Effectiveness of prefabricated myofunctional appliances on Vertical Dimension in Children: A Systematic Review and Meta-Analysis

A .Balian [1], C. Salerno [2,3,4], A. Manti [2], V. Lanteri [5], S. Cirio [2*], M. G. Cagetti [2]

[1]*Dental and Stomatology Unit, Surgical Area Department, Cittadella Hospital, ULSS6 Euganea, Via Pilastroni 15, 35013 Cittadella, Italy*
[2]*Department of Biomedical, Surgical and Dental Sciences, University of Milan, Via Beldiletto 1, 20142 Milan, Italy*
[3]*Department of Restorative, Preventive and Pediatric Dentistry, University of Bern, Freiburgstrasse 7, 3012 Bern, Switzerland*
[4]*Graduate School for Health Sciences, University of Bern, Bern, Switzerland*
[5]*Surgical, Medical and Dental Department, University of Modena and Reggio Emilia, Via del Pozzo 71, 41125 Modena, Italy*

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email: silvia.cirio@unimi.it

Abstract

Aim Prefabricated myofunctional appliances (PMAs) are widely adopted for correcting the sagittal and vertical dimensions during mixed dentition. Despite the effectiveness of the antero-posterior relationship has been recently evaluated, the effectiveness in correcting the vertical dimension is still uncertain. This systematic review aimed to assess the effectiveness of PMAs treatment in children with mixed dentition on the vertical dimension, including sagittal and transverse parameters that may affect the vertical dimension.

Methods PubMed, Scopus, Embase, Cochrane, Livivo, and Lilacs were searched from inception until November 5th, 2024. Selection criteria were: Randomized/non-randomized clinical studies (RCT/NRSI), prospective and retrospective cohort studies, before-and-after comparisons, and cross-sectional studies assessing PMAs treatment in mixed dentition children with deep-bite or open-bite malocclusion. The mean pre-treatment and post-treatment values of dental and/or skeletal variables and/or treatment changes as mean differences (MD)±SD, were extracted. Risk of bias was performed with Rob2 and the NHLBI quality assessment tools. Random-effect meta-analysis of MD and their 95% confidence intervals (ICs) were performed, followed by assessment of clinical relevance of significant results.

Results Two RCT, 7 case-control, and 2 before-and-after comparison studies involving 760 patients (51.18% females; mean age range 5.1-10.76 years) affected by deep-bite (n=576) and open-bite (n=184) malocclusions were included. Meta-analysis was performed for the nine studies over deep-bite; insufficient data were available for open-bite. Overbite significantly reduced after PMAs treatment (9 studies; MD 1.73; 95% IC: 1.27 to 2.19; P<0.001) and significant mean post-treatment differences were found compared to control (no treatment) (2 studies; MD 2.72; 95% IC: -4.58 to -0.86; P<0.001). Significant changes in skeletal effects were found mainly in sagittal relationships, rather than vertical ones, as the ANB angle decreased (5 studies; MD 1.24; 95% IC: 0.52 to 1.97; P < 0.001) and SNB increased (5 studies; MD 2.11; 95% IC: -2.81 to -1.41; P < 0.001). Overall, high inconsistency and low-to-moderate quality of studies were found, so the level of certainty of the observed results was very low.

Conclusions The PMAs treatment seems to be associated with a reduction of overbite in deep-bite malocclusion, whereas the vertical skeletal pattern seems to be unaffected.

KEYWORDS orthodontics, deep-bite, open-bite, elastodontic appliances, elastodontic devices, systematic review, meta-analysis.

Introduction

The development of malocclusion results from the complex interplay of various factors influencing craniofacial growth [Enlow and Bang, 1965; Harvold et al., 1981; Moss and Salentijn, 1969; Stahl et al., 2007; Vargervik et al., 1984]. Research has consistently highlighted the relationship between altered lip/tongue pressure, bad oral habits, such as oral breathing, and craniofacial growth [Moss and Rankow, 1968; Moss and York, 1997; Owman-Moll and Ingervall, 1984]. If not addressed in a timely manner, these conditions can disrupt normal growth patterns and lead to dento-skeletal malocclusions [Ortu et al., 2021]. Vertical discrepancies are often associated with specific oral habits and dysfunctions. Open bite is frequently associated to non-nutritive sucking habits, tongue thrusting, atypical swallowing, oral breathing, hypotonic perioral muscle tone, and incompetent lips. In contrast, deep-bite is more frequently related to hyperactivity of the mentalis muscle and the presence of a lower lip trap [Moss and Rankow, 1968; Moss and York, 1997; Owman-Moll and Ingervall, 1984]. Successful interceptive treatment aims to eliminate harmful oral habits where possible, restore oral muscular balance, and address dysfunction to support proper craniofacial development. This approach helps correct emerging problems or simplify subsequent orthodontic therapy. Notably, most malocclusions tend to worsen rather than self-correct with age [Sunnak et al., 2015]. Developing malocclusions during mixed dentition can be fully resolved with interceptive treatment in 15% and improved in 49% of cases [Sunnak et al., 2015]. Several authors have suggested the use of prefabricated myofunctional appliances (PMAs) as an effective interceptive orthodontic intervention for children and young adolescents [Janson et al., 2004; Janson et al., 2000; Keski-Nisula, et al., 2008; Keski-Nisula et al., 2008; Migliaccio et al., 2014; Myrlund et al., 2019]. PMAs devices are single-block, removable appliances made from soft, silicone-like materials [Huang Yong, 2022; Mohammed et al., 2020]. Over the years, the variety of elastomeric preformed appliances has expanded significantly, with numerous PMAs introduced, including the

