# Maxillary Expansion - A Comparative Analysis of Rapid, Slow, and Clear Aligner Approaches

Chien-Yu Chang

Hsinchu City, Taiwan

**Abstract**

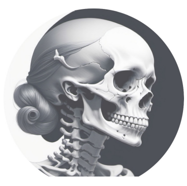
AIM: To compare the effectiveness of rapid maxillary expanders (RMEs), slow maxillary expanders (SMEs), and clear aligners (CAs) for maxillary expansion in children, including an evaluation of natural growth in untreated control groups.

METHODS: A systematic literature search was conducted on PubMed, limited to publications within the past 20 years, adhering to PRISMA guidelines. The search focused on maxillary expansion treatments utilising RMEs, SMEs, and CAs in paediatric patients. Following the removal of duplicate entries and application of predefined inclusion and exclusion criteria, 14 studies were selected for final analysis. The primary outcome parameters assessed were the anterior and posterior transverse differences of maxillary dentoalveolar expansion.

RESULTS: RME, SME, and CA demonstrated anterior and posterior maxillary expansion, achieving greater expansion than untreated controls. Reported mean differences ranged as follows: RME: 3.0–5.8 mm/2.7–6.6 mm; SME: 2.2–5.4 mm/2.2–6.7 mm; CA: 1.9–3.7 mm/2.0–3.2 mm; control: 0.1–0.9 mm/0.3–0.5 mm. Posterior maxillary expansion was significantly greater in the CA group compared with the other intervention groups. While RME and SME showed superior posterior expansion, CA achieved comparable anterior expansion, potentially attributable to the relatively inflexible central section of the aligners.

CONCLUSION: RME, SME, and CA facilitated greater transverse maxillary development than natural growth. These findings support the clinical application of non-surgical expansion appliances during growth phases to enhance transverse maxillary dimensions, offering clinicians a range of options for paediatric maxillary expansion.

* * *



**Archive of Orofacial Data Science**

**Submitted:** Tuesday 25th November, 2025.  **Data availability statement:** All relevant data are within the article or supplement files unless otherwise declared by the author(s). **Editor's note:** All claims expressed in this article are solely those of the authors and do not necessarily represent those of the journal and its associated editors. Any product evaluated or reviewed in this article, or claim that may be made by its manufacturer, is not warranted or endorsed by the journal and its associated editors. 

# 1 Introduction

Maxillary expansion has been performed for over a century and is widely used to correct maxillary constriction and arch length deficiency (McNamara, 2000). It is often considered the primary treatment approach during the mixed dentition period, when skeletal structures are still responsive to orthopaedic forces. According to the classic growth curve chart (Proffit et al., 2020), the growth rate of the maxilla begins to decline gradually after the eruption of permanent teeth in the early mixed dentition period. In contrast, the mandible's growth rate peaks during puberty or the late permanent dentition stage. This developmental pattern suggests that the ideal initial timing for maxillary expansion is during the early mixed dentition and should be completed before the late stages of pubertal growth, in order to maximise the skeletal effects before maxillary growth diminishes and help create a more favourable environment for guiding mandibular growth (Ugolini et al., 2024; Kluemper et al., 2001; Hass, 1961).

Traditionally, maxillary expansion has been accomplished using various appliances. Maxillary expanders are classified according to their activation protocols into rapid maxillary expanders (RME) and slow maxillary expanders (SME) (Jibin et al., 2021). RME typically involves daily activation of 0.2–0.5 mm per day, aiming to rapidly separate the midpalatal suture and induce skeletal expansion. In contrast, SME is activated more gradually, with adjustments of 0.5–1 mm per week, applying lighter and more physiologic forces. Each modality presents its own advantages and disadvantages. RME offers a shorter treatment duration and can open the midpalatal suture, providing significant skeletal changes (Hass, 1961; Lagravère et al., 2005). However, it is limited in its ability to rotate teeth, has potential to cause undesired tipping of the anchoring teeth, and is associated with more pain and discomfort (Godoy et al., 2011; Barone et al., 2023). On the other hand, SME leads to more stable outcomes with less buccal crown tipping of the anchoring teeth (Rutili et al., 2021), but it requires a longer treatment period and may be limited in tooth rotation capabilities. In terms of appliance removability, both RME and SME can be either removable or fixed. Fixed expanders can be anchored to both teeth and palatal tissue (tooth-tissue borne), or solely to teeth (tooth-borne) (Baccetti et al., 2001).

More recently, the use of clear aligners (CA) has been proposed as an alternative for achieving arch expansion, especially during early mixed dentition (Levering et al., 2021). CAs are typically activated with a maximum of 0.25 mm of movement per week, similar to SME protocols, and focus mainly on dentoalveolar changes. CAs, such as Invisalign® First, are designed as removable appliances that allow sequential and controlled expansion while maintaining better oral hygiene (Levering et al., 2021). Additionally, they offer unique advantages, including less pain and discomfort compared to traditional expanders, and the ability to rotate teeth with 1° of rotational movement per aligner change during arch expansion (Rossini et al., 2015). However, CA requires the longest treatment time among the three types of expanders, and the outcomes may be influenced by multiple factors, such as patient compliance and the complexity of the case (Rossini et al., 2015; Levering et al., 2024). Recent retrospective and systematic studies have evaluated the predictability of occlusal and transverse arch changes achieved with CA (Bowman et al., 2023; D'Antò et al., 2023). The findings suggest that, while aligners can effectively produce transverse dentoalveolar expansion, skeletal changes are minimal, and variations in individual treatment response, software prediction accuracy, and patient adherence remain significant influencing factors.

Given the variety of maxillary expansion apparatuses available, the evaluation of clinically significant transverse expansion achieved with respective expanders, i.e., RMEs, SMEs, and CAs, in the mixed or early permanent dentition period is warranted. The common assessment of maxillary expansion effectiveness can be classified as (i) skeletal or (ii) dentoalveolar changes, before and after treatment (Villa-Obando et al., 2024). The first involves measuring the midpalatal suture width, maxillary bone width, or nasal cavity width; the second entails measuring the changes in inter-distance between specific landmarks in the maxillary dentition. Currently, clinical tools used to evaluate the effectiveness of maxillary expansion in children and adolescent patients include dental impressions for cast models, oral scanning for digital models, posteroanterior cephalometric radiographs, and cone-beam computed tomography (CBCT). To routinely monitor the effectiveness of maxillary expansion while minimising radiation exposure during treatment, clinicians commonly assess dentoalveolar changes using dental cast models or oral digital scans (Pinheiro et al., 2014; Lu et al., 2023). However, some clinicians choose CBCT for evaluation of both skeletal and dentoalveolar changes (Luiz et al., 2020; Abate et al., 2023).

A systematic review by Zhou et al. (2014) compared the expansion effectiveness of RME and SME and suggested that, while both expanders were effective for maxillary expansion, SME was superior in expanding the molar region compared to RME. Recently, the treatment effectiveness of CA was also systematically reviewed and compared mainly to conventional edgewise braces in adult patients (Bhagwan et al., 2025). Although RME, SME, and CA have all been utilised for transverse maxillary expansion, no comprehensive analysis currently exists to evaluate and compare the relative clinical effectiveness of CA against RME and SME, particularly during the critical growth period of mixed or early permanent dentition. Therefore, this study aims to address this gap and provide clinicians with more informed guidance in selecting the most appropriate and tailored treatment for individual patient needs.

This study aimed to systematically evaluate and compare the effectiveness of various maxillary expansion devices, including rapid maxillary expanders (RME), slow maxillary expanders (SME), and clear aligners (CA), in achieving transverse maxillary expansion. By analyzing clinical outcomes measured through common assessment tools such as cast models, digital models, and CBCT imaging, the study sought to quantify the dimensional changes in the maxillary dentition and alveolar bone before and after treatment. Furthermore, it aimed to synthesize evidence from control groups to contextualize the treatment effects and identify the most effective modality for maxillary expansion.

