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Correlation between transverse and sagittal dimensions in early stage: a retrospective study between patients treated with clear aligners and untreated patients

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Abstract

Background The interceptive treatment of Class II malocclusion using clear aligners is still debatable. This retrospective study analyzes the short-term occlusal and cephalometric effects in 40 growing patients with Class II malocclusion.

Methods The sample was divided into 2 groups: Following the dentoalveolar expansion protocol, the first group was treated with clear aligners (GI). The second group was untreated (GN). Dental arches were scanned before and 1 year after the therapy. Similarly, linear measurements on digital casts and cephalometric ones on lateral X-rays were compared. Maxillary (Lmax), mandibular intermolar length (Lmand), and posterior transverse intermolar discrepancy (DIT) were evaluated. The distance between the mesiobuccal cusp of the upper first molar and the buccal groove of the first lower molar was considered at both sides (Cdx and Csx). The statistical descriptive analysis of T0 and T1 values was performed using a paired t-test, setting a p value < 0.05.

Results A greater improvement in molar and skeletal Class II parameters in the GI group compared to the GN group was detected. Specifically, in GI, Lmax improved by 3.3 mm, Lmand by 1.1 mm, and DIT improved from – 2.1 mm to 0.1 mm, while Cdx and Csx decreased by 1.28 mm and 1.13 mm, respectively. In contrast, the GN group showed smaller improvements, with Lmax increasing by 1 mm, Lmand by 0.8 mm, DIT improving from – 2 mm to -1.8 mm, and both Cdx and Csx exhibiting slight increases of 0.04 mm and 0.09 mm, respectively. No statistically significant differences were observed regarding divergence or the correlation between skeletal and dental measurements.

Conclusions Dentoalveolar expansion using Invisalign First appears effective and predictable with better outcomes than the control group. An improvement of skeletal Class II is detected in the treated group with dental improvements on maxillary arch.

Keywords Clear aligners, Growing patients, Digital orthodontics, Interceptive therapy

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Background

Class II Division 1 malocclusion is described as a distal relationship of the mandible to the maxilla with labioversion of the maxillary incisors and is relatively more prevalent in the North Indian population [1]. Much has also been discussed about the efficacy of two-stage therapy, i.e., acting with an early phase in the years leading up to adolescence, followed by a second phase of occlusal finishing.

Tulloch et al. argue that early treatment (stage 1) followed by late treatment (stage 2), on average, does not produce greater differences in jaw relationship or dental occlusion, compared with late treatment in a single stage [2]. In contrast, Kopecky et al., establishing a set of 11 "skeletal maturity indicators" by which the stage of skeletal maturity can be identified, assert that the best time to act is between SMI maturational stages 4 and 7, which are characterized by sesamoid ossification and a very rapid growth rate [3]. Bishara et al. in longitudinal studies examined changes in dentofacial and mandibular structures in untreated Class II subjects by comparing their data with those of untreated Class I patients. Their results reported that in untreated Class II and normal subjects, the direction of growth was essentially similar while the amount of mandibular growth was less in Class II subjects [4–5].

Some studies indicate that the transverse discrepancy may act as an additional input signal for anteroposterior adjustment between skeletal bases during the developmental stages [6–8]. In addition, it is important to evaluate whether this discrepancy may be a possible functional cause of distocclusion. Although successful treatment of this kind of malocclusion has been repeatedly demonstrated, clinicians and patients continue to seek more effective and simpler methods. Rapid Maxillary Expansion is a widespread orthopedic technique for widening the maxillary transverse dimension in young patients by separating the midpalatal suture. However, the most recorded side effects occurring during the use of RME are pain, oral ulcerations, and worsening of plaque index [6]. Also functional appliances have also shown positive effects about dental expansion, but require a higher level of compliance and discomfort than aligners [7].