oral shield, the Eruption Guidance Appliance proposed by Bergersen, Occluso-Guide®, LM-Activator™, Myobrace®, and Trainer for Kids™ [Bergersen, 1984; Cheney, 1963; Papageorgiou et al., 2019]. PMAs designs vary in size and shape based on their intended purpose, which may include facilitating myofunctional therapy, aiding in the correction of harmful oral habits, and promoting dentofacial orthopedic improvements [Bergersen, 1988, 1995; Fichera et al., 2021; Mohammed et al., 2020; Ravera et al., 2020]. PMAs devices apply gentle forces to the upper and lower dental arches, helping to correct the positioning of teeth and ensuring that the mandible maintains proper alignment with the maxilla [Huang Yong et al., 2022; Mohammed et al., 2020; Papageorgiou et al., 2019]. Equipped with features such as oral screens, bumpers, and tongue ramps, PMAs promote nasal breathing, facilitate proper tongue posture, and encourage the regular activity of oral soft tissues appliances, furthermore are comfortable, cost-effective, and versatile, allowing for various occlusal anomalies' treatment, including deep-bite, open-bite, excessive overjet, anterior crossbite, and crowding [Keski-Nisula et al., 2008; Migliaccio et al., 2014; Papageorgiou et al., 2019]. In mixed dentition, PMAs treatment has demonstrated significant functional and dento-alveolar outcomes, along with mild skeletal effects. These appliances are effective in correcting harmful habits and oral dysfunction, improving overjet, overbite, and teeth alignment, and modestly promoting mandibular growth [Habumugisha et al., 2022; Keski-Nisula et al., 2020; Papageorgiou et al., 2019]. To date, only a few systematic reviews have assessed the effectiveness of the PMAs [Huang et al., 2022; Mohammed et al., 2020; Papageorgiou et al., 2019]. These reviews have primarily focused on sagittal discrepancies, particularly excessive overjet and Class II malocclusion, as key population characteristics. The outcomes evaluated included overjet, molar and canine relationships, and skeletal parameters such as SNA, SNB, and ANB angles. Notably, overbite was the only vertical parameter considered [Huang Yong ; Chen Tianmu ; Mallineni Sreekanth Kumar ; McGrath Colman ; Hagg Urban, 2022; Migliaccio et al., 2014; Mohammed et al., 2020; Papageorgiou et al., 2019]. In a systematic review regarding the effectiveness of PMAs in correcting Class II division 1 malocclusion, it was reported that custom-made activators were more effective in correcting the overjet than the PMAs in the short term [Mohammed et al., 2020]. In another review of randomized clinical trials, the authors concluded that PMAs are less effective in producing dento-skeletal changes compared to customized functional devices but reported that they are more effective in improving overbite, overjet, crowding and establishing Class I relationship compared to no treatment [Papageorgiou et al., 2019]. The most recent systematic review and meta-analysis confirmed that PMAs treatment has a significant short-term effect on correcting overjet and overbite during early mixed dentition [Huang et al., 2022]. Regarding skeletal changes, only slight differences in SNA, SNB, and ANB angles were observed, based on the findings of the two included studies [Huang et al., 2022]. Despite several observational and randomized clinical trials demonstrating that early intervention with PMAs can improve overbite, anterior facial height, intermaxillary divergence, and the mandibular plane angle, their effectiveness in correcting vertical discrepancies remains uncertain [Condò et al., 2012; Habumugisha et al., 2022; Janson et al., 2000]. To the best of the authors' knowledge, no systematic reviews have yet been conducted evaluating the effectiveness of these appliances in the treatment of vertical malocclusions, specifically deep bite and open bite. The aim of this review was to systematically and critically evaluate the existing scientific literature on the effectiveness of prefabricated myofunctional appliances (PMAs) in producing vertical occlusal and skeletal changes in children with mixed dentition presenting with deep bite or open bite malocclusions. The review assessed the effectiveness by examining clinical outcomes related to the vertical dimension, including sagittal and transverse parameters that may influence it, in subjects undergoing PMA treatment, both as pre- and post-treatment changes and in comparison to untreated controls.

Materials and methods

Protocol and registration

The present systematic review was registered a priori in the International Prospective Register of Systematic Reviews (PROSPERO) under protocol number CRD42021289631 (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=289631) and it has been conducted and reported according to the Cochrane Handbook of Systematic reviews of Interventions and to the guidelines of Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement [Higgins et al., 2024; Page et al., 2021].

Pico question

The PICO model was used to structure the clinical research question and define the inclusion criteria [Richardson et al., 1995]. The present review aimed to answer the following questions: "Are prefabricated myofunctional appliances able to modify the vertical dimension of children with reduced or increased vertical dimension?"; "Are prefabricated myofunctional appliances able to modify sagittal and transverse parameters that may affect the vertical dimension in children with reduced or increased vertical dimension?".

The PICO criteria defined as follows:

- Partecipants/population: children of any sex in the mixed dentition phase with either increased or decreased vertical occlusal dimension.
- Intervention: PMAs, with no restriction on material, shape, treatment protocol or length.
- Comparator: no control or no intervention.
- Primary Outcome: correction of vertical dimension in children undergoing PMAs treatment.
- Secondary Outcome: correction of sagittal and transverse parameters that may affect vertical dimension in children undergoing PMAs treatment.

Eligibility criteria

Randomized clinical trials (RCTs) and non-randomized studies of interventions (NRSIs), prospective and retrospective cohort studies, before-and-after comparisons, and cross-sectional studies, were considered for inclusion. Eligible studies must have been published in English and focused on the assessment of PMAs treatment in children with mixed dentition and malocclusions affecting the vertical dimension. Vertical, sagittal, transversal dimension correction and dental relationships and/or alignment must have been assessed on study model and/or lateral cephalometry.

The following exclusion criteria were applied:

- Cleft lip and palate patients and syndromic patients.
- Patients with Obstructive Sleep Apnea Syndrome (OSAS).
- Studies that did not report or provide, upon request, pre- and post-treatment assessment of overbite (e.g., mean ± SD)
- Studies involving the combined use of PMAs with other types

Author, Year	Study location	Study Design	Study setting	Blinding	Follow up (months)	Funding	Journal	Electronic Data Base
Ortu et al. (2021)	Italy	Case-control study	University Dental Service	No blinding	12 months	No	BMC Oral Health	PubMed Scopus
Janson et al. (2000)	Brazil	Case-control study	University Dental Service	No blinding	26 months	n.a.	American Journal of Orthodontics and Dentofacial Orthopedics	Scopus PubMed
Fichera et al. (2021)	Italy	Case-control study	University Dental Service	Single Blinding (outcome assessor)	12 months	No	Materials	PubMed
Myrlund et al. (2014)	Norway	RCT	Public Dental Service	Single Blinding (outcome assessor)	12 months	Yes	European Journ.a.l of Orthodontics	Scopus
Myrlund et al. (2019)	Norway	RCT	Public Dental Service	Single Blinding (outcome assessor)	12 months	n.a.	Angle Orthodontist	Pubmed Scopus
Keski-Nisula et al. (2008)	Finland	Case-control study	Public Dental Service	No blinding	39 months (average)	Yes	Angle Orthodontist	PubMed Scopus
Habumugisha et al. (2022)	China.	Case-control study	University Dental Service	Single Blinding (outcome assessor)	13±1.1 months	Yes	BMC Pediatrics	Scopus
Lo Giudice et al. (2022)	Italy	Case-control study	University Dental Service	No blinding	12 months	n.a.	European Journ.a.l of Paediatric Dentistry	PubMed
Condò et al. (2012)	Italy	Before and after comparison	University Dental Service	No blinding	12 months	n.a.	European Journ.a.l of Paediatric Dentistry	Pubmed
Dinkova (2014)	Bulgary	Before and after comparison	University Dental Service	No blinding	>24 months	n.a.	Journ.a.l of IMAB	Embase
Lanteri et al. (2023)	Italy	Case-control study	University Dental Service	Single Blinding (outcome assessor)	12 months	No	European Journ.a.l of Paediatric Dentistry	Scopus

n.a.: not available; RCT: Randomised Controlled Trial

TABLE 1. General characteristics of the included studies.

of treatment.
- Studies for which full-text articles were not available.
- Case reports, case series, and non-clinical studies.

Information sources

An electronic literature search was conducted from inception to November 5, 2024, by two authors (C.S. and S.C.). Adapted search strings were employed for each databases used.

Manual research has been also performed, screening the reference list of the full-text eligibility studies and review articles to find additional proper articles. After retrieving all results from the databases, they were imported and merged into a specific screening tool Ryyan® [Ouzzani et al., 2016]. The software was used to automatically remove duplicates. Subsequently, a manual screening was performed to ensure no duplicate references remained.

Selection process

After removing duplicate references, the study selection process was conducted independently and in duplicate by two review authors (B.A. and M.A.). Titles and abstracts were screened, and all articles that did not meet the eligibility criteria were excluded. The full texts of articles meeting the eligibility criteria and appearing relevant to the purpose of this systematic review were retrieved and independently reviewed by the same two authors.

Throughout all phases, the reviewers received training, and periodic checks were performed to ensure consistent application of the eligibility criteria. Any disagreements or uncertainties during the selection process were resolved through the involvement of a third author (S.C.). When necessary, the authors of selected papers were contacted via email for additional information.