# 2 Methods

## 2.1 Search strategy

The National Library of Medicine database (MEDLINE via PubMed) was utilised to retrieve articles published up to December 2024, with the search restricted to studies involving human subjects. Selection of articles for this thesis followed the Population, Intervention, Comparison, and Outcomes (PICO) framework. The population consisted of children or adolescents requiring maxillary expansion during the mixed or early permanent dentition phases. The intervention involved the use of maxillary expanders intended to achieve maxillary arch expansion. Comparisons were drawn between different types of maxillary expanders, including rapid maxillary expansion (RME), slow maxillary expansion (SME), and clear aligners (CA), as well as groups without any maxillary expansion treatment, serving as controls. Outcomes were measured as dentoalveolar transverse changes, specifically in inter-primary canine, inter-first premolar, and inter-first molar widths.

A comprehensive literature search was conducted to identify studies examining maxillary expansion in mixed dentition, focusing on three treatment modalities: RME, SME, and CA (e.g., Invisalign). The search strategy incorporated keywords such as maxillary expansion", dental arch expansion", maxillary arch expansion", rapid maxillary expander", rapid maxillary expansion", slow maxillary expander", slow maxillary expansion", clear aligner", Invisalign system", and mixed dentition". Boolean operators AND" and OR" were employed in various combinations to optimise search sensitivity and specificity. The search was limited to studies published between 2005 and 2024.

## 2.2 Eligibility criteria

Eligible studies for inclusion were those that conducted linear measurements of the maxillary transversal distance between intra-arch teeth and evaluated the clinical implications of these transversal changes. The focus was on research involving patients in the mixed dentition or early permanent dentition stages. Acceptable study designs included retrospective cohort studies, prospective cohort studies, or randomized clinical trials that compared the effectiveness of expansion among rapid maxillary expansion (RME), slow maxillary expansion (SME), and clear aligners (CA). Additionally, only articles available in full-text and published in English were considered.

Studies were excluded if they failed to clearly specify the type of orthodontic appliances used or the expansion protocols employed during treatment. Research incorporating auxiliary interventions such as mini-screws, facemasks, or headgear during the arch expansion phase was also omitted. Systematic reviews, meta-analyses, and case reports did not meet the inclusion criteria. Furthermore, investigations involving patients with concurrent periodontal, dental, or systemic conditions influencing tooth movement, as well as those with orofacial malformations or syndromes, were excluded to ensure the homogeneity of the sample population.

A total of 352 articles were initially retrieved from the database. After preliminary filtering, 277 articles were selected for full-text screening and evaluation against the inclusion and exclusion criteria. As shown in **Figure 1**, studies were first identified through a filtered search, and several yielded hits were deemed ineligible due to duplication or failure to meet the inclusion criteria. A total of 56 studies were then selected for eligibility assessment using exclusion criteria. Of these studies, three articles were excluded due to unclear expansion protocols; ten articles were excluded owing to the use of mini-screws, facemasks, or headgear; 19 articles were excluded based on the publication type, including systematic reviews, meta-analyses, or case reports; ten articles were excluded because the study population involved orofacial malformations such as cleft palate or Down's syndrome. A final selection of 14 articles was obtained.

## 2.3 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

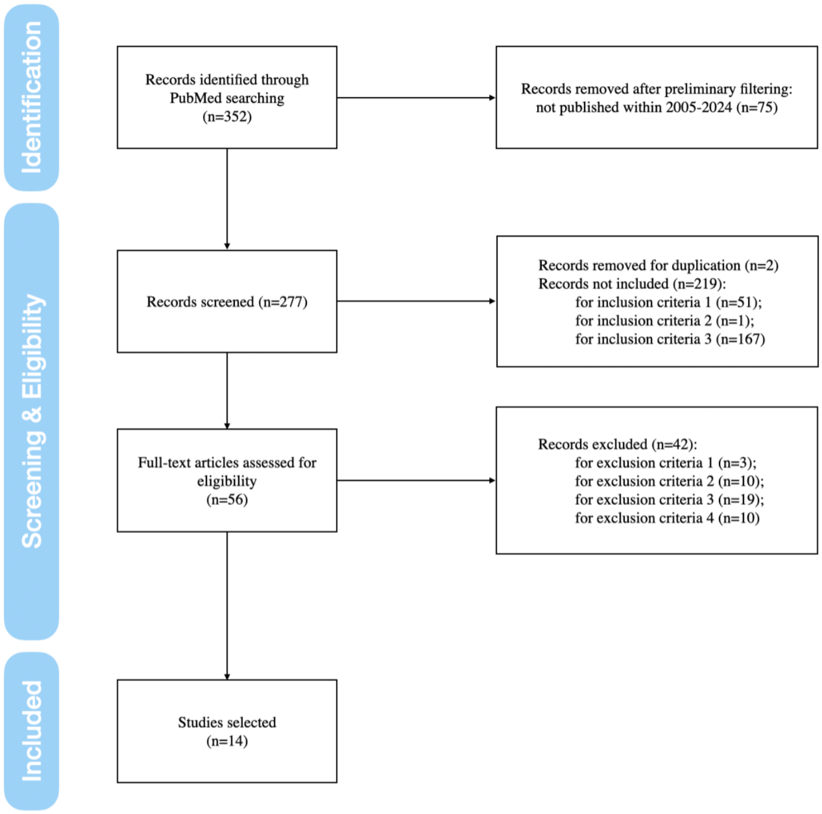



**Figure 1.** Flow chart of the study selection process.

# 3 Results

After full-text evaluation for eligibility, a total of 14 studies that met the inclusion and exclusion criteria were selected for analysis and discussion. The study type, sample size, data source, expander types, control groups, and reference points of the selected studies are summarised in **Table 1**.

**Table 1.** Characteristics of the included studies.

| AUTHOR (YEAR) | STUDY TYPE | SAMPLE | SOURCE | EXPANDER | CONTROL | REF CANINE | REF 1ST MOLAR |
|---|---|---|---|---|---|---|---|
| Abate (2023) | Retrosp. | 47 | CBCT | RME (B)/ SME (B) | - | cusp tip | MP cusp tip |
| Bruni (2024) | RCT | 39 | Digital model | RME (B)/ CA (R) | - | cusp tip | MB cusp tip |
| Lu (2023) | Prospective | 51 | Digital model | RME (B)/ CA (R) | Included (N) | cusp tip | MB cusp tip |
| Luiz (2020) | RCT | 29 | CBCT | RME (B)/ SME (B) | - | cusp tip | MP cusp tip |
| Moravedje (2024) | Retrosp. | 120 | Digital model | SME (B)/ CA (R) | Included (N) | cusp tip | central fossae |
| Montaruli (2022) | Retrosp. | 36 | Digital model | RME (B)/ SME (B) | - | U4 central fossae | central fossae |
| Martina (2012) | RCT | 26 | CBCT | RME (B)/ SME (B) | - | - | MP cusp tip |
| Pamukçu (2024) | Retrosp. | 34 | Digital model | SME (R)/ CA (R) | - | cusp tip | MB cusp tip |
| Paoloni (2022) | RCT | 56 | Digital model | RME (B)/ SME (B) | - | cusp tip | central fossae |
| Pereira (2017) | RCT | 37 | CBCT | RME(B)/ SME(B) | - | - | buccal alveolar bone crest |
| Pinheiro (2014) | Retrosp. | 90 | Impression | RME (B)/ SME (B) | Included (T) | U4 palatal gingival margin | palatal gingival margin |
| Rabah (2022) | RCT | 34 | CBCT | RME (B)/ SME (R) | - | U4 palatal cusp tip | MB cusp tip |
| Serafin (2022) | RCT | 32 | CBCT | RME (B)/ SME (B) | - | - | pulp chamber center |
| Wang (2023) | Retrosp. | 69 | Digital model | SME (B)/ CA (R) | Included (N) | palatal gingival margin | MP gingival margin |

*(B), bonded type. CA, clear aligner. MB, mesio-buccal. MP, mesio-palatal. (N), natural growth without any treatment. (R) removable type. RME, rapid maxillary expander. SME, slow maxillary expander. (T), treated only with the fixed edgewise appliance. U4, upper first premolar. Ref, reference point.*

Seven of the selected studies were randomized clinical trials, six were retrospective studies, and one was a prospective study. The included studies had sample sizes ranging from 26 to 120, comprising a total of 700 patients for analysis. With regard to the types of interventional appliances, nine studies compared rapid maxillary expansion (RME) with slow maxillary expansion (SME), of which only one included a control group without any expansion treatment; three studies compared SME with clear aligners (CA), two of which included a control group; two studies compared RME with CA, one of which included a control group. Regarding the data sources for study analysis, six studies utilised cone-beam computed tomography (CBCT) in the coronal view, seven studies used scanned digital models, and one study employed impression dental casts. For each study, measurements of maxillary transverse distances were collected from the intervention groups (RME, SME, or CA) before (T1) and after treatment (T2); similarly, measurements from the control groups were recorded at the start (T1) and after the observation period (T2), with the duration of observation matched to the treatment time of the intervention groups. Following either maxillary expansion treatment or natural growth observation, the differences between T1 and T2 ($T_2 - T_1$) were calculated and analysed within groups (intragroup comparison) and between groups (intergroup comparison) in the respective studies.