Interceptive treatment with aligners is a dedicated treatment option for growing patients in need of early phase 1 therapy. However, there are only a limited number of studies on the efficiency of tooth movement with clear aligners, especially the transverse expansion is still object of debate. Lu's prospective cohort study evaluated the treatment outcomes of the Invisalign First System versus a traditional Rapid Maxillary Expander (RME) in mixed dentition cases [8]. The findings indicated that the Invisalign group showed significant dental and dentoalveolar changes, establishing its effectiveness for mild to moderate maxillary transverse discrepancies. Levrini's preliminary study [9] assessed the effectiveness of Invisalign® First clear aligners in achieving palatal expansion during mixed dentition. The study also emphasized the comfort and esthetic advantages of Invisalign® First over traditional fixed appliances.

In this retrospective study, we aim to perform an analysis of the craniofacial, skeletal, and occlusal changes of growing subjects with Class II dental and skeletal malocclusion, orthodontically treated with clear aligners, with dentoalveolar maxillary expansion according to the protocol described below and compared with untreated subjects. The study aims to evaluate what are the actual occlusal and cephalometric improvements of patients treated by this method compared with untreated patients and re-evaluated in follow-up at one-year intervals.

Table 1 Mean initial age of samples

Group	Male mean age	Female mean age
GI	8.2 ± 0.96	7.93 ± 0.77
GN	7.65 ± 0.96	7.27 ± 0.96

Materials and methods

Study design

In this retrospective study, 40 growing subjects in the age range of 6–10 years were analyzed (Table 1). As proposed by Whitehead et al., a sample size of 20 subjects per group will be required to obtain an effect size of a clinically relevant change of 1.0 mm with a combined standard deviation of 1.5 mm for a type I error rate of 5% and a power of 80% [10]. The selected sample was divided into two groups of 20 subjects each. The first group consisted of 20 Class II Division 1 subjects with reduced maxillary arch and was treated with Invisalign First (GI) in private practice by the clinician. The second group was taken as the control group, with 20 Class II Division 1 subjects with constricted maxillary arch (GN). The control group was screened at the Orthodontic Service of the Institute of Dental Clinic from the European University in Valencia. All data was already in the department's documentary records and refers to check up earlier than the beginning of this study. The GI group consisted of 8 males and 12 females; while the GN group consisted of 9 males and 11 females. All selected subjects were characterized by mixed dentition. The inclusion criteria were as follows:

- No significant medical history, facial trauma, or temporomandibular joint disorder.
- No previous orthodontic treatment.
- Bilateral Class II molar relationship in maximum intercuspation.
- Absence of dental anomalies or posterior crossbite.
- Mixed (or early mixed) dentition.

- Absence of functional or structural asymmetries.
- Absence of menarche for female subjects.
- Initiation of therapy shortly after the first radiograph was taken (max 4 months).
- Moderate patient compliance as judged by the clinician during therapy and extrapolated from the patient's per diem regardless of clinical findings.
- Class II skeletal malocclusion (4°< ANB < 10°), minimal maxillary protrusion (SNA < 82°), mandibular hypodevelopment (SNB < 80°).
- Posterior interarch discrepancy (DIT): the presence of a difference between two calculated distances between the maxilla and mandible in the posterior region.

After a complete intraoral examination, intraoral scans were taken at the beginning of the study (T0) and approximately one year (T1) apart using iTero® Element™ Intraoral 3D Scanner for both treated (GI) and control (GN) subjects. Digital models were extrapolated from the scans and certain parameters were analyzed using OrthoCad® software.