Data collection process

The data extraction process from the articles evaluated for eligibility was conducted independently by four reviewers (B.A., S.C., M.A. and C.S), and disagreements were handled by a collegial discussion with the other two reviewers (C.M.G. and L.V.). Data were collected using a customized data collection form. The following information was collected: authorship, year, and country of publication; journal and electronic database from which the article was retrieved; study design; setting; blinding; main purpose of the study; characteristics of the sample (including size, sex, age, and phase of dentition development); type of malocclusion; type of evaluation (clinical and/or instrumental,

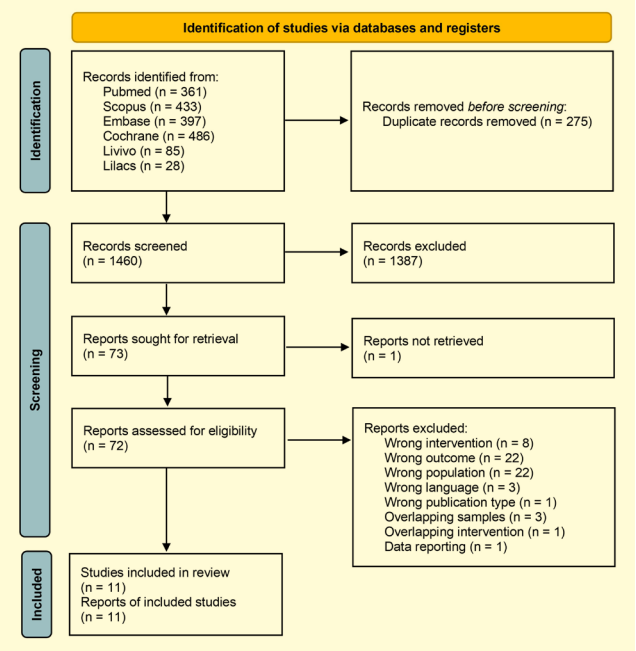

FIG. 1 Prisma flow diagram

including model casts and/or lateral cephalometry); type of assessment; type of PMAs used; orthodontic treatment protocol; follow-up duration; and funding sources. Numerical data for the outcomes of interest were extracted and rounded up to two decimals, if not possible, data were extracted as reported. If the means or percentages of the outcomes were not explicitly provided in the article, they were computed from the raw data when available.

Risk of bias in individual studies

The risk of bias was evaluated in duplicate by two reviewers (C.S. and S.C.). Disagreements were handled by contacting a third review author (L.V.) to resolve disagreements and provide the overall final judgment for each study. To assess the risk of bias in randomized controlled trials (RCTs), the recently revised Cochrane risk of bias tool (RoB 2.0) was adopted. The Microsoft Excel® tool for RoB 2 was used to input responses to signaling questions, with an algorithm estimating the overall risk of bias for each domain as: low risk, some concerns, or high risk. A plot was subsequently generated using the Cochrane RoBvis web application [McGuinness and Higgins, 2021]. The National Heart, Lung and Blood Institute (NHLBI) quality assessment tools were used for case-control studies and before-after studies with no control group [NHLBI., 2014]. The tools include questions designed to assess the potential risk of selection bias, information bias, measurement bias, or confounding. Each question in the tool could be answered as 'yes,' 'no,' 'CD' (cannot determine), 'NA' (not applicable), or 'NR' (not reported). The overall risk was categorized as low, moderate, serious, or critical based on the presence of none, one, up to four, or more than four critical items. The final appraisal was performed through joint discussion and agreement among the four authors, based on the tool responses and the specific characteristics of each study.

Dealing with missing data

Missing data were wielded by contacting the corresponding authors of the included studies. Two attempts were made to contact him/her. In the absence of answers, the data were not included. Otherwise, the Cochrane Handbook Chapter 16.1.3.2 recommendations were followed [Higgins et al., 2024; Papageorgiou, 2014].

Summary measures and data synthesis

Inter-author reliability was assessed as percentage of agreement using Cohen's Kappa statistics. Data were summarized and a comprehensive qualitative synthesis of the results was performed including the predetermined outcomes of this review. The following variables were considered for synthesis of results regarding vertical and sagittal dimension correction: overbite, overjet, mandibular plane angle to cranial base (SN/GoGn), Frankfort-mandibular plane angle (FMA), bispinal plane to cranial base through (SN/ANS-PNS), maxilla to mandibular plane angle (MX/MB, ANS-PNS/GoGn), Facial axis (BaN-PtGn), Upper Facial Height (UFH, N-ANS), Lower Facial Height (LFH, ANS-Me), sagittal relationships between the maxilla and the mandible (ANB), sagittal position of the maxilla (SNA) and the mandible (SNB), lower incisor angle to mandibular plane (IMPA), lower incisor tip distance to A-Pog (L1–A-Pog), upper incisal angle to cranial base (U1/SN), lower incisor angle to N-A (L1/NA), lower incisor tip distance to N-A (L1/NA), upper incisor angle to N-A (U1/NA), upper incisor tip distance to N-A (U1/NA), interincisal angle (U1/L1), and WITS appraisal. Moreover, a meta-analysis was undertaken if there were at least two studies reporting similar interventions and outcomes. Stata/SE 18.0 for Mac (Intel 64-bit) was used for meta-analysis. The difference (pre-treatment mean±SDT0 and post-treatment mean±SDT1) in the key variables was used to evaluate the effectiveness of the treatment in children undergoing treatment with PMAs, according to the primary outcome. The mean difference±SD(T1-T0) of the key variables was used to compare children undergoing treatment with PMAs and no treatment, according to secondary outcome. Using the I2 statistic, the proportion of variation in the effect estimates due to heterogeneity rather than chance was determined. The meta-analysis was conducted using a random effects model due to the high level of methodological heterogeneity of the included studies. The results of each meta-analysis were graphically presented by Effect Size of Forest plots. To explain the high heterogeneity, sub-group meta-analysis or metaregression were performed when possible. Clinical heterogeneity was gauged by inspecting the used appliances, timing of the outcome measurements, and the participants with regard to their age and malocclusion characteristics. The clinical relevance of the meta-analysis results was arbitrary judged as half the expected unit of change (half a Standardized Deviation) of the variable norm reported in Literature for Caucasian population with normal occlusion, as previously reported [Papageorgiou, 2014; Thilander, 2009; Thilander et al., 2005]. Effects greater than half, one, and two Standard Deviations (SD) were used as cut-off points to denote small, moderate, large, and very large effects [Papageorgiou, 2014; Papageorgiou et al., 2019].

Results

Study selection

The full PRISMA 2020 statement flowchart is reported in Figure 1. The initial electronic search yielded a total of 1,735 articles. After removing duplicates, 1,461 articles remained. Of these, 1,387 were excluded based on title and abstract review, with a Cohen's K agreement of 91% among reviewers. Seventy-three studies were deemed potentially eligible and underwent full-text assessment. Of these, 62 articles were excluded either because they did not meet the inclusion criteria

FIG. 2 (a) Risk of bias with Rob2 tool of RCTs studies. Quality assessment of (b) case-control and (c) before-after studies with no control group with NHLBI tools.

(Figure 1) or due to insufficient available data. A list of the excluded articles after full text screening, along with the reasons for their exclusion, is available on request to the corresponding author. Finally, 11 studies were included in this review [Condò et al., 2012; Dinkova, 2014; Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014, 2019; Ortu et al., 2021].