Additionally, with regard to the installation methods of maxillary expanders used in the selected studies, the majority utilised bonded-type expanders, while a few employed removable-type expanders. Specifically, 11 studies used RME or SME appliances with metal bands bonded at the primary second molars or permanent first molars, and extensions reaching the primary first molars, permanent first premolars, or primary canines. Two studies (Martina et al., 2012; Wang et al., 2023) used two-band palatal expanders in which metal bands were placed only at permanent first molars without any extending arms. According to current product descriptions available on the market, the CA used in these five studies (Bruni et al., 2024; Lu et al., 2023; Moravedje et al., 2024; Pamukçu et al., 2024; Wang et al., 2023) are considered removable appliances. Pamukçu et al. (2022) and Rabah et al. (2022) utilised removable SME appliances equipped with posterior bite planes and a midline split, incorporating a single expansion screw to achieve transverse maxillary expansion. Four studies included a control group without any maxillary expansion treatment. Three of these four studies (Lu et al., 2023; Moravedje et al., 2024; Wang et al., 2023) observed natural growth without any orthodontic intervention; one study (Pinheiro et al., 2014) did not undergo maxillary expansion but received treatment with a fixed edgewise appliance, which was also administered in the intervention groups of that study.

Cusp tips, central fossae, gingival margins, pulp chamber centres, or alveolar bone crests served as primary landmarks in the selected studies to assess maxillary dentoalveolar transverse changes following expansion treatment. All the studies measured posterior transverse changes, while 11 out of 13 studies evaluated both anterior and posterior transverse dimensions. In studies measuring anterior transverse dentoalveolar changes of the maxilla, the upper primary canine was predominantly used as the reference point during the mixed dentition stage, whereas the upper first premolar was adopted in studies focusing on the early permanent dentition stage.

In the studies involving mixed dentition, seven studies (Abate et al., 2023; Bruni et al., 2024; Lu et al., 2023; Luiz et al., 2020; Moravedje et al., 2024; Pamukçu et al., 2024; Paoloni et al., 2022) utilised the cusp tip of the upper primary canine as the anterior landmark; one study (Wang et al., 2023) used the palatal gingival margin of the primary canine as the reference point. In the studies of early permanent dentition, three studies (Montaruli et al., 2022; Pinheiro et al., 2014; Rabah et al., 2022) employed different landmarks of the upper first premolars to assess anterior transverse dentoalveolar changes, including the cusp tip, central fossa, and palatal gingival margin, respectively.

In this review, all selected studies used the upper first molars as the reference teeth for evaluating posterior transverse maxillary width changes before and after expansion. With regard to different cusp tips of the first molars, four studies (Bruni et al., 2024; Lu et al., 2023; Pamukçu et al., 2022; Rabah et al., 2022) adopted the mesio-buccal cusp tip, whereas three studies (Abate et al., 2023; Luiz et al., 2020; Wang et al., 2023) selected the mesio-palatal cusp tip for measurement reference. For gingival landmarks on the upper first molar, one study (Pinheiro et al., 2014) used the intersection of the palatal groove and the gingival margin, while another (Wang et al., 2023) selected the lowest point of the mesio-palatal gingival margin as the reference. In addition, three studies (Moravedje et al., 2024; Montaruli et al., 2022; Paoloni et al., 2022) used the central fossa of the upper first molar as the landmark, one study (Pereira et al., 2017) used the buccal alveolar bone crest at the furcation, and one study (Serafin et al., 2022) identified the centre of the pulp chamber in all three planes using CBCT imaging.

## 3.1 Intra-group comparison of transversal changes

Eleven of the 14 selected studies measured the maxillary anterior-transversal changes between primary canines or first premolars, depending on the mixed or early permanent dentition. All 14 selected studies measured the maxillary posterior-transversal changes between first molars. In most of the selected studies, the clinical significance of intragroup transversal changes ($T2$–$T1$) was analysed, apart from Luiz et al. (2020), Paoloni et al. (2022), and Rabah et al. (2022). Nevertheless, these three studies evaluated the clinical significance of intergroup differences based on $T2$–$T1$ measurements.

In studies utilising the RME appliances, the mean age of participants ranged from 7.8 to 13.8 years. The pre-treatment anterior-transversal measurements ($T1$) ranged from 23.7 mm to 33.6 mm, while the mean difference after treatment ($T2$–$T1$) ranged from 3.0 mm to 5.8 mm. Five of the eight selected studies provided the $p$ value of the mean differences, and all these studies confirmed their statistical significance ($p < 0.05$) (**Table 2**). For the posterior-transversal changes, the means of maxillary transversal measurements ($T1$) between first molars ranged from 31.8 to 53.1 mm at baseline; the post-treatment means of differences ($T2$–$T1$) ranged from 2.7 to 6.6 mm. Eight of the 11 selected studies reported the $p$ value of mean inter-molar differences. All of them confirmed the statistical significance of the differences ($p < 0.05$).

In the SME groups, 12 studies included participants with mean ages ranging from 7.8 to 14 years. The pre-treatment anterior-transversal measurements ($T1$) ranged from 23.0 mm to 34.5 mm, and the post-treatment mean differences ($T2$–$T1$) ranged from 2.2 mm to 5.4 mm. A total of six studies analysed the $p$ values, and all presented a significant increase ($p < 0.05$) (**Table 3**). The initial mean of posterior-transversal measurements ($T1$) between first molars ranged from 34.5 to 54.5 mm. The post-treatment measurements of differences ($T2$–$T1$) ranged from 1.8 to 6.7 mm. The statistical significance of mean inter-molar differences was analysed in nine studies, and all $p$ values were below 0.05.

Five studies employing CA treatment reported patient mean ages between 8.5 and 8.9 years (**Table 4**), which is also the officially recommended time to start using Invisalign® First. Before CA treatment, the mean maxillary transversal measurements at $T1$, between the primary canines, ranged from 25.3 to 32.7 mm; the post-treatment mean differences ($T2-T1$) ranged from 1.9 to 3.7 mm. All five studies confirmed statistically significant anterior

**Table 2.** Dentoalveolar transversal changes of the rapid maxillary expansion groups.

| AUTHOR (YEAR) | N | AGE (YEARS) | ANTERIOR | | POSTERIOR | |
|---|---|---|---|---|---|---|
| | | | T2-T1 (mm) | p value | T2-T1 (mm) | p value |
| Abate (2023) | 20 | 7.8 ± 1.2 | 4.2 ± 1.5 | <0.0001 | 4.1 ± 1.7 | <0.0001 |
| Bruni (2024) | 24 | 8.1 ± 0.7 | 5.8 ± 1.6 | <0.01 | 4.1 ± 2.4 | <0.01 |
| Lu (2023) | 17 | 6-10 | 4.9 ± 2.0 | 0.001 | 5.3 ± 1.1 | 0.001 |
| Luiz (2020) | 18 | 9.8 ± 1.7 | 4.3 | <0.0001 | 4.2 | <0.0001 |
| Moravedje (2024) | 28 | 8.4 ± 1.0 | 3.0 ± 1.3 | - | 4.5 ± 1.4 | - |
| Montaruli (2022) | 17 | 13.8 ± 0.3 | 4.1 ± 2.1 | - | 5.0 ± 2.5 | - |
| Martina (2012) | 16 | 8.5 ± 1.4 | - | - | 3.9 ± 1.9 | 0.001 |
| Pamukçu (2024) | 16 | 8.6 | 3.6 ± 2.0 | - | 6.6 ± 2.0 | - |
| Paoloni (2022) | 21 | 8.43 | - | - | 5.0 ± 1.7 | <0.001 |
| Pereira (2017) | 30 | 12.7 ± 1.2 | 4.4 ± 1.3 | <0.05 | 2.7 ± 1.8 | <0.05 |
| Pinheiro (2014) | 14 | 9.7 ± 1.5 | - | - | 5.7 ± 1.6 | <0.001 |