Subjects in the treated group (GI) underwent therapy with removable clear appliances, Invisalign technique (Align Technology, Los Angeles CA). After performing careful diagnostic processing, the collection of initial documentation (arch scans, intraoral and extraoral photographs, and the orthopanoramic and teleradiographic radiographs), virtual three-dimensional simulation for malocclusion resolution was analyzed, using ClinCheck® pro 6.0 software. The protocol used, Invisalign First, involves the use of some features and tools that help the clinician to approach orthodontic therapy with clear aligners in mixed dentition, that is, with the presence of deciduous and permanent teeth together. The protocol recommends the presence of the upper and lower permanent first molars, the four upper incisors, and the four lower incisors in the arch. The planned pattern of expansion is sequential:

(1) Initially, only the expansion of the first permanent molars is planned followed later by the lateral sectors. This method has a high predictability of movement because of the increased an-chorage present during the two moments of expansion. In this way, the intermediate sectors will serve as anchors while the aligner pushes the expanding first permanent molars.

(2) The intermediate sectors can start moving as soon as the first permanent molars have completed their movement or are at the end of their expansion.

During expansion, support attachments are applied to ensure greater retention at the level of the dental elements in the presence of short clinical crowns and are automatically placed by the software on lateral quadrants. At least two attachments per quadrant are required to ensure adequate retention. For each treatment subject, the same expansion treatment procedure was planned consistently: a maximum arch expansion of 4 mm (2 mm per side).

The expansion of the two arches was planned to give the opportunity to have a portion of dento-alveolar remodeling to also facilitate good dental alignment of the upper and lower inci-sors, especially if they were misaligned. In all, treatment phases of no more than 10 months were planned, with a maximum of 40 aligners to be changed every 7 days.

Measurement protocol on digital casts

As proposed by Tollaro et al. [11], measurements on digital models are as follows:

1. Maxillary intermolar width (Lmax): distance between the tips of the mesio-palatal cusps of the maxillary left and right first molars.
2. The mandibular intermolar width (Lmand): distance between the midpoints of the occlusal grooves of the right and left mandibular first molars.
3. The posterior transverse interarch discrepancy (DIT): the means of the distances between the mesial cusp of the maxillary first molar and the mesial sulcus of the mandibular first molar. (Fig. 1)
4. The distance between the mesial-vestibular cusp of the upper first molar and the vestibular sulcus of the lower first molar on the right side (Cdx) and left side (Csx) in lateral view, with the upper and lower arches in occlusion. (Fig. 2)

Measurements on lateral X-ray

After taking measurements on the digital models and dividing the patients into their respective groups, standardized lateral cephalograms were taken of all these subjects at T0 and T1. Each subject was given one teleradiography in lateral projection, and a second one about a year later. Cephalometric tracings were made on each teleradiography, and linear (in millimeters) and angular (in degrees) measurements were taken.

Sagittal Skeletal relationships.

- SNA (sagittal position of the maxilla).
- SNB (sagittal position of the mandible).
- ANB (maxillomandibular sagittal discrepancy).

Vertical Skeletal relationships.

- FMA (mandibular plane inclination on FP).
- SN/GoMe (jaw plane inclination on SN).
- SN/ANS-PNS (maxillary plane inclination on SN).
- ArGoMe (gonial angle).