Studies and samples characteristics

Five studies were conducted in Italy [Condò et al., 2012; Fichera et al., 2021; Lanteri et al., 2023; Lo Giudice et al., 2022; Ortu et al., 2021], one in Brazil [Janson et al., 2000], two in Norway [Myrlund et al., 2014; 2019], one in Finland [Keski-Nisula, Keski-Nisula, et al., 2008], one in China [Habumugisha et al., 2022], and one in Bulgary [Dinkova, 2014]. Papers were published in the last three decades, from 2000 to 2023, and five of them in the last 4 years, from 2021 to 2023 [Fichera et al., 2021; Habumugisha et al., 2022; Lanteri et al., 2023; Lo Giudice et al., 2022; Ortu et al., 2021], as shown in Table 1. The setting was University Dental Services in 8 studies [Condò et al., 2012; Dinkova, 2014; Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Lanteri et al., 2023; Lo Giudice et al., 2022; Ortu et al., 2021] and Public Dental Services in 3 studies [Keski-Nisula et al., 2008; Myrlund et al., 2014; Myrlund et al., 2019]. Single blinding of outcome assessors was reported in 5 studies. [Fichera et al., 2021; Habumugisha et al., 2022; Lanteri et al., 2023; Myrlund et al., 2014; Myrlund et al., 2019] Follow-ups ranged from 12 months [Condò et al., 2012; Fichera et al., 2021; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019; Ortu et al., 2021] to 39 months [Keski-Nisula et al., 2008]. Of the included studies, 2 were randomized clinical trials [Myrlund et al., 2014; Myrlund et al., 2019], 7 were case-control studies [Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Ortu et al., 2021], and 2 were before-and-after comparison studies [Condò et al., 2012; Dinkova, 2014]. Nine articles were 2-arms studies, comparing patients treated with PMAs with control untreated subjects (n=6) [Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lo Giudice et al., 2022; Myrlund et al., 2014], patients treated with two different type of PMAs (n=1) [Ortu et al., 2021], patients treated with the same PMAs at different phase of dentition (n=1) [Condò et al., 2012], or patients treated with prefabricated vs customized PMAs (n=1) [Lanteri et al., 2023], as shown in Table 2. Vertical occlusal correction was an explicit outcome in 2 studies [Dinkova, 2014; Ortu et al., 2021], while the other studies aimed to assess overall effects of PMAs on skeletal and/or dento-alveolar parameters. Samples characteristics are reported in Table 2. The included studies involved a total of 760 subjects, with 51.18% females (n=389) and 48.82% males (n=371); more than 200 of the subjects were from a single study [Keski-Nisula et al., 2008]. All subjects were children in mixed dentition. Mean age ranged from 5.1 to 10.76 years. Nine studies involved subjects with increased overbite and/or deep-bite [Dinkova, 2014; Fichera et al., 2021; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019; Ortu et al., 2021], and two studies subjects with decreased overbite and/or open-bite [Condò et al., 2012; Habumugisha et al., 2022]. Six studies included both Class I and/or Class II malocclusion [Condò et al., 2012; Dinkova, 2014; Janson et al., 2000; Lanteri et al., 2023; Myrlund et al., 2014; Myrlund et al., 2019], while four studies focused exclusively on Class II malocclusion [Fichera et al., 2021; Keski-Nisula et al., 2008; Lo Giudice et al., 2022; Ortu et al., 2021], and one study included only Class I malocclusion [Habumugisha et al., 2022]. Overall, the baseline vertical occlusal dimension

Author, Year	Vertical Discrepancy	Intervention N (F, M) age (mean ± SD)	Comparison N (F; M) age (mean ± SD) Variable	Intervention Protocol	Vertical Dimension Assessment[b]		
					Variable	Intervention Results (mean ± S.D.)	Comparison Results (mean ± S.D.)
Ortu et al. (2021)	Deepbite	Ortho-tain (Occlus-o-guide™, G-series) 30 (F:15, M:15) 10.76±2.52 yrs.	n.a.	Overnight	OB (mm)	T0: 4.50±1.17 T1: 3.03±.1.38 Δ: na	n.a.
		Eptamed (Equilibrator™, Series II) 30 (F:16; M:14) 10.66±2.12 yrs	n.a.	Overnight	OB (mm)	T0: 4.80±0.99 T1: 1.97±0.72 Δ: na	n.a.
Janson et al. (2000)	Deepbite	Ortho-tain (Occlus-o-guide™, G-series) 30 (F:13, M:17) 9.0 yrs (SD na)	Untreated 30 (F:13, M:17) 9.0 yrs (SD na)	Overnight + 4h daytime Appliance's activation exercises	OB (mm) SN/GoGn (°) MX/MB (°) UFH (mm) LFH (mm)	T0: na T1: na Δ: -1.95±1.41 T0: na T1: na Δ: -0.53±2.68 T0: na T1: na Δ: -0.63±1.78 T0: na T1: na Δ: 3.33±1.82 T0: na T1: na Δ: 3.58±3.22	T0: na T1: na Δ: 1.71±1.28 T0: na T1: na Δ: -0.67±2.70 T0: na T1: na Δ: -0.88±2.60 T0: na T1: na Δ: 3.08±2.20 T0: na T1: na Δ: 1.16±1.19
Fichera et al. (2021)	Deepbite	Micerium (AMCOP® Second Class) 20 (F:12, M:8) 8.4±0.6 yrs	Untreated 20 (F:11, M:9) 8.1±0.8 yrs	Overnight + 1h daytime Appliance's activation exercises	OB (mm)	T0: 4.50±0.90 T1: 1.90±1.20 Δ: na	T0: 4.20±1.30 T1: 4.90±1.40 Δ: na
Myrlund et al. (2014)	Deepbite	LM-Dental (LM-Activator™) 24 (F:12, M:12) 7.7±0.6 yrs	Untreated 22 (F:10, M:12) 7.7±0.5 yrs	Overnight + 2h daytime	OB (mm) SN/GoGn (°) SN/ANS-PNS (°) Facial Axis (°) UPH (mm) LFH (mm)	T0: 3.40±1.30 T1: 2.10±1.30 Δ: -1.32±1.62 T0: 33.20±5.10 T1: 33.00±5.00 Δ: -0.5±0.7 T0: 8.30±3.10 T1: 8.90±3.40 Δ: na T0: 92.30±3.10 T1: 94.10±3.60 Δ: na T0: 44.50±2.30 T1: 45.50±3.10 Δ: na T0: 53.20±3.50 T1: 55.00±4.10 Δ: na	T0: 4.10±1.30 T1: 4.60±0.10 Δ: 0.44±0.91 n.a. n.a. n.a. n.a.
Myrlund et al. (2019)	Deepbite	LM-Dental (LM-Activator™) 14 (F:8, M:6) 9.1±0.6 yrs	n.a.a	Overnight + 2h daytime	OB (mm)	T0: 4.50±1.10 T1: 3.00±1.10 Δ: -1.85±1.35	n.a.
Keski-Nisula et al. (2008)	Deepbite	Ortho-tain (Niti-guide™ or Occlus-o-guide™) 115 (F:53, M:62) 5.1±0.5 yrs	Untreated 104 (F:52, M:52) 5.1±0.5 yrs	Overnight	OB (mm) FMA (°) Facial Axis (°) LFH (mm)	T0: 3.20±1.60 T1: 2.00±1.00 Δ: na T0: 24.60±4.90 T1: 27.60±18.00 Δ: na T0: 92.50±3.40 T1: 91.00±3.80 Δ: na T0: 44.80±3.90 T1: 44.40±4.20 Δ: na	T0: 3.30±1.90 T1: 4.10±1.90 Δ: na T0: 24.20±4.90 T1: 24.40±5.20 Δ: na T0: 92.30±3.20 T1: 91.60±3.40 Δ: na T0: 44.30±5.90 T1: 43.60±3.80 Δ: na

