Comparative evaluation of vertical dimension changes with clear aligners and fixed appliances: A prospective cephalometric cohort study

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Background: The control of vertical dimension remains a critical aspect of comprehensive orthodontic treatment. This study compared vertical dimensional changes produced by clear aligners (CAs) to those produced by fixed appliances (FAs) during comprehensive orthodontic treatment, assessing whether modern aligner therapy provides comparable vertical control with conventional mechanics. **Methods:** A prospective cohort of 52 adults (CA group: 26 and FA group: 26) was evaluated. Baseline comparability was confirmed for age, sex, malocclusion type, and skeletal pattern. Standardized lateral cephalograms were obtained before (T_0) and after treatment (T_1). Cephalometric variables included the SN-GoGn (mandibular plane angle), FMA (Frankfort-mandibular plane angle), N–Me (total anterior facial height), S–Go (posterior facial height), and ANS–Me (lower anterior facial height). Intraobserver and interobserver reliability exceeded an intraclass correlation coefficient of 0.90. Paired and intergroup comparisons were performed ($\alpha = 0.05$). **Results:** Both groups exhibited small increases in vertical parameters within physiological limits. In the CA group, the SN-GoGn angle showed a statistically significant but clinically minor increase ($<1°$; $P = 0.016$). The FA group presented slightly greater increases in SN-GoGn and plane angle FMA ($P < 0.05$), consistent with mild clockwise mandibular rotation. Linear measurements (N–Me, ANS–Me, and S–Go) increased slightly in both groups. Intergroup comparisons (ΔT_1-T_0) revealed no statistically significant differences in any variable ($P > 0.05$), and effect sizes were small (Cohen $d < 0.30$). **Conclusions:** Vertical dimensional changes associated with CA and FA treatments were minimal and comparable. Under current protocols, CAs provide adequate vertical control in mild-to-moderate malocclusions without inducing clinically relevant mandibular rotation. Further randomized and 3-dimensional studies are warranted to confirm these findings in more complex vertical discrepancies. (Am J Orthod Dentofacial Orthop 2026;■:■-■)

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Clear aligner therapy (CAT) has transformed orthodontic practice over the past 2 decades. Since its introduction in 1999, the technique has evolved from managing minor alignment problems to addressing increasingly complex malocclusions, establishing itself as a credible alternative to conventional fixed appliances (FAs).[1–3] Its clinical success has been driven by patient-centered advantages, such as improved esthetics, comfort, oral hygiene maintenance, and shorter chair time, which make it particularly appealing to adult and adolescent populations.[3,4] The ongoing digitalization of orthodontic workflows and the precision of computer-aided design/computer-aided manufacturing technologies have further enhanced the efficiency and reproducibility of aligner-based treatments.[5,6]

Despite these advantages, the biomechanical behavior of aligners differs substantially from that of FAs, particularly in force distribution, moment-to-force ratios, and 3-dimensional control of tooth movement.[7,8] Among these differences, vertical dimension control remains one of the most debated and less predictable aspects of aligner therapy. The ability to maintain or modify vertical dimension is crucial in managing deepbite and open bite malocclusions, as it directly influences facial esthetics, occlusal function, and temporomandibular joint stability.[9–11]

Early reports suggested that the occlusal coverage and resilient thermoplastic properties of aligners might generate a posterior bite-block effect, acting similarly to removable posterior biteplates by limiting posterior eruption and promoting slight intrusion.[4,5] This phenomenon could theoretically favor the correction of anterior open bites or hyperdivergent growth patterns through counterclockwise mandibular rotation.[6,7] However, it is important to distinguish this posterior bite-block effect from the opposite vertical response induced by anterior bite turbos, which may promote posterior extrusion and clockwise mandibular rotation. Therefore, vertical effects observed during aligner therapy should not be interpreted as an intrinsic property of the appliance itself, but rather as the result of occlusal planning and auxiliary biomechanics.