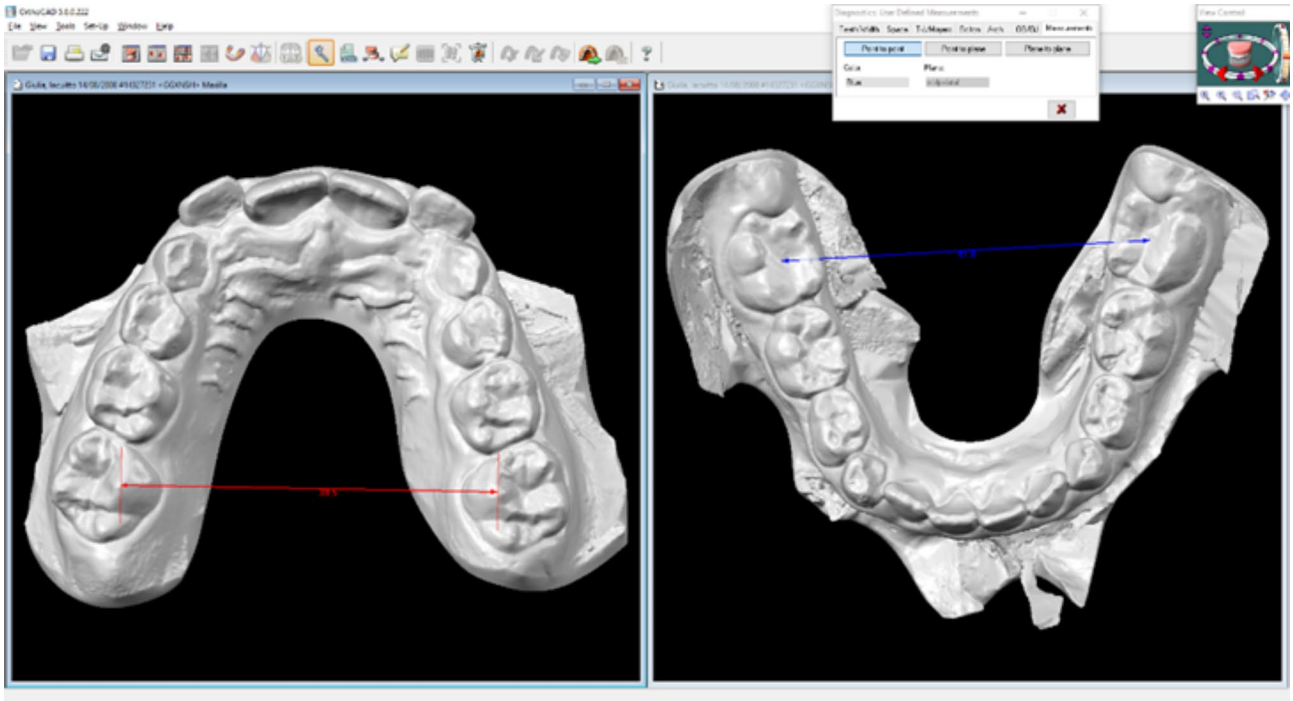

Fig. 1 Example of digital model and use of measurement systems, within OrthoCad® software, in occlusal view