Habumugisha et al. (2022)	Openbite	Myofunctional Research Co. Myobrace® 66 (F:38, M:37) 7.41±1.21 yrs	Untreated 68 (F:32, M:38) 7.30±1.21 yrs	Overnight + 2h daytime Myofunctional exercises	OB (mm) SN/GoGn (°) FMA (°) LFH (mm)	T0: -1.70±1.10 T1: 0.52±1.06 Δ: na T0: 34.72±1.45 T1: 34.76±1.28 Δ: na T0: 30.77±1.50 T1: 31.30±3.00 Δ: na T0: 55.65±2.33 T1: 56.30±2.25 Δ: na	T0: -0.63±0.98 T1: -1.24±0.99 Δ: na T0: 34.79±1.36 T1: 35.75±1.02 Δ: na T0: 30.97±1.51 T1: 32.29±1.09 Δ: na T0: 56.12±2.57 T1: 59.69±2.50 Δ: na
Lo Giudice et al. (2022)	Deepbite	Micerium (AMCOP® Second Class) 19 (F:10, M:9) 9.1±0.7 yrs	Untreated 17 (F:10, M:7) 8.8±0.8 yrs	Overnight + 1h daytime Appliance's activation exercises	OB (mm)	T0: 4.30±0.82 T1: 2.10±0.32 Δ: na	T0: 4.00±1.10 T1: 4.50±1.20 Δ: na
Condò et al. (2012)	Openbite	Micerium (Habit Corrector™) 25 (F:15, M:10) 4-7 yrs (range reported only)	n.a.	Overnight + 2h daytime	OB (mm) Facial Axis (°)	T0: -2.12±na T1: 1.02±na Δ: na T0: 90.08±na T1: 89.92±na Δ: na	n.a. n.a.
		Micerium (Habit Corrector™) 25 (F:12, M:13) 8-12 yrs (range reported only)	n.a.	Overnight + 2h daytime	OB (mm) Facial Axis (°)	T0: 0.78±na T1: 1.66±na Δ: na T0: 89.16±na T1: 90.08±na Δ: na	n.a. n.a.
Dinkova (2014)	Deepbite	Myofunctional Research Co. (Trainer System™) 32 (F:20, M:12) 8.32 yrs	n.a.	Overnight + 2h daytime	OB (mm) FMA (°) MX/MB (°)	T0: 4.81±1.36 T1: 3.00±1.10 Δ: -1.85±1.35 T0: 25.63±4.66 T1: 25.27±4.40 Δ: -0.36±2.24 T0: 24.60±4.47 T1: 24.66±5.39 Δ: -0.06±2.30	n.a. n.a.
Lanteri et al. (2023)	Deepbite	Ortho-tain (Occlus-o-guide™, G-series) 33 (F:18, M:15) 7.7± 0.5 yrs	Customized EGA Class II deep-bite 36 (F:19, M:17) 7.9± 0.7 yrs	Overnight + 2h daytime Appliance's activation exercises	OB (mm) SN/GoGn (°) SN/ANS-PNS (°) MX/MB (°) UFH (mm) LFH (mm)	T0: 3.66±1.81 T1: 2.42±1.87 Δ: -1.24±na T0: 32.21±3.69 T1: 33.19±5.45 Δ: 0.98±na T0: 9.32±2.34 T1: 8.93±2.74 Δ: 0.39±na T0: 22.08±3.86 T1: 23.80±4.11 Δ: 1.72±na T0: 43.87±3.72 T1: 44.09±4.27 Δ: 0.55±na T0: 54.10±3.38 T1: 54.77±3.85 Δ: 0.67±na	T0: 4.19±1.50 T1: 2.33±1.24 Δ: -1.96±na T0: 31.05±4.58 T1: 33.28±4.79 Δ: 2.23±na T0: 8.96±2.71 T1: 8.73±2.44 Δ: 0.23±na T0: 22.89±4.24 T1: 25.37±3.75 Δ: 2.48±na T0: 44.12±3.67 T1: 44.84±4.12 Δ: 0.72±na T0: 53.87±4.12 T1: 44.91±3.96 Δ: 1.04±na

a We consider no comparison available, as the two groups considered in the paper were both treated with elastodontic device and the results of one of them were already reported in Myrlund, 2015.
b Main comparable results were reported
c Additional data provided by the Author

TABLE 2. Main characteristics and results of the vertical dimension changes reported in the included studies.
n.a.: not available; T0: pre-treatment value; T1: post-treatment value; Δ: difference between pre- and post-treatment values; OB: overbite; SN/GoGn: mandibular plane angle to cranial base; FMA: Frankfort-mandibular plane angle; SN/ANS-PNS: bispinal plane to cranial base through; Facial axis (BaN-PtGn); MX/MB: maxilla to mandibular plane angle; UFH: Upper Facial Height; LFH: Lower Facial Height.

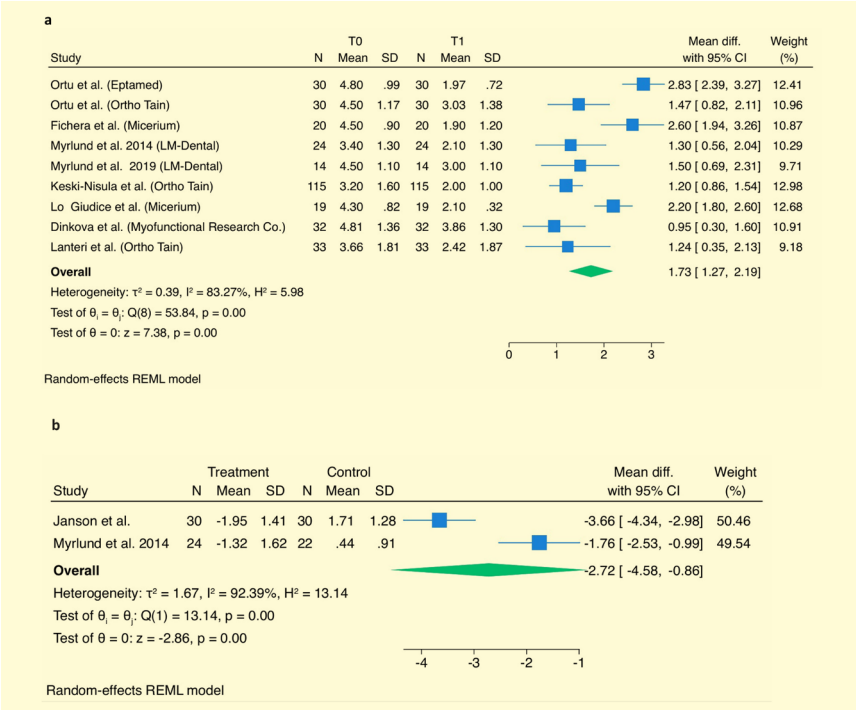

FIG. 3 (a) Forest plot for the effect of PMA treatment (T0 vs T1) on overbite.
(b) Forest plot for the effect of the PMA treatment compared to controls on overbite. CI, confidence interval; MD, mean difference; N, number of subjects; SD, standard deviation.