**Table 3.** Dentoalveolar transversal changes of the slow maxillary expansion groups.

| AUTHOR (YEAR) | N | AGE (YEARS) | ANTERIOR | | POSTERIOR | |
|---|---|---|---|---|---|---|
| | | | T2-T1 (mm) | p value | T2-T1 (mm) | p value |
| Moravedje (2024) | 40 | 9.1 ± 1.1 | 3.7 ± 1.9 | <0.0001 | 4.4 ± 1.4 | <0.0001 |
| Pamukçu (2024) | 17 | 8.8 ± 1.0 | 3.5 ± 2.9 | 0.001 | 4.6 ± 3.8 | 0.0001 |
| Abate (2023) | 23 | 7.8 ± 0.6 | 5.4 ± 1.3 | <0.01 | 3.4 ± 2.2 | <0.01 |
| Wang (2023) | 23 | 8.3 ± 0.8 | 4.8 ± 0.9 | <0.05 | 4.8 ± 1.3 | <0.05 |
| Montaruli (2022) | 18 | 11.7 ± 2.0 | 4.6 | <0.0001 | 4.4 | <0.0001 |
| Paoloni (2022) | 28 | 8.0 ± 1.3 | 2.2 ± 1.4 | - | 4.1 ± 1.7 | - |
| Rabah (2022) | 17 | 14.0 ± 0.3 | 5.1 ± 2.8 | - | 6.7 ± 2.6 | - |
| Serafin (2022) | 16 | 9.0 ± 0.9 | - | - | 2.2 ± 1.7 | 0.003 |
| Luiz (2020) | 13 | 9.3 | 3.0 ± 1.4 | - | 4.1 ± 1.7 | - |
| Pereira (2017) | 16 | 8.7 | - | - | 4.9 ± 1.4 | <0.001 |
| Pinheiro (2014) | 30 | 13.7 ± 5.2 | 3.8 ± 2.9 | <0.05 | 1.8 ± 2.9 | <0.05 |
| Martina (2012) | 12 | 10.3 ±2.5 | - | - | 6.3 ± 2.1 | <0.001 |

transversal changes ($p < 0.05$). Regarding posterior transversal changes, the baseline ($T1$) measurements ranged from 32.5 to 50.3 mm, while the post-treatment differences ($T2 - T1$) ranged from 2.0 to 3.2 mm. All five expansions were indicated as significant ($p < 0.05$).

**Table 4.** Dentoalveolar transversal changes of the clear aligner groups.

| AUTHOR (YEAR) | N | AGE (YEARS) | ANTERIOR | | POSTERIOR | |
|---|---|---|---|---|---|---|
| | | | T2-T1 (mm) | p value | T2-T1 (mm) | p value |
| Bruni (2024) | 19 | 8.5 ± 1.4 | 3.5 ± 2.2 | <0.0001 | 3.2 ± 2.4 | <0.0001 |
| Moravedje (2024) | 40 | 8.9 ± 1.2 | 3.7 ± 1.2 | <0.0001 | 2.5 ± 1.2 | <0.0001 |
| Pamukçu (2024) | 17 | 8.8 ± 0.8 | 2.1 ± 1.7 | 0.001 | 2.2 ± 2.9 | 0.001 |
| Lu (2023) | 17 | 6-10 | 1.9 ± 1.6 | 0.001 | 2.4 ± 1.4 | 0.001 |
| Wang (2023) | 23 | 8.5 ± 0.7 | 3.1 ± 1.3 | <0.05 | 2.0 ± 1.6 | <0.05 |

Four selected studies included a control group, with the mean patient age ranging from 8.4 to 13.0 years (**Table 5**). The mean anterior transversal measurements between primary canines or first premolars before treatment ($T1$) ranged from 24.6 to 33.3 mm; the mean post-observation differences ($T2 - T1$) ranged from 0.1 to 0.9 mm. Wang et al. (2023) was the only study to report a statistically significant mean difference (0.54 mm, $p = 0.003$); however, the magnitude of this change was smaller than the mean difference of 0.9 mm reported by Pinheiro et al. (2014), who did not find it statistically significant ($p = 0.11$). Regarding posterior transversal changes, the initial transverse dimensions in the four studies ranged from 30.9 to 50.9 mm, and mean differences ranged from 0.3 to 0.5 mm. Among these, two measurements reached statistical significance (Moravedje et al., 2024; Wang et al., 2023), while the others did not.

**Table 5.** Dentoalveolar transversal changes of the control groups.

| AUTHOR (YEAR) | N | AGE (YEARS) | ANTERIOR | | POSTERIOR | |
|---|---|---|---|---|---|---|
| | | | T2-T1 (mm) | p value | T2-T1 (mm) | p value |
| Moravedje (2024) | 40 | 8.9 ± 1.3 | 0.3 ± 1.2 | 0.2 | 0.5 ± 0.7 | <0.0001 |
| Lu (2023) | 17 | 6-10 | 0.1 ± 0.9 | 0.563 | 0.3 ± 0.6 | 0.092 |
| Wang (2023) | 23 | 8.4 ± 0.8 | 0.5 ± 0.8 | 0.003 | 0.5 ± 0.7 | 0.001 |
| Pinheiro (2014) | 30 | 13.0 ± 1.5 | 0.9 ± 2.0 | 0.11 | 0.3 ± 2.9 | 0.6 |

The studies reporting the smallest initial anterior-transversal measurements were Pinheiro et al. (2014) (RME, 23.7 mm) and Wang et al. (2023) (SME, 23.0 mm; CA, 25.3 mm). Wang et al. (2023) used the palatal gingival margin of either the primary canines or the first premolars as the reference points. In the RME, SME, and CA groups, all studies that analysed the mean differences (T2–T1) demonstrated statistically significant increases in anterior-transversal width (all $p < 0.05$), indicating consistent dentoalveolar expansion after treatment. In contrast, among the control groups included in four studies, the changes in anterior-transversal measurements were minimal in all cases and did not reach statistical significance in three. Only one study reported a statistically significant difference in the control group, but the magnitude of change remained substantially smaller compared with the intervention groups.

A similar pattern was observed in posterior-transversal changes, which increased significantly following maxillary active expansion treatment. In the control groups, 50% of the posterior-transversal results indicated a statistically significant difference; nevertheless, the magnitude was markedly smaller than that of the intervention groups. The smallest mean posterior-transversal increase in the RME group (2.72 mm; Pinheiro et al., 2014) was observed, using reference points located at the palatal gingival margin of the first molars.

Overall, neither anterior nor posterior transverse dimensions exhibited a consistent tendency for significant expansion across all active maxillary expansion therapies, whereas minimal changes without statistical significance were observed in most untreated control groups.

## 3.2 Inter-group comparison of transversal changes

### 3.2.1 Anterior-transversal changes

When comparing the RME and SME groups in terms of anterior-transversal mean difference, only one of the six selected studies demonstrated statistically significant results (RME vs. SME, 3.0 mm vs. 2.2 mm, $p = 0.005$; Paoloni et al., 2022) (**Table 6**). Two studies compared the RME and CA groups in terms of anterior-transversal change, and one of them reported no statistically significant difference (RME vs. CA, 4.2 mm vs. 3.5 mm; Bruni et al., 2024). Three studies compared the SME and CA groups, and only one study showed the anterior-transversal mean difference to be statistically significant (SME vs. CA, 4.8 mm vs. 3.1 mm, $p < 0.05$; Wang et al., 2023).