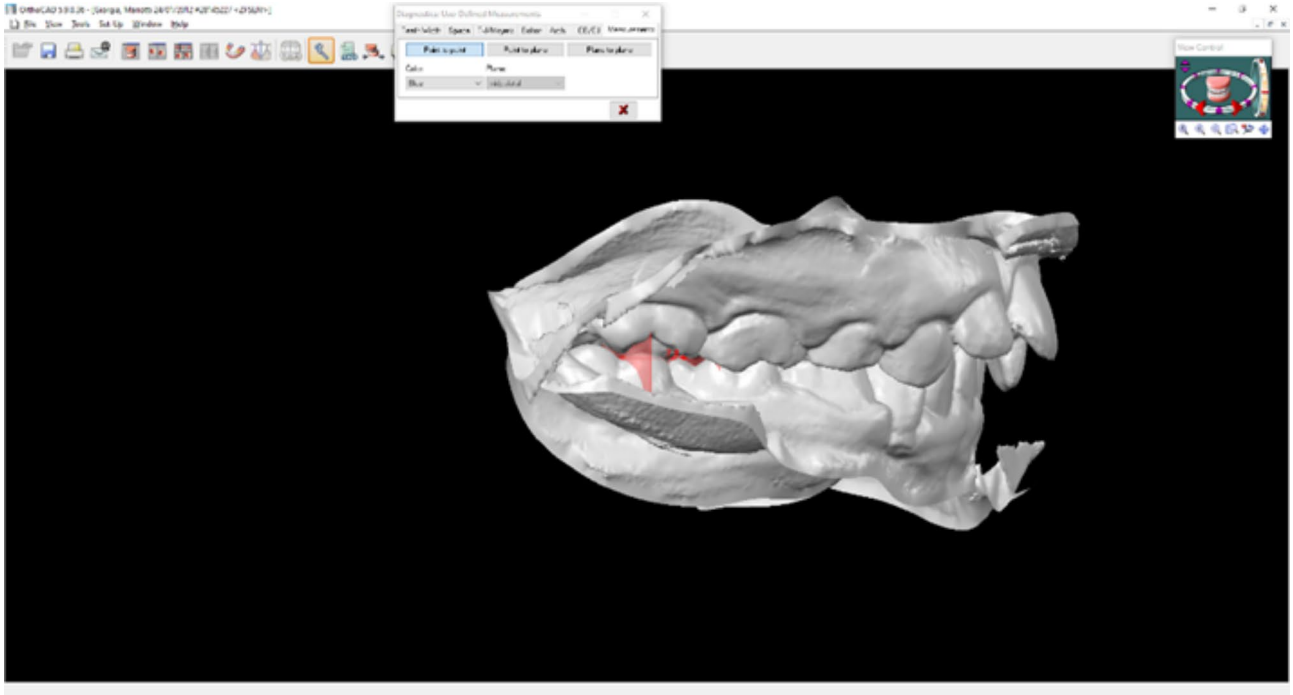

Fig. 2 Example of digital model and use of measurement systems, within OrthoCad® software, in right side view

Mandibular dimensions.

- Co-Pg (mm).
- Ar-Go (mm).

Cephalometric tracing and measurements were performed by two different operators at different times and twice. The errors between the two operators and between the two measurements by the same operator were negligible when less than 0.5 mm and 0.5°.

Statistical analysis

The sample size was calculated setting type I error at 0.05 and type II error at 0.20 For this two-group comparison it was calculated that at least 20 patients per group were needed to be enrolled, by set-.

Data were collected for each group at T0 and T1 and entered into appropriate grids. The results were tabulated and statistically analyzed. Normal values were determined according to standard norms [12–13]. Descriptive statistical analyses were performed for both the values collected from the digital models and the values from the cephalometric measurements for the GI and GN groups at T0 and T1.

All measurements were performed by the researcher. A randomly selected 20% of the sample was re-measured after a minimum interval of 15 days and analyzed by intraclass correlation coefficient (ICC) to assess reliability. A value of 0.9 or higher was considered necessary to indicate measurement reliability. The degree of correlation between the amount of expansion achieved with therapy and the reduction in values characterizing the second Class was found by Spearman's correlation analysis. A p-value < 0.05 was considered statistically significant (Table 2).

Results

The mean values of DIT in the non-treatment (GN) group decreased from – 2 mm at T0 to -1.8 mm at T1. Therefore, DIT remains negative at the beginning of the study and at approximately one year later in the GN group, ameliorating just 0.2 mm. In the treated group (GI), instead, DIT decreases from – 2.1 mm before treatment to 0.1 mm after treatment. For this reason, DIT in the treated group with clear aligner ameliorates 2.2 mm. The difference of the mean values of Cdx at T0 and T1, for the GN group, is 0.04 mm. The mean value of the distance on the right side in the untreated group tends, albeit slightly, to increase. The difference of the mean values of Cdx at T0 and T1, for the GI group, is -1.28 mm. The mean value of the distance on the right side in the treated group tends significantly to decrease. To ensure measurement reliability, the intraclass correlation