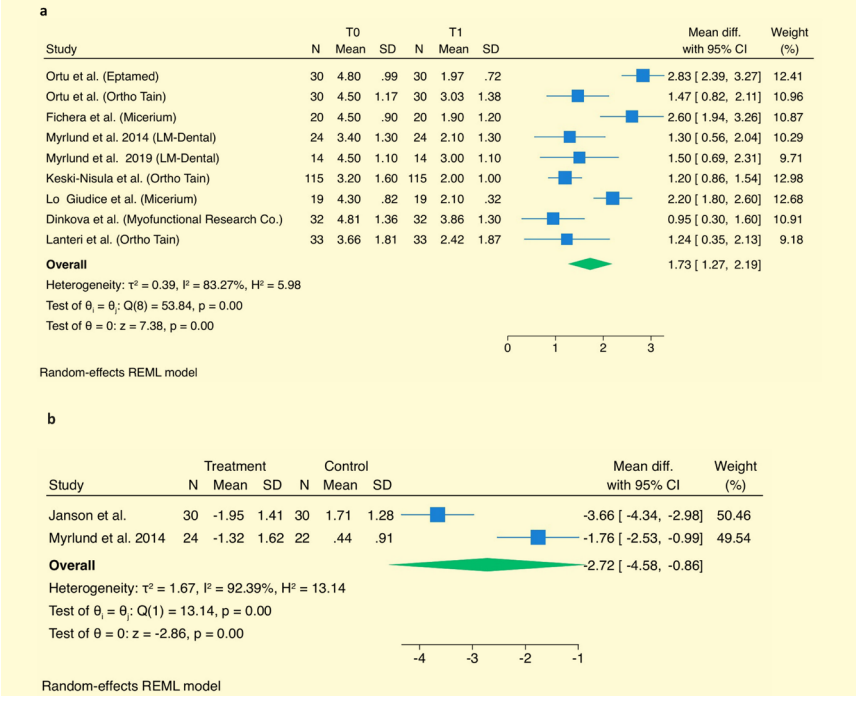

FIG. 4. (a) Forest plot for the effect of the PMA treatment (T0 vs T1) on overjet.
(b) Forest plot for the effect of PMA treatment in treated subjects compared to controls on overjet. CI, confidence interval; MD, mean difference; N, number of subjects; SD, standard deviation.

discrepancy in the included patients was mild-to-moderate as the mean pre-treatment overbite ranged from 3.80 to 4.81 mm in deep-bite subjects and from -2.12 to 0.78 mm in open-bite subjects (Table 2). Similarly, the baseline sagittal occlusal dimension discrepancy showed a mean pre-treatment overjet ranging from 3.00 mm to 5.60 mm in deep-bite subjects and from 2.96 to 4.04 mm in open-bite subjects (Table 2). The intervention protocol in all included studies involved the use of the PMAs overnight, with an additional 1 to 4 hours of daytime use, divided into periods of 30 minutes to 1 hour each, as described in 10 studies [Condò et al., 2012; Dinkova, 2014; Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019]. Appliance activation exercises (e.g., gentle biting into the appliance) or specific myofunctional exercises for correcting oral bad habits (e.g., orofacial muscle training) were recommended and explicitly detailed in the treatment protocol in four studies [Fichera et al., 2021; Janson et al., 2000; Lanteri et al., 2023; Lo Giudice et al., 2022] and one study [Habumugisha et al., 2022], respectively.

Risk of bias

The risk of bias of the included studies is reported in Figure 2. Of the two RCTs, one was judged at low-risk of bias [Myrlund et al., 2014] and one with some concern due to the randomization process [Myrlund et al., 2019]. Among the seven case-control

Comparison	Outcome	Groups (n)	Effect (95% CI)	P	τ^2	I^2
PMAs T0 vs T1	OB	9	MD 1.73 [1.27, 2.19]	<0.001	0.39	83.27%
	OJ	9	MD 1.98 [1.51, 2.45]	<0.001	0.40	83.53%
	SN/GoGn	2	MD -0.53 [-2.30, 1.24]	0.56	0.00	0.00%
	FMA	2	MD -1.06 [-4.31, 2.19]	0.52	3.49	61.86%
	SN/ANS-PNS	2	MD 0.08 [-0.94, 1.11]	0.87	0.00	0.00%
	Facial axis	2	MD -0.04 [-3.27, 3.19]	0.98	4.86	89.29%
	MX/MB	2	MD -1.00 [-6.75, 4.76]	0.78	0.00	0.00%
	UFH	2	MD -0.70 [-1.90, 0.51]	0.26	0.00	0.00%
	LFH	3	MD -0.42 [-1.66, 0.83]	0.51	0.56	45.64%
	ANB	5	MD 1.24 [0.52, 1.97]	<0.001	0.49	74.39%
	SNA	5	MD -0.66 [-1.14, -0.17]	0.01	0.00	0.00%
	SNB	5	MD -2.11 [-2.81, -1.41]	<0.001	0.20	31.24%
	IMPA	4	MD -4.97 [-8.08, -1.86]	<0.001	8.35	84.12%
	L1/A-Pog	3	MD -2.32 [-3.99, -0.66]	0.01	2.07	95.87%
	U1/SN	4	MD -1.46 [-9.51, 6.59]	0.72	65.34	97.36%
	U1/L1	6	MD 3.15 [-4.90, 11.20]	0.44	96.75	96.70%
	WITS	2	MD 1.39 [-0.71, 3.49]	0.19	2.05	89.16%
PMAs vs control	OB	2	MD -2.72 [-4.58, -0.86]	<0.001	1.67	92.39%
	OJ	2	MD -2.42 [-3.02, -1.83]	<0.001	0.00	0.00%

PMAs: Preformed Myofunctional Appliances; n: numbers; CI: confidence interval; τ2: variance; I2: heterogeneity; OB: Overbite; OJ Overjet; SN/GoGn: mandibular plane angle to cranial base; FMA: Frankfort-mandibular plane angle; SN/ANS-PNS: bispinal plane to cranial base through; MX/MB: maxilla to mandibular plane angle; UFH: Upper Facial Height; LFH: Lower Facial Height; ANB: sagittal relationships between the maxilla and the mandible; SNA: sagittal position of the maxilla; SNB: sagittal position of the mandible; IMPA: lower incisor angle to mandibular plane; L1–A-Pog: lower incisor tip distance to A-Pog; U1/SN: upper incisal angle to cranial base; U1/L1: interincisal angle; WITS: WITS appraisal.

TABLE 3. Results of meta-analyses (≥2 studies) showing PMA post-treatment effects and in with untreated subjects in deepbite malocclusion.

studies, two had low [Habumugisha et al., 2022; Lanteri et al., 2023], one moderate [Fichera et al., 2021], three serious [Keski-Nisula et al., 2008; Lo Giudice et al., 2022; Ortu et al., 2021], and one critical risk of bias [Janson et al., 2000]. The main flaws identified included lack of sample size justification, inadequate randomization in the selection of cases and controls, absence of concurrent controls, and confounding factors. The two before-after studies with no control group were judged as having a serious [Condò et al., 2012] and critical risk of bias [Dinkova, 2014], due to multiple flaws related to patient and sample selection, sample size, blinding, follow-up rates, and statistical analysis.