The evolution of aligner materials and staging protocols has likely influenced these outcomes. Earlier appliances, commonly made of EX30-type polyethylene-based materials, displayed limited elasticity and less predictable force delivery. The introduction of SmartTrack (Align Technology, San Jose, Calif) material in 2012, a multilayer polyurethane-based polymer, improved mechanical resilience and force continuity, potentially enhancing force delivery and treatment predictability.[10,12] Nevertheless, a substantial portion of the evidence available today was derived from cohorts treated before these innovations, often using retrospective designs and heterogeneous diagnostic criteria.[6,9,12,13]

From a biomechanical standpoint, aligners may influence vertical dimension through several interacting mechanisms: the occlusal coverage that restricts eruption, intermittent forces that modulate neuromuscular adaptation, and modified occlusal contacts that alter vertical equilibrium. By contrast, FAs—with continuous archwire engagement and auxiliary mechanics such as elastics—may generate vertical changes through differential extrusion or intrusion of posterior segments.[2,8,13] Therefore, comparing aligner- and bracket-based treatments requires prospective evaluation under standardized conditions, with reliable cephalometric indicators, such as the mandibular plane angle (SN-GoGn), Frankfort-mandibular plane angle (FMA), total anterior facial height (N-Me), posterior facial height (S-Go), and lower anterior facial height (ANS-Me).[5,8]

To date, the available literature remains inconsistent as to whether clear aligners (CAs) maintain or alter the vertical dimension differently from FAs. Systematic reviews have highlighted methodological heterogeneity, small sample sizes, and the scarcity of prospective studies incorporating modern aligner materials.[11,14–16] Considering the potential clinical implications for the management of both open bite and deepbite malocclusions, updated evidence based on prospective designs is warranted.

Accordingly, this study aimed to prospectively compare vertical dimension changes in patients treated with CAs and FAs under standardized conditions. It was expected that modern aligner therapy would not produce clinically significant differences in SN-GoGn or facial height compared with FAs, thus supporting the assumption of comparable vertical control between the 2 modalities.

MATERIAL AND METHODS

This research was conducted as a prospective, controlled, observational cohort study, comparing vertical dimension changes between patients treated with CAs and those treated with conventional FAs. The study was performed at the Department of Orthodontics, Catholic University of Valencia (Spain), between January 2022 and December 2024, following the recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology guideline for cohort studies to ensure transparent reporting and methodological consistency. The patients included in the study were recruited from several orthodontic clinics across the city of Valencia and were all treated by the same orthodontist, ensuring uniform diagnostic and therapeutic criteria throughout the sample. All participants were consecutively recruited from patients initiating comprehensive orthodontic treatment within the same institution and were treated by the same experienced orthodontist, which minimized operator variability and ensured comparable treatment protocols. The prospective design was chosen to avoid bias associated with retrospective records, particularly regarding variability in appliance generation, radiographic quality, and follow-up intervals.

The study protocol received ethical approval from the institutional ethics committee of the Catholic University of Valencia (Ref. ODP/2021/47). All procedures complied with the principles of the Declaration of

Helsinki (2013 revision) and with the European General Data Protection Regulation (EU 2016/679). Written informed consent was obtained from all adult participants and from parents or legal guardians in the case of minors. Participation was entirely voluntary, and no incentives were provided.

A total of 52 participants were enrolled, divided equally into 2 groups: 26 patients treated with CAs and 26 treated with FAs. All patients presented complete permanent dentition, good periodontal health, and mild-to-moderate malocclusions suitable for both techniques. Patients with previous orthodontic treatment, craniofacial anomalies, significant dental restorations, extraction cases, or the use of auxiliary vertical control devices were excluded. Patients showing anterior open bites >3 mm or severe skeletal discrepancies (ANB >6° or <−1°) were also excluded. The final sample size was determined through a priori power analysis ($\alpha = 0.05$, power = 0.80), estimating a minimum of 22 patients per group to detect a 1.5° difference in SN-GoGn. To account for potential dropouts, 26 patients were finally included in each cohort.

Participants were assigned to the CA group or the FA group according to the treatment plan proposed by the attending orthodontist and patient preference, following a nonrandomized but consecutive allocation design. Although randomization was not feasible because of patient-specific clinical and esthetic preferences, both groups were matched for age, sex, and malocclusion severity to minimize potential selection bias.

Only patients presenting a normal overjet (2-4 mm) and a moderate overbite (1-4 mm) at the baseline were included. Patients with an anterior open bite >3 mm or a deepbite >5 mm were excluded to avoid confounding effects related to extreme vertical discrepancies.