Table 2 Results of descriptive statistical analysis

Measurements	Mean (± Standard deviation)				Minimum				Maximum			
Time	T0		T1		T0		T1		T0		T1	
Group	GN	GI	GN	GI	GN	GI	GN	GI	GN	GI	GN	GI
LMax (mm)	38.3 (± 2.37)	38,1 (± 2.47)	39.3 (± 2.21)	41.4 (± 2.14)	35	35	36	38	42	42	43	45
LMand (mm)	40.3 (± 2.21)	40.2 (± 2.2)	41.1 (± 2.36)	41.3 (± 2.26)	42	35	43	44	35	42	36	38
Cdx (mm)	3.97 (± 1.2)	4.42 (± 1.27)	4.01 (± 1.36)	3.14 (± 1.27)	2,5	2,8	2,5	1,6	6,1	6,3	6,2	5,6
Csx (mm)	3.89 (± 1.24)	4.34 (± 1.29)	3.98 (± 1.36)	3.21 (± 1.35)	2,3	2,7	2,4	1,8	5,8	6,2	6,1	5,4
SNA (°)	81.36 (± 2.81)	82.01 (± 2.25)	81.01 (± 2.36)	81.14 (± 2.57)	78	79	79	80	85	84	85	84
SNB (°)	77.03 (± 2.46)	76.33 (± 2.65)	76.01 (± 2.33)	79.14 (± 2.49)	72	73	73	76	78	78	77	82
ANB (°)	4.33 (± 1.44)	5.83 (± 1.65)	5.02 (± 1.37)	2 (± 1.64)	3,2	3,7	2,4	2,4	6,2	6,4	6,2	4,1

Legend: T0 = Results before therapy; T1 = Results after therapy; GN = Untreated group; SNA = Angle formed by connecting S point, N point, and A point; SNA = Angle formed by connecting S point, N point, and A point; ANB = Angle formed by connecting A point, N point, and B point

Table 3 Descriptive statistical analysis for linear Ar-Go (mm) and Co-Pg (mm) measurements for GI and GN groups

Group	Male mean age		Female mean age	
Measurement	**Ar-Go**	**ΔCo-Pg**	**ΔAr-Go**	**ΔCo-Pg**
Media	1.05	2.62	0.70	1.94
Standard error	0.43	1.11	0.29	0.55
Media	1.50	2.24	0.23	3.11
Standard deviation	1.63	2.17	0.91	1.74
Sample variance	2.64	1.39	0.84	30.4
Asimmetry	2.35	1.81	1.13	-0.11
Minimum	0.29	1.22	0.00	0.90
Maximum	2.91	7.09	2.56	5.05

coefficient (ICC) was calculated, yielding a value of 0.9, indicating excellent reliability.

The difference of the mean values of Csx at T0 and T1, for the GN group, is 0.09 mm. The mean value of the distance on the left side in the untreated group tends, albeit slightly, to increase. The difference of the mean values of Cdx at T0 and T1, for the GI group, is -1.13 mm. The mean value of the distance on the left side in the treated group tends significantly to decrease.

In the GN group, the mean ANB value, which gives an idea of the maxillomandibular sagittal discrepancy, tends not to change one year later; in the GI group, the value tends to decrease, with more anterior dislocation by mandibular structures. For the mean FMA value (mandibular plane inclination on FP) in both groups, no major changes are noteworthy. The same consideration can be made for the values SN/GoMe (mandibular plane inclination on SN); SN/ANS-PNS (maxillary plane inclination on SN) and ArGoMe (goniac angle), which had minimal angular variations. Relative to the FMA value, the selected subjects belonging to GI or GN, were all in normodivergence because they had values very close to 24°, which did not change during the evaluation year.

As shown in Table 3, for the statistical analysis of the Ar-Go (mm) and Co-Pg (mm) values, it was necessary to calculate the standard deviation of the error of each measurement, which was calculated according to Dahlberg's formula: (∑D2/2 N)1/2 where D is the difference between the first and second detections and N is the number of detections. The standard deviation of the error for Ar-Go and Co-Go measurements was calculated to be 0.89 mm and 1.07 mm, respectively.

The inferential analysis of the two-tailed t-test was applied to compare the means between groups (inter-group) and within the same group over time (intra-group), assuming normal distribution and the significance of the results confirm the data of the descriptive analysis with p-values < 0.05 except in the case of the linear increments of Co-Pg with significance values $p < 0.07$. Variations in the significance of p are probably related to the difficulty of reproducing the cephalometric points, especially Co.