Synthesis of studies results

Main characteristics of studies results are presented in Table 2 for primary outcome and in Supplementary materials for secondary outcomes. Baseline and post-treatment evaluation of vertical and sagittal dimensions were performed using study models in 7 studies [Dinkova, 2014; Habumugisha et al., 2022; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014, 2019; Ortu et al., 2021], and lateral cephalometry radiology in 10 studies [Condò et al., 2012; Dinkova, 2014; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019]. Overbite improved after PMAs treatment in both deep-bite and open-bite [Condò et al., 2012; Dinkova, 2014; Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019; Ortu et al., 2021]. For deep-bite subjects, the mean post-treatment overbite reduction ranged from 1.16 mm [Dinkova, 2014] to 1.95 mm [G. R. Janson et al., 2000], while for open-bite subjects, the mean post-treatment overbite increase ranged from 2.61 [Condò et al., 2012] mm to 3.14 mm [Condò et al., 2012]. Conversely, untreated controls experienced a worsening of overbite overtime, irrespective of whether they had deep-bite [Janson et al., 2000; Myrlund et al., 2014] or open-bite [Habumugisha et al., 2022] conditions (Table 2). The effects of PMAs treatment on vertical skeletal dimensions varied across different studies. In deep-bite subjects, LFH showed a significant post-treatment increase [Janson et al., 2000; Lanteri et al., 2023; Myrlund et al., 2014], ranging from 0.67 mm [Lanteri et al., 2023] to 3.58 mm [Janson et al., 2000] and this increase was also significant compared to that of 1.16 mm observed in untreated controls [G. R. Janson et al., 2000]. Additional slight increases were observed in Facial Axis [Myrlund et al., 2014], MX/MB [Lanteri et al., 2023], FMA [Lanteri et al., 2023], and UFH [Myrlund et al., 2014] (Table 2). In open-bite cases, only an increase in LFH [Habumugisha et al., 2022] was noted. However, significant post-treatment differences were observed between treated and untreated group for parameters such as in SN/GoGN, FMA, and LFH, with the untreated group showing a considerable increase overtime of these parameters [Habumugisha et al., 2022] (Table 2). Sagittal occlusal and skeletal dimensions improved after PMAs treatment in both deepbite and openbite patients, with studies consistently reporting a decrease in overjet [Condò et al., 2012; Dinkova, 2014; Fichera et al., 2021; Habumugisha et al., 2022; Janson et al., 2000; Keski-Nisula et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019; Ortu et al., 2021], with mean overjet reduction ranging from 0.76 mm [Condò et al., 2012] to 2.51 mm [Janson et al., 2000], and ANB [Dinkova, 2014; Fichera et al., 2021; Habumugisha et al., 2022; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014], alongside an increase in SNB [Dinkova,

2014; Fichera et al., 2021; Habumugisha et al., 2022; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014]. Post-treatment evaluations revealed notable changes in anterior dental relationships. In deep-bite cases, there was a linear protrusion [Keski-Nisula et al., 2008; Lanteri et al., 2023; Myrlund et al., 2014] and proclination [Dinkova, 2014; Keski-Nisula et al., 2008; Lanteri et al., 2023; Myrlund et al., 2014] of the lower incisors, while the upper incisors exhibited either lingual [Janson et al., 2000] or labial tipping [Lanteri et al., 2023] after PMAs. In contrast, open-bite cases consistently showed lingual tipping and retrusion of both upper and lower incisors [Condò et al., 2012; Habumugisha et al., 2022]. The inter-incisal angle demonstrated variable changes, increasing [Condò et al., 2012; Fichera et al., 2021; Lanteri et al., 2023] or decreasing [Dinkova, 2014; Keski-Nisula et al., 2008; Myrlund et al., 2014] regardless of the vertical discrepancy. Transversal dimension correction was assessed in five studies by measuring mandibular and/or maxillary inter-canine width [Dinkova, 2014; Habumugisha et al., 2022; Keski-Nisula, et al., 2008; Myrlund et al., 2014; Myrlund et al., 2019]. Significant increases in inter-canine width was reported in both subjects with deep-bite and open-bite compared to untreated controls [Keski-Nisula, Keski-Nisula, et al., 2008a; Myrlund et al., 2014, 2019]. Additionally, a notable reduction in anterior crowding [Keski-Nisula, et al., 2008; Lanteri et al., 2023; Myrlund et al., 2019] and the number of subjects affected by dental crowding [Lanteri et al., 2023] was observed following PMAs treatment in patients with deep-bite. Information concerning the presence of bad oral habits was available only for open-bite subjects, who exhibited mouth breathing [Habumugisha et al., 2022] and atypical deglutition [Condò et al., 2012]. However, no data were reported on the cessation of these habits following PMAs treatment.

Meta-analysis

Data synthesis was run for the nine studies addressing treatment of deep-bite malocclusion with PMAs [Dinkova, 2014; Fichera et al., 2021; G. R. Janson et al., 2000; Keski-Nisula, et al., 2008; Lanteri et al., 2023; Lo Giudice et al., 2022; Myrlund et al., 2014; Myrlund et al., 2019; Ortu et al., 2021]; the two studies involving patients with open-bite malocclusion [Condò et al., 2012; Habumugisha et al., 2022] were excluded due to insufficient available data. One of the included studies was a comparison between two groups of subjects treated with different type of PMA [Ortu et al., 2021], so they were considered as distinct intervention groups for the purpose of the meta-analysis. Comparison between PMAs treated groups and untreated controls was possible only for overbite and overjet, due to the lack of comparable data for the other dento-skeletal variables.

The results of meta-analysis with at least two studies are reported in Table 3. As regards vertical occlusal correction, random-effects metanalysis indicated that overbite significantly reduced after treatment with PMAs of on average 1.73 mm (95% IC: 1.27 to 2.19; P<0.001), as shown in Table 3 and Fig. 3a. Compared to control groups of untreated subjects, patients treated with PMAs showed a significative mean improvement of 2.72 mm (95% IC: -4.58 to -0.86; P < 0.001), as shown Table 3 and Fig. 3b. The overall pooled estimates showed large-to-very large clinical effects of PMAs treatment on overbite correction compared to normal growth, with mean differences greater than one and a half times the expected standard deviation of the occlusal norm, which was 0.94 mm. However, high heterogeneity was found among studies, indicating a considerable amount of inconsistency (pre- vs post-treatment analysis, I2 = 83.27%; PMAs treated vs controls, I2 = 92.39%). Regarding occlusal sagittal correction, patients treated with PMAs showed a significant reduction of on average 1.98 mm in overjet (95% IC: 1.51 to 2.45; P < 0.001), as shown in Fig. 4a. A significant mean difference of -2.42 mm was found between patients treated with PMAs and controls (95% IC: -3.02 to -1.83; P < 0.001), as shown in Fig. 4b. The overall pooled estimates indicated very large clinical effects of PMAs on overjet correction and compared to untreated control; mean differences in overjet were higher more than double the expected SD of the occlusal norm of 0.73 mm. When analyzing heterogeneity among studies, inconsistency was considerable when comparing pre- vs post-treatment results (I2 = 83.53%), while it was non-important in the comparison of PMAs treated vs untreated results (I2 = 0.00%). Vertical skeletal relationships remained substantially unchanged after treatment with PMA, as revealed by the meta-analysis: no significant differences were found in SN/GoGn, FMA, SN/ANS-PNS, MX/MB, Facial axis, UFH, and LFH. Sagittal skeletal relationship significantly changed after treatment with PMA in deepbite patients, as revealed by the mean reduction of 1.24 mm in ANB (95% IC: 0.52 to 1.97; P<0.001), the mean increase of 0.66 mm in SNA (95% IC: -1.14 to -0.17; P=0.01) and of 2.11 in SNB (95% IC: -2.81 to -1.41; P<0.001). The overall pooled estimates indicated clinical effects of small magnitude for SNA (less than half SD of 3.03 mm), and of moderate magnitude for SNB and ANB (between half and one SD expected of 2.85 and 1.93 mm, respectively). Heterogeneity analysis revealed non-important inconsistency for SNA (I2 = 0.00%), moderate for SNB (I2 = 31.24%), and substantial for ANB (I2 = 74.39%). Regarding dento-alveolar relationships, significant increase of on average 4.97 mm in lower incisor angle to mandibular plane (IMPA; 95% IC: -8.08 to -1.86; P < 0.001) and of 2.32 mm in lower incisor tip distance to A-Pog (L1–A-Pog; 95% IC: -3.99 to -0.66; P = 0.01) were observed after PMAs treatment in patients with deep-bite. The overall pooled estimates indicated moderate clinical effect for both IMPA (more than half SD expected of 5.5 mm) and lower incisor tip distance to A-Pog (more than half SD expected of 2.70 mm). Meta-analysis revealed no significant changes for U1/SN, U1/L1, and WITS appraisal. High heterogeneity was found for all the dento-alveolar variables analyzed (I2 from 84.12% to 97.36%), indicating a considerable inconsistency among studies.