**Table 6.** Intergroup comparison of dentoalveolar anterior-transversal change in the intervention groups. RME, rapid maxillary expander; SME, slow maxillary expander; CA, clear aligner.

| AUTHOR, YEAR | RME | SME | P VALUE |
|---|---|---|---|
| | T2-T1 (mm) | T2-T1 (mm) | |
| Abate (2023) | 5.8 ± 1.6 | 5.4 ± 1.3 | 0.13 |
| Montaruli (2022) | 4.3 | 4.6 | 0.6279 |
| Paoloni (2022) | 3.0 ± 1.3 | 2.2 ± 1.4 | 0.005 |
| Rabah (2022) | 4.1 ± 2.1 | 5.1 ± 2.8 | 0.243 |
| Luiz (2020) | 3.6 ± 2.0 | 3.0 ± 1.4 | 0.365 |
| Pinheiro (2014) | 4.4 ± 1.3 | 3.8 ± 2.9 | >0.05 |
| | **RME** | **CA** | |
| Bruni (2024) | 4.2 ± 1.5 | 3.5 ± 2.2 | 0.275 |
| Lu (2023) | 4.2 ± 2.0 | 1.9 ± 1.6 | 0.002 |
| | **SME** | **CA** | |
| Moravedje (2024) | 3.7 ± 1.9 | 3.7 ± 1.2 | 0.98 |
| Pamukçu (2024) | 3.5 ± 2.9 | 2.1 ± 1.7 | 0.256 |
| Wang (2023) | 4.8 ± 0.9 | 3.1 ± 1.3 | <0.05 |

Most studies indicate that RME did not result in significantly greater anterior-transversal expansion compared with SME. When compared with the CA groups, the increased amount of $T2-T1$ in the RME or SME groups was not substantially greater. Most $T2-T1$ results in the CA groups were over 3 mm (**Figure 2**). As a result, the significance of intergroup comparison in anterior-transversal expansion was not strongly associated with any specific type of maxillary expanders.

In the four selected studies, all comparisons between the control and intervention groups in terms of anterior-transversal mean differences were shown to be significant, i.e., with $p < 0.05$ (Lu et al., 2023; Moravedje et al., 2024; Pinheiro et al., 2014; Wang et al., 2023) (**Table 7**). The anterior-transversal mean differences in all types of maxillary expansion appliances were significantly greater than those resulting from natural growth in the control groups (**Figure 2**).

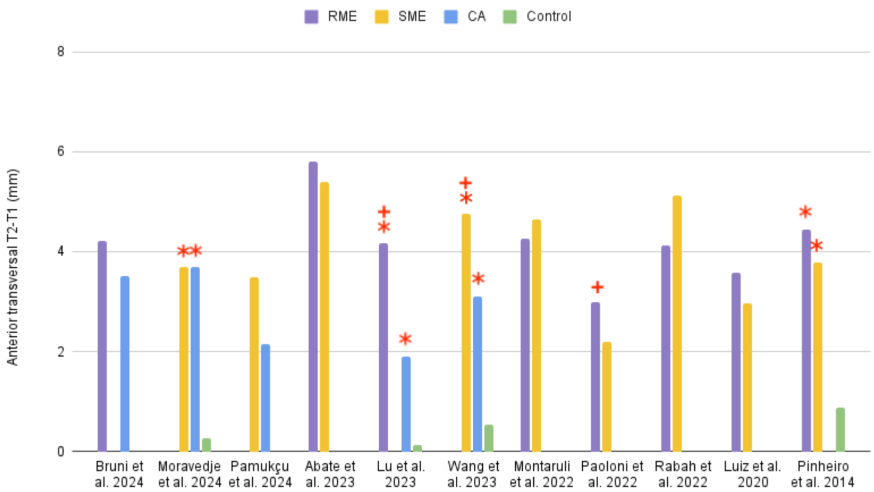



**Figure 2.** The anterior-transversal mean differences from T1 to T2 are presented. CA, clear aligner; RME, rapid maxillary expander; SME, slow maxillary expander; T2–T1, difference between pre- and post-treatment. + indicates that the comparison between the intervention groups was statistically significant (p value < 0.05). ∗ indicates that the comparison between the intervention and control groups was statistically significant (p value < 0.05).

**Table 7.** Intergroup comparison of dentoalveolar anterior-transversal change in the control and intervention groups. CA, clear aligner. RME, rapid maxillary expander. SME, slow maxillary expander. T2-T1, difference between pre- and post-treatment.

| **AUTHOR (YEAR)** | **INTERVENTION** | | **CONTROL** | |
|---|---|---|---|---|
| | | **T2-T1 (mm)** | **T2-T1 (mm)** | **p value** |
| Moravedje (2024) | **SME** | 3.7 ± 1.9 | 0.3 ± 1.2 | <0.0001 |
| | **CA** | 3.7 ± 1.2 | 0.3 ± 1.2 | <0.0001 |
| Lu (2023) | **RME** | 4.2 ± 2.0 | 0.1 ± 0.9 | <0.05 |
| | **CA** | 1.9 ± 1.6 | 0.1 ± 0.9 | <0.05 |
| Wang (2023) | **SME** | 4.8 ± 0.9 | 0.5 ± 0.8 | <0.05 |
| | **CA** | 3.1 ± 1.3 | 0.5 ± 0.8 | <0.05 |
| Pinheiro (2014) | **RME** | 4.4 ± 1.3 | 0.9 ± 2.0 | <0.05 |
| | **SME** | 3.8 ± 2.9 | 0.9 ± 2.0 | <0.05 |

### 3.2.2 Posterior-transversal changes

In the eight selected studies that compared the RME and SME groups in terms of posterior-transversal mean differences, only three reported statistically significant comparisons (Luiz et al., 2020, $p = 0.001$; Pinheiro et al., 2014, $p < 0.05$; Serafin et al., 2022, $p = 0.025$) (**Table 8**). When comparing the RME with CA groups, one of the two selected studies did not find a statistically significant difference (RME vs. CA, 4.1 mm vs. 3.2 mm; Bruni et al., 2024). When comparing the SME with CA groups, all three studies reported statistically significant differences (Moravedje et al., 2024; Pamukçu et al., 2024; Wang et al., 2023). Most studies reported that RME did not lead to significantly greater posterior transversal expansion compared with SME. In contrast, all studies demonstrated that the SME appliance produced significantly greater posterior-transversal changes than the CA appliance. Only one of the T2-T1 results in the CA group exceeded 3 mm (**Figure 3**).

**Table 8.** Intergroup comparison of dentoalveolar posterior-transversal change in the intervention groups. CA, clear aligner. RME, rapid maxillary expander. SME, slow maxillary expander. T1, pre-treatment measurement. T2-T1, difference between pre- and post-treatment. *, the upper first molar central fossa used as reference point. **, the upper first molar mesio-buccal cusp tip used as reference point.

| AUTHOR (YEAR) | RME | SME | P VALUE |
|---|---|---|---|
| Abate (2023) | 4.1 ± 2.4 | 3.4 ± 2.2 | 0.84 |
| *Montaruli (2022) | 4.2 | 4.4 | 0.8572 |
| Paoloni (2022) | 4.5 ± 1.4 | 4.1 ± 1.7 | 0.365 |
| Rabah (2022) | 5.0 ± 2.5 | 6.7 ± 2.6 | 0.062 |
| Serafin (2022) | 3.9 ± 1.9 | 2.2 ± 1.7 | 0.025 |
| Luiz (2020) | 6.6 ± 2.0 | 4.1 ± 1.7 | 0.001 |
| Pereira (2017) | 5.0 ± 1.7 | 4.9 ± 1.4 | 0.736 |
| Pinheiro (2014) | 2.7 ± 1.8 | 1.8 ± 2.9 | <0.05 |
| Martina (2012) | 5.7 ± 1.6 | 6.3 ± 2.1 | > 0.05 |
| | **RME** | **CA** | |
| Bruni (2024) | 4.1 ± 1.7 | 3.2 ± 2.4 | 0.196 |
| Lu (2023) | 5.3 ± 1.1 | 2.4 ± 1.4 | <0.05 |
| | **SME** | **CA** | |
| Moravedje (2024) | 4.4 ± 1.4 | 2.5 ± 1.2 | <0.0001 |
| **Pamukçu (2024) | 4.6 ± 3.8 | 2.2 ± 2.9 | 0.008 |
| Wang (2023) | 4.8 ± 1.3 | 2.0 ± 1.6 | <0.05 |

In the four selected studies, all comparisons between the control and intervention groups in posterior-transversal mean difference were shown to be statistically significant (Lu et al., 2023; Moravedje et al., 2024; Pinheiro et al., 2014; Wang et al., 2023) (**Table 9**). Similar to the results for anterior-transversal mean differences, the posterior-transversal mean differences for all types of maxillary expansion appliances were greater than those associated with natural growth, as observed in the control groups (**Figure 3**).