Table 4 Correlation between DIT and the other variables

Variables	*N*	Spearman Correlation	*P* value*
DIT vs. Cdx	20	-0.457	0.000*
DIT vs. Csx	20	-0.567	0.000*
DIT vs. ΔCo-Pg	20	0.386	0.005*
DIT vs. ΔAr-Go	20	0.142	0.005*

The correlation of DIT with Cdx and Csx and DIT with ΔCo-Pg and ΔAr-Go was evaluated in Table 4.

Discussion

The posterior transverse discrepancy, as seen in some cases of Class II Division 1 malocclusion in the mixed dentition period, may be related to typical skeletal-facial features. In the transverse plane, expansion of the upper maxilla is determined by the development of the nasal capsule of the pterygoid planes. In addition, mechanical actions of muscular origin are transmitted to the upper maxilla by the tongue and masticatory muscles, lips, and cheeks. Teeth also participate in the growth of the maxilla in the three planes of space: in the vertical plane the height of the maxilla is influenced by the downward migration of erupting dental elements; in the sagittal plane the increase in the number of teeth influences the anteroposterior dimension; in the transverse plane the direction of eruption of dental elements results in a posterior enlargement of the palate by divergent elongation of the arch [14].

Among the appliance used for constricted maxillary arch, the Rapid Maxillary Expander is the most widely chosen. The Invisalign® First system is a novel orthodontic approach designed to resolve crowding and enhance the arch form by inducing dentoalveolar changes in growing patients with early mixed dentition. The objective of this study was to verify effective mandibular bone repositioning in young patients with Class II malocclusion, treated with orthodontic appliances (clear aligners in the Invisalign technique), following the Invisalign First protocol of sequential expansion. In this retrospective study, we aim to perform an analysis of the changes in craniofacial, skeletal, and occlusal characteristics of growing subjects with Class II dental malocclusion who were orthodontically treated and compared with untreated subjects. This research analyzed the changes that occurred in one year in the selected subjects, evaluating the evolution of pathognomonic elements of Class II dysgnathia. This study aims to estimate an improvement, worsening, or stabilization of such dysgnathia both in the group of treated subjects (with dentoalveolar expansion with aligners) and in the selected untreated group. Our findings are consistent with those reported by Cretella Lombardo et al. The authors noted a greater

intermolar in the treated group, confirming that clear aligners effectively expand a narrow maxilla and alter the arch shape. Furthermore, it was detected that clear aligners can increase dental width differentially anteroposteriorly, whereas the rapid expander cannot [15].

Moyers and Wainright stated that a distal relationship in deciduous dentition likely reflects an underlying skeletal imbalance and typically results in a Class II malocclusion in the permanent dentition [16]. Varrela compared the cephalometric values of children in Class II deciduous dentition with children at the same developmental stage but with normal occlusion [17]. He observed that subjects with distal relation had a shorter mandibular body and a wider goniac angle than those with normal occlusion. Dianiskova et al., instead, evaluated the effects of clear aligners associated to elastics and compared to fixed orthodontic therapy. Their research did not appreciate a statistically significant difference in the correction of the sagittal intermaxillary relation but a better lower incisor control in the group treated with clear aligners [18]. Arya et al. reported that all patients with a distal relation of deciduous second molars evolve into a Class II molar relation in permanent molars [19]. Bishara et al. observed that a Class II malocclusion diagnosed based on occlusal relationships is never "self-correcting" [4]. Bacetti et al. agree with all previous authors and, given the absence of spontaneous improvement, suggest that early treatment is for this reason justified [12].

Moreover, Sun et al. evaluated the effects of clear aligners compared with a group treated with twin block appliance. The first group revealed has more advantages in retraction of anterior teeth and backward movement of point A. The group treated with functional appliance instead showed a greater forward movement of point B [20].

Zybutz et al., proposing a similar project, highlighted the greater discomfort perceived by the group treated with twin block [21].