Patients assigned to the CA group underwent treatment with Invisalign (Align Technology, Santa Clara, Calif) using SmartTrack material and virtual setups created in ClinCheck software (Align Technology). Aligners were worn approximately 22 hours per day and replaced every 7-10 days.

No vertical, Class II, or Class III intermaxillary elastics were used in any patient in either group throughout treatment.

Interproximal reduction was performed when required, according to the degree of crowding. The interproximal reduction protocol was included in the intraexaminer calibration procedure. No skeletal expansion procedures were performed in any patient.

All final virtual setups were programmed with a 0.5-mm overjet to avoid anterior premature contacts at the end of treatment.

No bite turbos or anterior ramps were used in any patient. All patients were treated between 2016 and 2018, before the clinical introduction of precision bite ramps in the G5 protocol. Deepbite correction in this cohort was achieved mainly through posterior attachments and aligner biomechanics.

The FA group was treated with 0.022-in McLaughlin Bennett Trevisi prescription brackets (Victory Series; 3M Unitek, Monrovia, Calif) following a conventional archwire sequence from 0.014-in to 0.019 × 0.025-in nickel-titanium and stainless steel wires. Both groups aimed for bilateral Class I relationships with normalized overjet and overbite and coincident dental midlines. All procedures were performed under the same clinical supervision and following standard biomechanical principles.

Standardized lateral cephalometric radiographs were obtained before treatment initiation (T_0) and immediately after treatment completion (T_1) using the same digital cephalostat (Planmeca ProMax; Helsinki, Finland) under uniform exposure settings (66-70 kV, 10 mA, and 0.5 seconds). Each patient was positioned in natural head posture with teeth in maximum intercuspation.

Before data collection, both examiners underwent a calibration session using 10 pilot cephalograms not included in the final analysis. Interexaminer and intraexaminer agreement was verified, and tracing criteria were standardized according to the definitions proposed by Athanasiou[17] to ensure consistency in landmark identification and measurement procedures.

Cephalometric tracings were performed using the Nemoceph software (version 11.95; Chatsworth, Calif) by 2 calibrated orthodontists blinded to group allocation. The analysis included both angular and linear parameters characterizing the vertical skeletal relationships. Angular measurements comprised SN-GoGn and FMA. Linear variables included N-Me, S-Go, and ANS-Me. In addition, the Jarabak ratio (S-Go/N-Me × 100) was calculated to describe the proportional relationship between posterior and anterior facial heights. All measurements were recorded to the nearest 0.1 mm for linear values and 0.1° for angular values, and individual treatment changes ($\Delta T_1 - T_0$) were computed for each patient.

To assess measurement reproducibility, 10 randomly selected radiographs were retraced by each examiner after a 2-week interval. Both intraobserver and interobserver agreement were evaluated using intraclass correlation coefficients, with results showing values between 0.92-0.98 for intraobserver and 0.90-0.96 for interobserver reliability, indicating excellent concordance. Random error was estimated according to the

Table I. Baseline demographic and clinical characteristics of both groups

Variable	*CA (n = 26)*	*FA (n = 26)*	*P value*
Sex			0.78
Female	14	15	
Male	12	11	
Mean age at T_0 (y)	22.4 ± 5.3	21.9 ± 4.8	0.67
Malocclusion type			0.92
Class I	16	17	
Class II	8	7	
Class III	2	2	
Initial skeletal pattern			0.89
Hypodivergent	5	6	
Normodivergent	15	14	
Hyperdivergent	6	6	
Treatment duration (mo)	23.3 ± 7.9	25.4 ± 6.5	0.21

Note. Values are expressed as mean ± standard deviation or absolute frequencies. Intergroup comparisons were performed using the Mann-Whitney U test for continuous variables and the χ^2 test for categorical variables. No statistically significant differences were found ($P > 0.05$).

Dahlberg formula ($Se^2 = \Sigma d^2/2n$) and did not exceed 0.4° for angular or 0.3 mm for linear measurements. No significant systematic differences were detected using paired-samples *t* tests ($P > 0.05$). These results confirm that both examiners performed consistently and that the cephalometric data were highly reproducible.

