome: Upper incisor angulation.



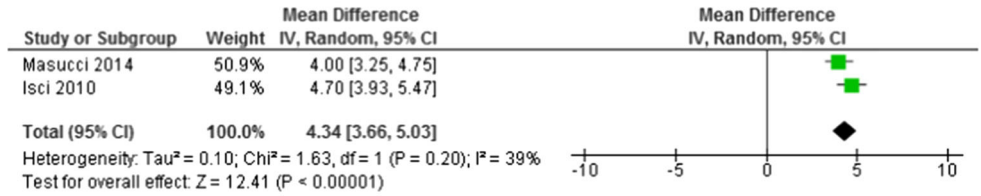
3.7: Forest plot of comparison: Maxillary protraction + expansion vs. no intervention, outcome: A-Point (horizontal).



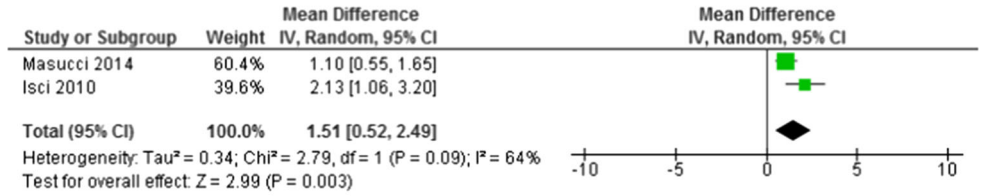
4.1: Forest plot of comparison: Maxillary protraction + expansion/constriction vs. no intervention, outcome: SNA.



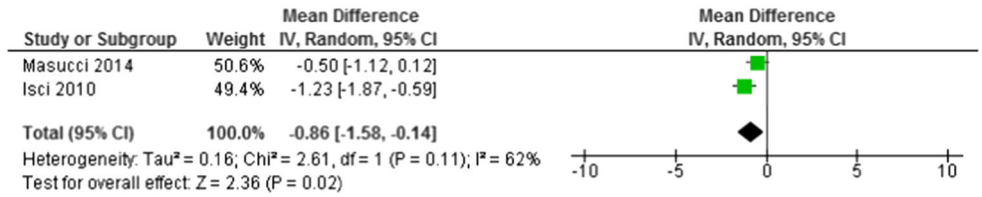
4.2: Forest plot of comparison: Maxillary protraction + expansion/constrictionvs. no intervention, outcome: SNB.



4.3: Forest plot of comparison: Maxillary protraction + expansion/constriction vs. no intervention, outcome: ANB.



4.4: Forest plot of comparison: Maxillary protraction + expansion/constrictionvs. no intervention, outcome: Mandibular plane.



4.5: Forest plot of comparison: Maxillary protraction +expansion/constrictionvs. no intervention, outcome: Palatal plane.

Fig. 4 Forest plots for meta-analysis of the cephalometric parameters: maxillary protraction using orthopedic face mask and transverse expansion/constriction protocol (alt-RAMEC) (with subdivision for each cephalometric variable, *4.1–4.5*)

out, it does not substitute for high-quality randomized controlled investigations.

Conclusion

- Class III treatment in growing patients using a face mask appliance is efficient for correction of the sagittal malocclusion when various clinical factors are taken into consideration.
- The need for single transverse expansion is primarily determined by dentoalveolar abnormalities in the transverse dimension (such as edge-to-edge occlusion or crossbites). Recent findings underline that there is no significant improvement of maxillary protraction when additional expansion is carried out.

- Weakening and opening the circumaxillary sutures by alternating expansion and compression of the maxillary complex are able to *enhance* class III therapy mechanics.
- An essential need for further randomized controlled trials (RCTs) is present to improve the degree of evidence, especially for the influence of alternate activation and deactivation of the expansion appliance. Not only the possible improvement of face mask therapy by the alt-RAMEC protocol (or its modifications) but also dental and especially periodontal side effects as well as long-term results should be subject of further studies.

Clinical relevance

The influence of transverse palatal expansion on sagittal therapeutic changes is crucial for the treatment of both patients with or without transverse deficit. Maxillary protraction therapy is efficient in correction of a class III malocclusion. According to our findings, the transverse palatal expansion does not per se improve the protraction. Concepts of weakening and opening the circumaxillary sutures by expansion and constriction are legitimately suspected to enhance class III treatment.

Ethical standards The manuscript does not contain clinical studies or patient data.

Conflict of interest The authors declare that they have no competing interests.

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