Through the virtual simulations of tooth movements, given by ClinCheck, one can program exactly the amount of dentoalveolar expansion of the upper arch so that, after the design the upper arch width, understood as the distance between the tips of the mesial-palatal cusps of the first molars of the upper arch, should be the same as the width of the lower arch, understood as the distance between the midpoints of the occlusal grooves of the lower first molars. This condition is well established and easily found in Class I [22]. The study shows a greater amount of average maxillary expansion in the treated group than in the control. This difference is less pronounced when comparing mandibular expansion between the two groups. Patients treated with aligners have a higher mean maxillary dental expansion compared with both the mandibular dental expansion level and the control group. Recently, Invisalign Palatal Expander (AlignTechnology, Los Angeles CA) is available as a new option to expand maxillary dental arch, changing day by day a sequence of removable appliances, realized after a scan and a digital project of dental expansion. Further studies should compare the results obtained with Clear Aligner and the ones achieved by Invisalign Palatal Expander. In the GN group, the mean value of ANB, which gives an idea of the maxillomandibular sagittal discrepancy, tends not to vary one year later; in the GI group, the value tends to decrease, with greater anterior dislocation by mandibular structures. The result of this study is, therefore, consistent, with the hypothesis of mandibular repositioning favored by arch expansion alone [23]. The other important finding is that the technique used involves the application of h22/h24 aligners, which, with their thickness, can nullify contacts and occlusal interferences that deviate normal jaw development and cause malocclusions and can inhibit impulses that go on the neuromuscular systems and feedback via periodontal receptors, giving rise to new positional adjustments at the mandible [24]. Based on these findings, interceptive therapy with clear aligners provide an efficient alternative to treat also class II malocclusion, avoiding the use of intermaxillary elastics or more uncomfortable appliance. Given the small sample size, and despite the efforts used to reduce technical errors in taking measurements, the overall analyses in this study may be burdened with errors, particularly for considerations that may arise from analyses of cephalometric readings. The inclusion of a control group in this study, tried to overcome the limitation posed by possible confounder as growth-related variations among subjects [25]. All measurements, on the other hand, taken on the digital models have absolutely certain values because they are calculated directly by the software on anatomical structures with real dimensions, as they are reported from the intraoral scan.

Conclusions

The study showed greater tooth expansion in the treated group, with a greater impact at the level of the maxillary arch. Therefore, the expansion method with Invisalign First should be considered effective and predictable. In addition, measurements on digital models revealed an improvement in Class II molar condition compared with the control group. From cephalometric measurements, the treated group shows a fair improvement in skeletal class. In contrast, no changes in divergence between the two groups are evident. Likewise, there are no statistically significant correlations between cephalometric values and dental measurements. Further studies with a larger sample size and long follow-ups will be needed to verify the actual effectiveness of interceptive aligner

therapy at an early stage of growth. The debate on the mode of intervention remains open, although it is almost unanimously agreed to intervene in the ascending phase of peak growth velocity if additional growth of the mandible is desired. However, these findings suggest that dentoalveolar expansion using Invisalign First appears effective and predictable option to treat constricted maxillary arch: The group treated achieved an amelioration of transverse intermolar discrepancy of 2.2 mm, unlike the control group, which only improves by 0.2 mm. Moreover, dental expansion using clear aligners proved to be a seamless approach to improve skeletal Class II, working digitally on maxillary arch.

Supplementary Information

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Supplementary Material 1

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Author contributions
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Data availability
The datasets analyzed during this study are available from the corresponding author on reasonable request.

Declarations

Human ethics and consent to participate
The study was conducted according to the guidelines of the Declaration of Helsinki and received approval from the Ethics Committee on Human Research of the European University of Valencia, Spain (reference number: CI/2023 – 358). The ethical approval was obtained before accessing retrospective data. Informed consent to anonymized data release was obtained from all legal guardians of the patients included in this study.

Consent for publication
Not applicable.

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Competing interests
The authors declare no competing interests.

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