Statistical analysis

Statistical analyses were performed using the SPSS software (version 29.0; IBM Corp, Armonk, NY). The normality of data distribution was assessed using the Shapiro-Wilk test. Descriptive statistics (mean ± standard deviation) were calculated for all variables. Baseline equivalence between groups was examined using the Mann-Whitney U test for continuous variables and the chi-square test for categorical variables, such as sex and malocclusion type. Longitudinal intragroup changes between T_0 and T_1 were analyzed using the Brunner-Langer nonparametric model for repeated measures, and the ANOVA-type statistic-type analysis of variance statistic was applied to evaluate main effects. Intergroup differences in the amount of change (ΔT_1–T_0) were assessed using the Mann-Whitney U test. Effect sizes were estimated using Cohen *d*. Statistical significance was set at $P < 0.05$.

All data were anonymized and securely stored in the institutional research database of the Catholic University of Valencia. Each participant was assigned a numeric code to ensure confidentiality. Access to the data was restricted to the research team, and all management procedures complied with the institution's ethical standards and General Data Protection Regulation requirements.

Table II. Baseline cephalometric measurements (T_0) and intergroup comparison

Variable	*FA*	*CA*	*P value*
SN-GoGn (°)	23.1 ± 6.67	23.5 ± 5.03	0.678
FMA (°)	26.4 ± 4.90	26.8 ± 5.12	0.742
N-Me (mm)	113.3 ± 6.18	115.0 ± 8.76	0.446
S-Go (mm)	75.5 ± 6.88	76.9 ± 8.54	0.679
ANS-Me (mm)	63.4 ± 4.85	64.2 ± 5.02	0.512
Jarabak ratio (%)	66.6 ± 3.12	66.9 ± 3.25	0.811

Note. Values are expressed as mean ± standard deviation. Intergroup comparisons were performed using the Mann-Whitney U test. No statistically significant differences were found ($P > 0.05$), confirming baseline homogeneity between groups.

RESULTS

A total of 52 participants completed the study, 26 in the CA group and 26 in the FA group. The mean age at baseline was similar between groups (CA: 22.4 ± 5.3 years; FA: 21.9 ± 4.8 years; $P > 0.05$), and the sex distribution was balanced (CA: 14 females and 12 males; FA: 15 females and 11 males). There were no statistically significant intergroup differences in the type of malocclusion, initial skeletal pattern, or treatment duration (Table I).

At T_0, the 2 groups showed comparable vertical skeletal relationships. Mean values for SN-GoGn, FMA, N-Me, S-Go, ANS-Me, and the Jarabak ratio did not differ significantly between the CA and FA groups ($P > 0.05$), indicating that both cohorts were homogeneous at baseline and suitable for comparison (Table II).

In the CA group, treatment produced small but statistically significant increases in the SN-GoGn angle ($P = 0.016$), amounting to <1°, which can be regarded as a minor variation without clinical relevance. Linear measurements (N-Me, S-Go, and ANS-Me) also exhibited slight increases, reflecting limited vertical development or dental elongation within physiological limits.

In contrast, the FA group displayed a modest but statistically significant increase in SN-GoGn and FMA ($P < 0.05$), consistent with a mild clockwise mandibular rotation. Similarly, N-Me and ANS-Me increased significantly ($P < 0.05$), whereas S-Go remained largely stable. These findings indicate a tendency toward a small vertical opening pattern during treatment with conventional FAs (Table III; Fig 1).

When the overall treatment-induced changes (ΔT_1-T_0) were compared between groups, no statistically significant differences were found for any of the vertical

Table III. Intragroup changes in cephalometric parameters (T_0-T_1)