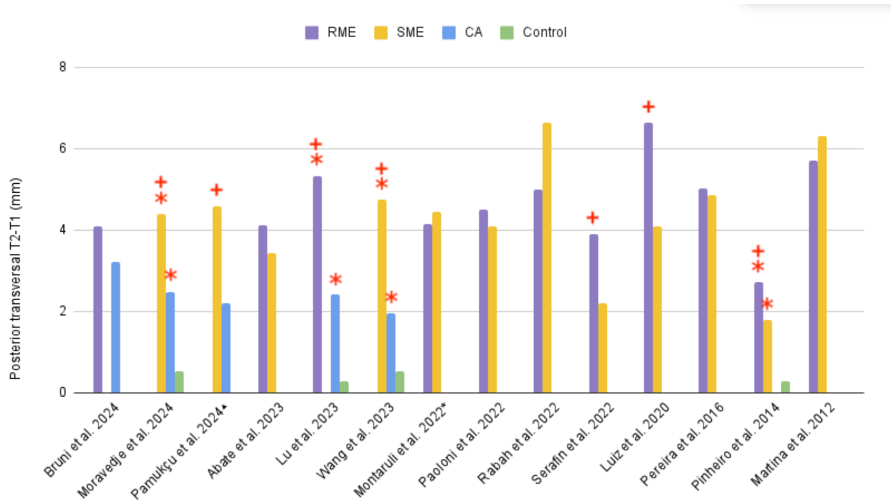



**Figure 3.** Posterior-transversal mean differences from T1 to T2. CA, clear aligner; RME, rapid maxillary expander; SME, slow maxillary expander; T2-T1, difference between pre- and post-treatment. * in black, the upper first molar central fossa used as the reference point; ▲, the upper first molar mesio-buccal cusp tip used as the reference point. +, the comparison between the intervention groups was statistically significant ($p < 0.05$). * in red, the comparison between the intervention and control groups was statistically significant ($p < 0.05$).

**Table 9.** Intergroup comparison of dentoalveolar posterior-transversal change in the control and intervention groups. CA, clear aligner. RME, rapid maxillary expander. SME, slow maxillary expander. T2-T1, difference between pre- and post-treatment.

| AUTHOR (YEAR) | INTERVENTION | | CONTROL | |
|---|---|---|---|---|
| | | T2-T1 (mm) | T2-T1 (mm) | p value |
| Moravedje (2024) | SME | 4.4 ± 1.4 | 0.5 ± 0.7 | <0.0001 |
| | CA | 2.5 ± 1.2 | 0.5 ± 0.7 | <0.0001 |
| Lu (2023) | RME | 5.3 ± 1.1 | 0.3 ± 0.6 | <0.05 |
| | CA | 2.4 ± 1.4 | 0.3 ± 0.6 | <0.05 |
| Wang (2023) | SME | 4.8 ± 1.3 | 0.5 ± 0.7 | <0.05 |
| | CA | 2.0 ± 1.6 | 0.5 ± 0.7 | 0.001 |
| Pinheiro (2014) | RME | 2.7 ± 1.8 | 0.3 ± 2.9 | <0.05 |
| | SME | 1.8 ± 2.9 | 0.3 ± 2.9 | <0.05 |

# 4 Discussion

This review aimed to assess and compare the effectiveness of various non-surgical maxillary expanders. Across all the studies included in this review, the intervention groups, whether using RME, SME, or CA, demonstrated a statistically significant increase in maxillary width following treatment (**Tables 2–4**). Namely, regardless of the type of appliance used, all modalities proved to be effective in promoting transverse expansion of both the anterior and posterior teeth of the maxilla. However, the capacity to achieve maxillary expansion may still vary depending on the specific characteristics of the expansion appliance used.

There are multiple factors that influence the effectiveness of maxillary expansion, the first of which is the expander installation method, i.e., fixed vs. removable. Among the 14 selected studies reviewed in this thesis, those utilising RME or SME predominantly employed bonded and rigid appliances. In contrast, the CA group consisted of removable and flexible plastic appliances. As the results illustrated in **Figures 2** and **3**, the average transverse expansion achieved by RME or SME generally ranged between 3 to 6 mm in both the anterior and posterior regions of the maxilla. In contrast, the mean expansion associated with CA use was approximately 2 to 4 mm in the anterior segment and 2 to 3 mm in the posterior segment. This demonstrates that the maxillary expansion achievable with the removable CA remains lower than that obtained with conventional bonded expansion devices. One of the most commonly cited drawbacks of CA is the difficulty in ensuring patient compliance with appliance wearing as prescribed. This is likely one of the primary factors for the relatively low effectiveness observed in CA treatments (Timm et al., 2021; Vigneshkumar et al., 2024).

The second factor affecting the effectiveness of maxillary expansion is the rigidity of the expansion appliance material. Both RME and SME typically employ metal frameworks or acrylic splints as their primary structural components. Although these two expanders differ in their activation protocols, from the viewpoint of the current systematic analysis, more than 73% of the reviewed studies reported no significant difference between RME and SME in effectiveness. Thus, in terms of expansion capacity, the two methods appear to be comparable, a finding consistent with the conclusion of the systematic review by Zhou et al. (2014). Contrary to Zhou et al.'s findings, the results of this review suggest that SME was not superior to RME in achieving maxillary intermolar expansion. This is based on the finding that although the posterior-transversal differences of SME were numerically greater compared with RME in three studies (Montaruli et al., 2022; Rabah et al., 2022; Martina et al., 2012), the comparisons were not statistically significant.

When comparing CA with these two conventional expanders, more instances of significant differences were found in posterior-transversal expansion (**Table 8**) than anterior-transversal expansion (**Table 6**). This suggests that the expansion capacity of CA may be greater in the anterior than the posterior region of the maxilla. Furthermore, in some studies, CA was able to achieve expansion results comparable to those with RME and SME in the anterior part of the maxilla (Bruni et al., 2024; Moravedje et al., 2024; Pamukçu et al., 2024). One possible explanation for this outcome is that the terminal section of the flexible plastic aligner delivers less force compared to its middle section, as a study with Invisalign® First indicated less expansion predictability in the first molars (55.61%) than the primary canines (59.68%) (Levrini et al., 2024). A case series study also observed that the planned maxillary transversal expansion width in the primary canine region achieved by Invisalign® First was superior to that in the first molar region (Reistenhofer & Filipitsch, 2023).

In this review, only one comparison among the selected studies between CA and other expansion appliances did not find a statistically significant change in the posterior transverse difference (Bruni et al., 2024). The authors speculated that this result may be attributed to the greater degree of buccal tipping and limited bodily movement of the molars in the CA group, leading to expansion comparable to that in the RME group.

The third factor that influences the effectiveness of maxillary expansion is the teeth anchored or engaged by the expansion appliance, as well as the mode by which orthodontic forces are applied. Traditional maxillary expansion appliances are typically anchored on selected posterior teeth and apply unidirectional lateral forces to increase the arch perimeter, thereby creating interproximal spacing. When space becomes available, previously misaligned or rotated teeth due to crowding may spontaneously reposition themselves through passive movement (Haas, 1961). Since both RME and SME rely on this type of unidirectional force application on specific teeth, the expansion forces tend to be more concentrated and less likely to be dispersed. The design of Invisalign® First aligners covers all the presented teeth to apply specific forces to achieve desired tooth movements. According to manufacturer recommendations, the Invisalign® First protocol suggests initiating maxillary expansion with the first molar movement priorly, followed by simultaneous staging in all the teeth, as this approach tends to produce more stable and predictable posterior expansion (Garlington, 2019). While all studies involving CA included in this review consistently implemented this strategy, the effectiveness of posterior-transversal expansion remained significantly lower than that of the bonded conventional expanders. Despite the Invisalign® First protocol moving the first molars at the beginning for about 4 to 8 stages, the following multiple types of movements of other teeth, such as expansion, rotation, and alignment, are usually programmed simultaneously. This may lead to a dilution of the forces intended for each specific movement, potentially compromising the effectiveness of the expansion. Therefore, in order to improve the effectiveness of maxillary expansion with CA in paediatric patients, it is important not only to implement a molar-movement-first protocol and to reinforce patient compliance, but also to consider applying overtreatment in the first molar region during treatment planning (Levrini et al., 2024). This approach may help compensate for the lower effectiveness and predictability of aligner-mediated tooth movement in the posterior segments, particularly in mixed dentition cases.