Discussion

Interceptive treatment with PMAs in mixed dentition has been previously investigated, but only a limited number of studies have focused specifically on the correction of vertical occlusal discrepancies [Dinkova, 2014; Ortu et al., 2021]. While PMAs have demonstrated good clinical effectiveness in improving overjet and mild skeletal Class II malocclusion, as corroborated by previous reviews, there is still a lack of evidence regarding their effectiveness in treating deep-bite or open-bite malocclusions [Huang Yong et al., 2022; Mohammed et al., 2020; Papageorgiou et al., 2019]. The strength of this review lies in its novelty, as it is the first, to the best of the authors' knowledge, aimed at assessing the effectiveness of PMAs in treating deep-bite or open-bite. The results of the meta-analysis suggest that PMAs are effective in improving overbite in patients with deep-bite during mixed dentition, but the overall scientific evidence remains limited. Significant heterogeneity among the studies, including variations in sample characteristics, types of myofunctional appliances used and the low-to-medium quality of the studies, contributes to the lack of robust evidence. PMAs were found to primarily produce vertical dento-alveolar effects, with vertical skeletal changes showing no significant improvement. However,

the pooled sample from the nine studies included in the meta-analysis predominantly consisted of cases with mild skeletal deep-bite and prevalent dento-alveolar discrepancies, which may have influenced the results, favoring occlusal improvements over skeletal ones. The included studies suggest that improvement in overbite occurs through a relative anterior intrusion and posterior extrusion of erupting teeth, as previously reported [Fichera et al., 2021; Lo Giudice et al., 2022]. However, except for one study [Janson et al., 2000], no cephalometric measures were provided to assess these changes, making it impossible to definitively confirm this hypothesis. Using PMAs, significant labial inclination and forward displacement of lower incisors were found in patients with deep-bite. These findings are in accordance with previous studies and may have contributed to overbite correction [Ciftci and Uzel, 2021; Usumez et al., 2004], as deep-bite subjects often exhibit lingual tipping of the lower incisors due to impingement and excessive labial trap overjet [Ciftci and Uzel, 2021; Keski-Nisula et al., 2020]. However, clinicians should exercise caution, particularly in patients with borderline Class II deep-bite malocclusion and those with periodontal issues, because an undesirable uncontrolled proclination of the lower incisor may occur. The treatment of deep-bite with PMAs produced a significant improvement in sagittal skeletal relationships, which was generally greater than previously reported in subjects with normal vertical pattern [Huang et al., 2022; Papageorgiou et al., 2019]. The concurrent increase in SNB and reduction in ANB angles, with minimal changes in SNA, suggest that a forward movement of the mandible may have occurred following PMA treatment [Huang et al., 2022; Papageorgiou et al., 2019]. Posterior positioning of the mandible is frequently observed in deep-bite malocclusion with upper incisors overeruption and/or vertical maxillary overgrowth recognized as risk factors. These factors create an "anterior wall" that restricts the sagittal displacement of the mandible during growth [Bishara, 1997; Siriwat PP, 1985]. The reduction of overbite after treatment with PMAs may have reduced such constraints on the mandibular growth, allowing a forward displacement and improving skeletal sagittal relationships, as previously observed with other functional appliances [Cozza et al., 2006; Isik et al., 2006; Pancherz et al., 1997]. PMAs seemed to be effective in treating open-bite malocclusion associated with atypical swallowing, as reported in two of the articles included in the present review [Condò et al., 2012; Habumugisha et al., 2022]. Observed effects included an increase in overbite, a reduction in overjet, improvement in sagittal skeletal relationships, and backward displacement with lingual tipping of both lower and upper incisors. These changes may be attributed to the correction of harmful oral habits [Begnoni et al., 2020; Saccomanno et al., 2021]. However, no definitive conclusions can be drawn regarding PMAs effectiveness in this context, as a meta-analysis could not be conducted due to insufficient available data.

This review has several limitations. First, the reduced number of studies included, especially in the meta-analysis, presents a challenge. Second, there was a significant variability among studies in terms of inclusion/exclusion criteria as well as the dento-skeletal variables assessed. The studies analyzed involved subjects with varying degrees of deep-bite malocclusion, making it challenging to distinguish between mild and severe cases. Furthermore, the average dentition stage of the pooled sample ranged from early mixed to late mixed dentition. Previous studies have shown that the response to functional therapy can be influenced by patient's growth phase, particularly in terms of orthopedic outcomes [Keski-Nisula et al., 2020; Keski-Nisula, et al., 2008; Myrlund et al., 2015]. The lack of differentiation by malocclusion severity and patient age may have impacted the meta-analysis results, potentially leading to either an overestimation or underestimation of the treatment effect. A third limitation is the variability in PMA types and intervention protocols among the studies. However, due to insufficient data, it was not possible to perform a subgroup or sensitivity analysis to assess potential differences. Previous research suggests that the design of the appliance ensures a tight fit between the tooth and the device, and extended daytime use led to a better overbite correction and control of the vertical dimension and sagittal incisors' position. These factors warrant further investigation [Lanteri et al., 2023; Myrlund et al., 2015].

Conclusion

This review suggests that PMA treatment is effective in reducing overbite in deep-bite malocclusion cases, with no observed impact on the vertical skeletal pattern. However, confidence in these findings is low due to significant heterogeneity, inconsistencies among studies, and their moderate-to-low methodological quality. Further research is needed, comparing treated and untreated subjects using more rigorous study designs, well-defined inclusion and exclusion criteria, and improved data reporting. Additionally, greater consistency in dento-skeletal variables and patient characteristics across studies is essential to facilitate meaningful comparisons.

Registration

PROSPERO registration (CRD42021289631)

Conflict of interest

The Authors declare no conflict of interest.

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Supplementary materials are available upon request from the corresponding author.

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