Variable	*Group*	*T_0*	*T_1*	*Intragroup P value*	*Intergroup P value*
SN-GoGn (°)	FA	23.1 ± 6.67	23.5 ± 6.74	0.374	0.390
	CA	23.5 ± 5.03	24.3 ± 4.78	0.016*	–
FMA (°)	FA	26.4 ± 4.90	27.1 ± 4.85	0.041*	0.401
	CA	26.8 ± 5.12	27.0 ± 5.08	0.128	–
N-Me (mm)	FA	113.3 ± 6.18	114.5 ± 6.15	0.002**	0.987
	CA	115.0 ± 8.76	116.5 ± 8.94	0.013*	–
S-Go (mm)	FA	75.5 ± 6.88	76.3 ± 6.61	0.019*	0.465
	CA	76.9 ± 8.54	77.4 ± 8.06	0.685	–
ANS-Me (mm)	FA	63.4 ± 4.85	64.5 ± 4.91	0.008**	0.529
	CA	64.2 ± 5.02	65.0 ± 5.10	0.067	–
Jarabak ratio (%)	FA	66.6 ± 3.12	66.7 ± 3.08	0.723	0.648
	CA	66.9 ± 3.25	66.6 ± 3.20	0.538	–

Note. Values are expressed as mean ± standard deviation. Statistical tests used are the Brunner-Langer ATS model for repeated measures (within-group) and the Mann-Whitney U test for intergroup comparisons.
*P <0.05; **P <0.01

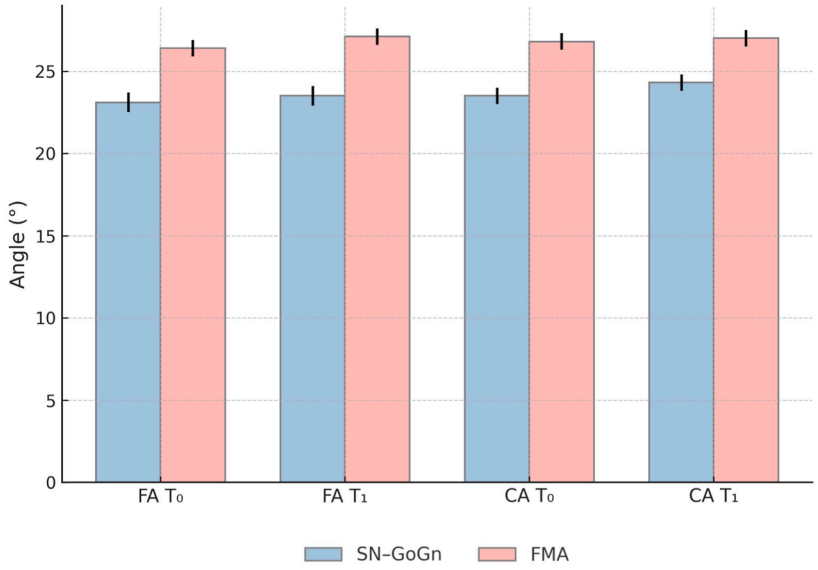


Fig 1. Mean values of SN-GoGn and FMA at baseline (T0) and after treatment (T1) in the FA and CA groups.

parameters analyzed (P >0.05). The mean difference in SN-GoGn between the CA and FA groups was <1°, and differences in facial height parameters did not exceed 0.5 mm. Cohen *d* values for all comparisons were <0.30, indicating small effect sizes and negligible clinical relevance (Table IV).

Figure 2 illustrates the comparative distribution of changes in the SN-GoGn and the Jarabak ratio between treatment modalities, highlighting the overlapping variability and absence of systematic divergence.

Correlation tests exploring the relationship between treatment duration and the magnitude of vertical change revealed no significant associations (P >0.05). Similarly, no relationship was observed between the initial skeletal patterns (hypodivergent, normodivergent, or hyperdivergent) and vertical responses within

Table IV. Intergroup comparison of mean changes (ΔT_1-T_0) and effect sizes (Cohen *d*)

Variable	*ΔFA*	*ΔCA*	*P value*	*Effect size (Cohen d)*
SN-GoGn (°)	+0.40 ± 1.02	+0.80 ± 1.12	0.678	0.26
FMA (°)	+0.70 ± 0.94	+0.20 ± 0.89	0.523	0.23
N-Me (mm)	+1.20 ± 0.85	+1.50 ± 0.90	0.446	0.24
S-Go (mm)	+0.80 ± 0.75	+0.50 ± 0.82	0.679	0.19
ANS-Me (mm)	+1.10 ± 0.78	+0.80 ± 0.85	0.631	0.22
Jarabak ratio (%)	+0.10 ± 0.45	−0.30 ± 0.50	0.571	0.18

Note. Values are expressed as mean ± standard deviation. Positive values indicate an increase, and negative values indicate a decrease. The Mann-Whitney U test was used for intergroup comparison. Effect size was calculated using Cohen *d*. No statistically significant differences were observed ($P > 0.05$), and all effect sizes were small ($d < 0.30$), indicating negligible clinical relevance.
Δ, posttreatment minus pretreatment difference (T_1-T_0).