In certain challenging clinical cases, such as patients with severely constricted maxillary arches and bilateral crossbites, CA may not be a viable substitute for RME or SME. Per indication, Invisalign® First is suitable only for children aged approximately 6 to 10 years during the mixed dentition phase. For patients presenting with moderate to severe arch constriction, severe dental crowding, or an unfavourable growth pattern, there remains a high likelihood of requiring a Phase II orthodontic treatment during adolescence, even after early interceptive therapy (Pinho et al., 2022; Blevins, 2019). Although CA is generally less effective than traditional expanders in achieving posterior maxillary expansion, CA treatment results in superior overall alignment of maxillary dentition and induces significant morphological modification of the upper arch shape compared to RME (Cretella et al., 2022).

In the four selected studies involving a control group, patients who did not receive treatment with RME, SME, or CA exhibited a natural maxillary transverse growth of less than 1 mm. Such minimal changes were mostly statistically insignificant (Moravedje et al., 2024; Lu et al., 2023; Pinheiro et al., 2014). When compared with the intervention groups, i.e., RME, SME, and CA, all control groups showed significantly smaller transverse increases. This indicates that any form of maxillary expansion appliance may result in more effective anterior and posterior transverse expansion than that achieved through natural growth alone. Currently, many clinical studies comparing maxillary expansion appliances in children have primarily focused on evaluating pre- and post-treatment outcomes within treated groups (Rossini, 2015; Ugolini, 2024). Few studies have included a separate control group composed of patients who required treatment but did not receive any intervention, in order to observe natural growth. In the limited number of studies that do include control groups, these are often composed of children with normal occlusion who do not require early orthodontic treatment. As a result, comparisons are typically made between the treatment outcomes of malocclusion cases and the natural development of normal occlusion subjects, which may compromise the objectivity and validity of the control group.

## 4.1 Limitations

A key limitation of this literature review is the heterogeneity in study design and patient characteristics, observed even among investigations examining the same type of maxillary expansion appliance. Variations in appliance design components, the specific teeth involved, the duration of active treatment and retention, and the magnitude of expansion required based on individual case conditions may contribute to inconsistent comparison criteria across studies, thereby limiting the reliability and generalizability of the findings.

Another limitation pertains to the variability in reference point selection among studies, which affects the assessment of maxillary expansion outcomes. Although this review specifically focused on dentoalveolar changes, differences in measurement landmarks—such as cusp tips, central fossae, or the gingival margin—introduce inconsistencies that hinder direct comparison of treatment results across studies.

Finally, current research comparing the effectiveness of maxillary expansion between clear aligners (CA) and traditional appliances such as rapid maxillary expansion (RME) or slow maxillary expansion (SME) remains limited in both quantity and quality. Most available CA studies were not randomised controlled trials and thus failed to provide high-quality evidence based on standardised measurement methods and unified treatment protocols. Moreover, to enable a more comprehensive comparison across developmental stages, future research designs should consider evaluating the full treatment course from childhood to adolescence. One possible approach is to define a study group receiving traditional maxillary expansion followed by fixed edgewise appliances, and a comparison group receiving a clear aligner-based two-phase treatment—such as Invisalign® First in Phase I followed by Invisalign® Comprehensive in Phase II—to evaluate and compare their respective outcomes in transverse maxillary development.

# Conclusions

1. All maxillary expansion appliances (RME, SME, and CA) included in this review demonstrated statistically significant increases in transverse width, confirming their effectiveness in promoting dentoalveolar expansion.

2. RME and SME appliances showed superior expansion in the posterior region, likely due to their fixed design and rigid materials.

3. CA achieved less posterior expansion but showed comparable results in the anterior region, possibly explained by the aligner terminal parts being relatively weak in force in contrast to the middle section.

4. When compared with intervention groups, the control groups showed significantly smaller transverse expansion. Therefore, the use of any maxillary expansion appliance

(RME, SME, or CA) resulted in more effective transverse development than relying on natural growth alone.


## Acknowledgements

I want to express my sincere gratitude to Prof. Dr. Thomas Stamm for his professional guidance and continuous support throughout this master thesis. I would also like to express my appreciation to Dr. Chris Chang of the Beethoven Orthodontic Center, whose mentorship provided a solid foundation in orthodontics and sparked my interest in the field. Finally, I am grateful to my parents and husband for their support and assistance in caring for our family, enabling me to concentrate on my studies without distraction.


## Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

## Consent for publication

Not applicable.

## Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

## Competing interests

The author(s) declare that there are no competing interests related to this work.

## Author responsibility for image and data rights

The images, figures and other data used in this article were provided by the authors or by third parties. The authors are solely responsible for verifying that all such material is free of copyright, licence, privacy or other third-party rights and for obtaining, documenting and declaring any necessary permissions, licences or releases. Where third-party rights apply, rights-holders and the relevant licence or source information must be clearly identified in the article.

The Journal, its editors and its publisher do not review images, figures or data for copyright, licence or other third-party rights and accept no responsibility or liability for any infringement of such rights arising from material contained in this article. Any claims or disputes relating to alleged rights infringements must be directed to, and will be the responsibility of, the authors.

**Correspondence should be addressed to:**
Chien-Yu Chang, DDS, 3 F., No. 225, Guanxin Rd., East Dist., Hsinchu City 300052, Taiwan. E-Mail: b202095059@gmail.com

# References

Abate, A., Ugolini, A., Maspero, C., Silvestrini-Biavati, F., Caprioglio, A., & Lanteri, V. (2023). Comparison of the skeletal, dentoalveolar, and periodontal changes after Ni-Ti leaf spring expander and rapid maxillary expansion: A three-dimensional CBCT-based evaluation. *Clinical Oral Investigations, 27*(9), 5249–5262.

Baccetti, T., Franchi, L., & McNamara, J. A. Jr. (2001). Skeletal effects of early expansion therapy in Class III malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics, 119*(3), 283–293.

Barone, M., De Stefani, A., Cavallari, F., Gracco, A., & Bruno, G. (2023). Pain during rapid maxillary expansion: A systematic review. *Children, 10*(4), 666.

Bhagwan, N., Handa, A., Mane, D., Ghule, P., Srivastava, H., & Sarda, A. (2025). Comparing the effectiveness of clear aligners with other orthodontic methods–A systematic review. *Advances in Human Biology, 15*(2), 152–157.

Blevins, R. (2019). Phase I orthodontic treatment using Invisalign First. *Journal of Clinical Orthodontics, 53*(2), 73–83.

Bruni, A., Ferrillo, M., Gallo, V., Parrini, S., Garino, F., Castroflorio, T., & Deregibus, A. (2024). Efficacy of clear aligners vs rapid palatal expanders on palatal volume and surface area in mixed dentition patients: A randomized controlled trial. *American Journal of Orthodontics and Dentofacial Orthopedics, 166*(3), 203–214.

Bowman, E., Bowman, P., Weir, T., Dreyer, C. W., & Meade, M. J. (2023). Evaluation of the predicted vs. achieved occlusal outcomes with the Invisalign® appliance: A retrospective investigation of adult patients. *International Orthodontics, 21*(2), 100746.

Cretella Lombardo, E., Paoloni, V., Fanelli, S., Pavoni, C., Gazzani, F., & Cozza, P. (2022). Evaluation of the upper arch morphological changes after two different protocols of expansion in early mixed dentition: Rapid maxillary expansion and Invisalign® First system. *Life, 12*(9), 1323.