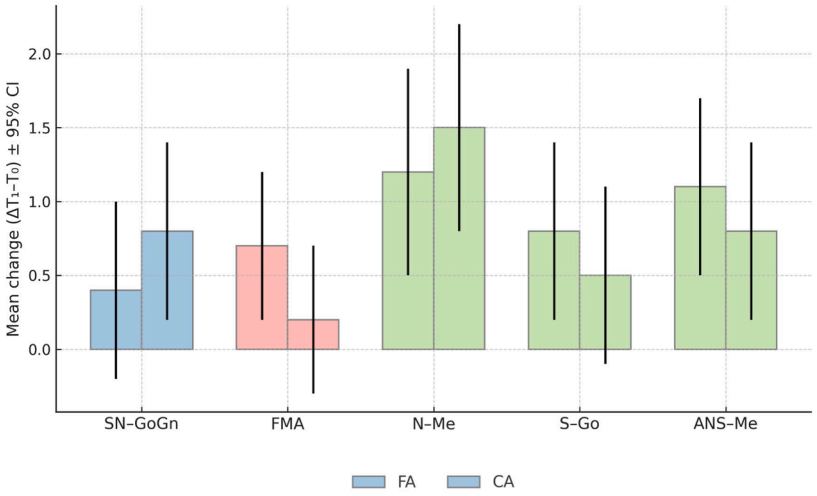


Fig 2. Distribution of changes (ΔT_1-T_0) with 95% confidence intervals for SN-GoGn, FMA, N-Me, S-Go, and ANS-Me in the CA and FA groups.

each treatment group. These findings suggest that the type of appliance, rather than individual growth pattern or treatment length, was not a determining factor in vertical dimensional change.

Reproducibility analysis confirmed excellent consistency of cephalometric measurements. The intraclass correlation coefficients ranged 0.92-0.98 for intraobserver agreement and from 0.90-0.96 for interobserver agreement. Random error estimated by the Dahlberg formula was <0.4° for angular variables and <0.3 mm for linear measurements, confirming high measurement precision and supporting the reliability of the reported results.

Both CA and FA therapies produced minimal and clinically insignificant variations in vertical dimension. Although minor clockwise mandibular rotation was observed in the FA group, the overall pattern of vertical change did not differ significantly between the 2 treatment modalities. These outcomes support the assumption that modern CAs can maintain vertical control comparable with FAs when used in patients with mild-to-moderate malocclusion.

DISCUSSION

The present prospective cohort study demonstrated that both CAs and FAs produced only minimal and clinically insignificant vertical skeletal and dentoalveolar changes. No relevant intergroup differences were observed in SN-GoGn or facial height parameters. Although FAs showed a greater tendency toward dentoalveolar vertical modification, particularly in overbite

reduction, these changes did not translate into clinically relevant skeletal divergence. These findings support the concept that, under controlled treatment protocols, CAT provides vertical control comparable with FAs.

The present results are consistent with several recent studies reporting minimal or clinically insignificant changes in vertical dimension during CAT compared with conventional FAs.[6,8,9] Both Garnett et al[9] and Rask et al[8] observed no relevant differences in SN-GoGn or facial height changes between the 2 modalities, confirming that modern aligners allow adequate control of vertical relationships. Similarly, Lin et al found that CA and FA therapies achieved comparable posttreatment vertical parameters in a randomized clinical trial.[2]

In contrast, earlier investigations described divergent outcomes, particularly concerning the so-called bite-block effect. Boyd[4] and Moshiri et al[5] reported that the occlusal coverage of aligners might limit posterior eruption and promote counterclockwise mandibular rotation, facilitating open bite correction. These early observations were mainly based on first-generation aligners fabricated from EX30-type polyethylene-based materials, which exhibited greater force decay and less precise staging. Such material and protocol differences likely contributed to the apparent intrusive effects described in those studies. Subsequent developments, particularly the introduction of SmartTrack material, have improved elastic recovery and force continuity, which allows more controlled vertical tooth movements and reduces unwanted mandibular rotation.[18-20]