D'Antò, V., Valletta, R., Di Mauro, L., Riccitiello, F., Kirlis, R., & Rongo, R. (2023). The predictability of transverse changes in patients treated with clear aligners. *Materials (Basel), 16*(5), 1910.

Garlington, T. (2019). Clinical protocol for phase 1 orthodontic treatment of the mixed dentition with Invisalign First. Align Technology.

Godoy, F., Godoy-Bezerra, J., & Rosenblatt, A. (2011). Treatment of posterior crossbite comparing two appliances: A community-based trial. *American Journal of Orthodontics and Dentofacial Orthopedics, 139*(1), 45–52.

Haas, A. J. (1961). Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. *Angle Orthodontist, 31*(2), 73–90.

Jibin, V., & Anilkumar. (2021). Methods of maxillary arch expansion in orthodontics: A literature review. *International Journal of Applied Dental Sciences, 7*(2), 251–254.

Kluemper, G. T., & Spalding, P. M. (2001). Realities of craniofacial growth modification. *Atlas of the Oral and Maxillofacial Surgery Clinics of North America, 9*(1), 23–51.

Lagravere, M. O., Major, P. W., & Flores-Mir, C. (2005). Long-term skeletal changes with rapid maxillary expansion: A systematic review. *The Angle Orthodontist, 75*(6), 1046–

1052.

Levrini, L., Carganico, A., & Abbate, L. (2021). Maxillary expansion with clear aligners in the mixed dentition: A preliminary study with Invisalign® First system. *European Journal of Paediatric Dentistry, 22*(2), 125–128.

Levrini, L., Zecca, P. A., Deppieri, A., Caccia, M., Scurati, E. I., Legramandi, V. A., & Carganico, A. (2024). Predictability of maxillary expansion with Invisalign® First: Treatment planning vs. outcome. *Applied Sciences, 14*(21), 9871.

Lu, L., Zhang, L., Li, C., Yi, F., Lei, L., & Lu, Y. (2023). Treatment effects after maxillary expansion using Invisalign First system vs. acrylic splint expander in mixed dentition: A prospective cohort study. *BMC Oral Health, 23*(1), 598.

Luiz Ulema Ribeiro, G., Jacob, H. B., Brunetto, M., da Silva Pereira, J., Tanaka, O. M., & Buschang, P. H. (2020). A preliminary 3-D comparison of rapid and slow maxillary expansion in children: A randomized clinical trial. *International Journal of Paediatric Dentistry, 30*(3), 349–359.

Martina, R., Cioffi, I., Farella, M., Leone, P., Manzo, P., Matarese, G., Portelli, M., Nucera, R., & Cordasco, G. (2012). Transverse changes determined by rapid and slow maxillary expansion: A low-dose CT-based randomized controlled trial. *Orthodontics and Craniofacial Research, 15*(3), 159–168.

McNamara, J. A. Jr. (2000). Maxillary transverse deficiency. *American Journal of Orthodontics and Dentofacial Orthopedics, 117*(5), 567–570.

Montaruli, G., Virgilio, S., Laurenziello, M., Tepedino, M., & Ciavarella, D. (2022). Maxillary transverse deficit: A retrospective study of two biologically oriented devices through a digital workflow. *Bioengineering, 9*(1), 31.

Moravedje Torbaty, P., Suh, H., Tai, S. K., Baird, M., Boyd, R. L., & Oh, H. (2024). Vertical and transverse treatment effects of Invisalign First system compared to Hyrax maxillary expanders with fixed appliances in mixed dentition patients. *The Angle Orthodontist, 94*(5), 496–503.

Pamukçu, H., Özsoy, S., Aksoy, P. C., & Polat Özsoy, Ö. (2024). Evaluation of maxillary dimensional changes in the mixed dentition: Clear aligners vs acrylic expanders. *The Angle Orthodontist, 94*(4), 392–399.

Paoloni, V., Giuntini, V., Lione, R., Nieri, M., Barone, V., Merlo, M. M., Mazza, F., Passaleva, S., Cozza, P., & Franchi, L. (2022). Comparison of the dento-skeletal effects produced by Leaf expander versus rapid maxillary expander in prepubertal patients: A two-center randomized controlled trial. *European Journal of Orthodontics, 44*(2), 163–169.

Pereira, J. D. S., Jacob, H. B., Locks, A., Brunetto, M., & Ribeiro, G. L. U. (2017). Evaluation of the rapid and slow maxillary expansion using cone-beam computed tomography: A randomized clinical trial. *Dental Press Journal of Orthodontics, 22*(2), 61–68.

Pinheiro, F. H., Garib, D. G., Janson, G., Bombonatti, R., & de Freitas, M. R. (2014). Longitudinal stability of rapid and slow maxillary expansion. *Dental Press Journal of Orthodontics, 19*(6), 70–77.

Pinho, T., Rocha, D., Ribeiro, S., Monteiro, F., Pascoal, S., & Azevedo, R. (2022). Interceptive treatment with Invisalign® First in moderate and severe cases: A case series. *Children, 9*(8), 1176.

Proffit, W. R., Fields, H. W., Larson, B. E., & Sarver, D. M. (2019). *Contemporary orthodontics* (6th ed.). Elsevier-Health Sciences Division.

Rabah, N., Al-Ibrahim, H. M., Hajeer, M. Y., & Ajaj, M. A. (2022). Evaluation of rapid versus slow maxillary expansion in early adolescent patients with skeletal maxillary constriction using cone-beam computed tomography: A short-term follow-up randomized controlled trial. *Dental and Medical Problems, 59*(4), 583–591.

Reistenhofer, B., & Filipitsch, S. (2023). Invisalign First: A case series comparing the transverse maxillary expansion simulated in the ClinCheck software and the expansion achieved. *Journal of Aligner Orthodontics, 7*(2), 129–140.

Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A., & Debernardi, C. L. (2015). Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review. *Angle Orthodontist, 85*(5), 881–889.

Rutili, V., Mrakic, G., Nieri, M., Franceschi, D., Pierleoni, F., Giuntini, V., & Franchi, L. (2021). Dento-skeletal effects produced by rapid versus slow maxillary expansion using fixed jack screw expanders: A systematic review and meta-analysis. *European Journal of Orthodontics, 43*(3), 301–312.

Serafin, M., Fastuca, R., & Caprioglio, A. (2022). CBCT analysis of dento-skeletal changes after rapid versus slow maxillary expansion on deciduous teeth: A randomized clinical trial. *Journal of Clinical Medicine, 11*(16), 4887.

Timm, L. H., Farrag, G., Baxmann, M., & Schwendicke, F. (2021). Factors influencing patient compliance during clear aligner therapy: A retrospective cohort study. *Journal of Clinical Medicine, 10*(14), 3103.

Ugolini, A., Abate, A., Donelli, M., Gaffuri, F., Bruni, A., Maspero, C., & Lanteri, V. (2024). Spontaneous mandibular dentoalveolar changes after rapid maxillary expansion, slow maxillary expansion, and leaf expander–a systematic review. *Children, 11*(4), 501.

Vigneshkumar, V., Deepak, E. R., Ferreira, V., Waremani, A. S., Nishaevitha, N. A. K., Ammal, K. T., & Singh, G. (2024). Accuracy and stability of clear aligner treatment: A systematic review. *Journal of Pharmacy and Bioallied Sciences, 16*(Suppl 4), S3077–S3079.

Villa-Obando, Y. A., Correa-Osorio, S. M., Castrillon-Marin, R. A., Vivares-Builes, A. M., & Ardila, C. M. (2024). Effect of anchorage modifications on the efficacy of miniscrew-assisted rapid palatal expansion: A systematic review and meta-analysis. *Cureus, 16*(10), e72008.

Wang, J., Bukhari, A., Tai, S. K., & Zou, B. (2023). Dimensional changes in the palate associated with Invisalign First System: A pilot study. *The Angle Orthodontist, 93*(5), 524–530.

Zhou, Y., Long, H., Ye, N., Xue, J., Yang, X., Liao, L., & Lai, W. (2014). The effectiveness of non-surgical maxillary expansion: A meta-analysis. *European Journal of Orthodontics, 36*(2), 233–242.