Discrepancies among studies may also stem from methodological variations. Many early reports were retrospective, included heterogeneous malocclusion types, and did not control for confounding variables, such as growth pattern, occlusal coverage, or the use of intermaxillary elastics.[11,14] The present study differs by employing a prospective design with standardized inclusion criteria, excluding patients with severe vertical discrepancies or open bites >3 mm. This design feature may explain the absence of pronounced bite-block effects or significant vertical divergence in our sample.

Taken together, these distinctions highlight how both technological advances and stricter methodological control influence the reported outcomes of aligner therapy. Overall, the consistency between our data and previous evidence supports the notion that vertical control with CAs has improved substantially with current materials and digital treatment planning, reaching parity with conventional fixed therapy in mild-to-moderate malocclusions.

From a clinical perspective, the present findings indicate that CAT provides satisfactory vertical control in patients with mild-to-moderate malocclusions and balanced skeletal patterns. The small angular and linear changes observed suggest that aligners can maintain vertical stability comparable with FAs when no extreme vertical discrepancies are present. This supports their use as a viable esthetic alternative in adult patients requiring comprehensive treatment without significant skeletal divergence.

However, the results should not be extrapolated to patients with severe open bite, hyperdivergent patterns, or complex vertical problems because these conditions were excluded from the present sample. In such cases, aligner biomechanics may behave differently, and combined or hybrid protocols could still be required. Future research specifically designed to evaluate these critical vertical scenarios is warranted before broader clinical generalization can be made.

The main limitations of this investigation include its sample size and the absence of randomization in group allocation. Participants were assigned according to clinical indication and patient preference, which may have introduced selection bias despite the efforts to match groups for age, sex, and malocclusion severity. Furthermore, all treatments were performed by a single experienced orthodontist, which ensured procedural consistency but may limit the external validity and generalization of the results to different operators or clinical settings.

The study also excluded patients with severe vertical discrepancies, skeletal asymmetries, or complex combined treatments, restricting the applicability of the findings to mild-to-moderate malocclusions. In addition, only 2-dimensional cephalometric data were analyzed; therefore, subtle 3-dimensional dentoalveolar changes could not be captured. Future research should include larger randomized controlled trials and 3-dimensional imaging techniques, such as cone-beam computed tomography or digital model superimpositions, to validate and expand the present findings.

CONCLUSIONS

Within the limitations of this prospective cohort study, vertical dimensional changes observed during treatment with CAs and FAs were small and largely comparable. Both modalities produced minimal variations in mandibular plane and facial height measurements, remaining within the range of normal physiological change. A slight tendency toward clockwise mandibular rotation was detected in the FA group, whereas vertical

control appeared stable in the CA group, although without statistically or clinically relevant intergroup differences. These findings suggest that, under current protocols, CAT may offer vertical control similar to that of FAs in patients with mild-to-moderate malocclusions. Nevertheless, further studies with larger samples, longer follow-up, and 3-dimensional analyses are needed to confirm these observations and better delineate the vertical response achievable with aligner systems.

AUTHOR CREDIT STATEMENT

Lidia Galán-López performed data collection, data curation, and preliminary descriptive analyses; Clara Guinot-Barona contributed to study design, coordinated data acquisition, supervised methodological procedures and data accuracy, and drafted and revised the manuscript; Iciar San-Orrio Soler performed data collection, data curation, and preliminary descriptive analyses; Raquel Laparra-Hernández developed methodology, prepared tables and figures, and organized data presentation; Esther Garcia-Miralles conducted data analysis and interpretation, validated statistical analyses, and edited and revised the manuscript; Juan Ignacio Aura-Tormos conceived and designed the study, supervised all research stages, coordinated data analysis and interpretation, and revised the final manuscript. All authors reviewed the results, revised the final manuscript, and approved it for submission.

DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used artificial intelligence tools (eg, Grok by xAI) to assist in drafting and refining manuscript text and generating figures (eg, Fig 2). After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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