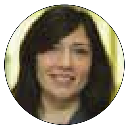
Short term dentoskeletal effects of mandibular advancement clear aligners in Class II growing patients. A prospective controlled study according to STROBE Guidelines



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Abstract

Aim To evaluate the dentoskeletal effects of the Invisalign® Mandibular Advancement (MA) (Align Technology, San José, CA, USA) feature in skeletal Class II growing patients with mandibular retrusion, at pre-pubertal and pubertal stages.

Materials and methods Study design: Forty skeletal Class II patients were prospectively recruited and treated with Invisalign® MA. They were divided into two subgroups according to the CVM stage of growth (CVM2 and CVM3) at the beginning of treatment (T0). For each patient, lateral radiographs were collected at the beginning (T0) and at the end of the mandibular advancement treatment (T1) and their measurements were compared with those obtained by an untreated control group of 32 subjects, matched for growth stage and malocclusion.

Results Patients in CVM2 showed significant reduction of ANB angle, A:Po, Wits index, 11^Spp angle and significant increase of 11^41 and B Downs point. In CVM3 significant reduction of the Wits index and of 41^GoGn angle, and significant increase of the linear Co-Gn measurement, were revealed. Statistics: The STROBE guidelines were followed. Linear regression analysis was performed to estimate the differences of δ (T1 – T0) means between group (control was used as reference) stratifying by CVM levels.

Conclusions The use of Invisalign® MA is effective in treating Class II growing patient with retrognathic mandible in the short term period. While treatment at prepubertal stage of growth results in dentoalveolar rather than skeletal effects, treatment during the pubertal spurt produces skeletal effects with an annual rate of change of 5.8 mm.

KEYWORDS Class II malocclusion; Clear aligners; Growing subjects: Mandibular advancement.

Introduction

Class II malocclusion is one of the most frequent skeletal disharmonies in the Caucasian population with a great prevalence of mandibular retrusion, rather than maxillary protrusion [McNamara,1981].

The efficacy of early treatment of Class II malocclusions in its long-term effects, is still under debate [Keski-Nisula et al., 2003]: some authors recommend an early interceptive treatment, considering that malocclusion tends to worsen over time instead of self-correcting [Keski-Nisula et al., 2003; Stahl et al., 2008; Baccetti et al., 2005; Franchi and Baccetti, 2006; Quinzi et al., 2018; Piancino et al., 2019].

A wide range of functional appliances have been designed across the years to obtain a supplementary growth of the mandible by its forward posturing to correct mandibular retrusion. Several animal studies showed skeletal mandibular changes by posturing the mandible forward [Wang et al., 2018; Patil et al., 2012], but a general consensus about the potential effects in humans is still lacking. In a review published by Cozza et al. [2006], the efficiency of functional appliances used in humans in terms of supplementary growth of the mandible per month of treatment, was measured. The Herbst appliance had the highest coefficient of efficiency (0.28 mm per month) followed by the Twin-block (0.23 mm per month).

On the other hand, a systematic review highlighted the reduction of the incidence of the upper incisors' trauma as the only advantage that can be obtained by a two-phase Class II correction therapy (as opposed to a single phase in adolescence) [Thiruvenkatachari et al., 2015].

Biological timing of intervention seems to be the key to understand the contrasting results found in the existing literature [Franchi and Baccetti, 2006; Cozza et al., 2006; Perinetti et al., 2015]. Perinetti et al. [2015] and Cozza et al. [2006] claimed that functional treatment by removable appliances may be effective in treating Class II malocclusion with clinically relevant skeletal effects if performed during the pubertal growth phase.

A factor that should be taken into account when planning Class II treatment with removable functional appliances, is the patient compliance [Al-Moghrabi et al., 2017]. Impairment in terms of function, speech, sleep and schooling and social interaction were very important in a recent study focused on the Twin Block therapy [El -Huni, 2019 et al.]. A more discrete approach could be represented by clear aligners, with their potentials in terms of comfort and aesthetics and with different forms permitting the forward posturing of the mandible. To the best of our knowledge there are no studies on the effects of these novel appliances. In order to fill this gap, we designed a prospective controlled study, investigating the efficacy of Invisalign® clear aligners with Mandibular Advancement feature (Align Technology, San José, CA, USA) in skeletal Class II growing patients at different stages of growth, according to cervical vertebral maturation method (CVM2 and CVM3) [Baccetti et al., 2005], and comparing them to untreated subjects matched for skeletal morphology characteristics', age and sex.

The null hypothesis was that Invisalign® with Mandibular Advancement feature is not effective in Class II malocclusion therapy in growing patients.

Materials and methods

This prospective clinical pilot study was conducted according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for prospective case-control studies (Fig. 1). This study was performed in accordance with the Declaration of Helsinki; the protocol was approved by the Ethical Committee of Città della Salute e della Scienza in Turin (Italy) (Prot. #0019079); a signed informed consent was obtained from the patients' parents, before collecting the data, and researchers provided to protect the privacy.

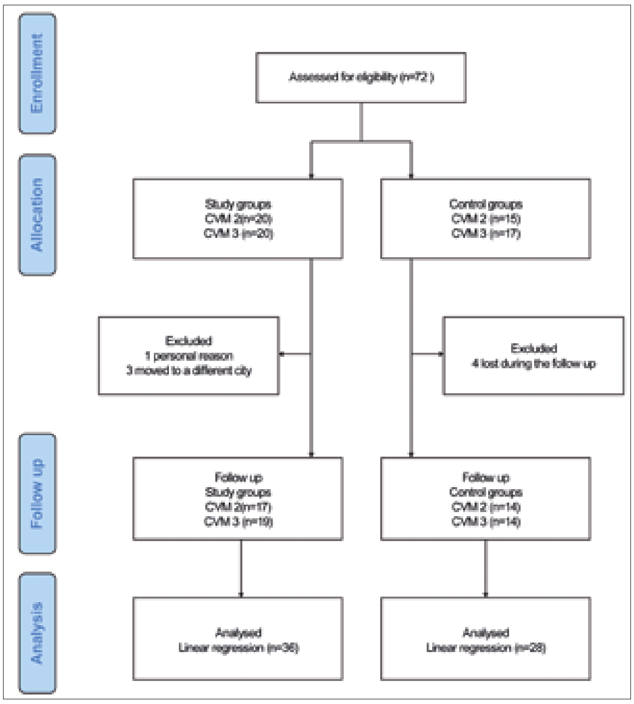

FIG. 1 STROBE Flowchart.

Sample selection

In this prospective controlled study, a total of 72 Caucasian growing Steiner Class II subjects were recruited. Patients were treated by 2 orthodontists expert in the field (TC and FG) in their private practices. The recruiting period lasted from July 2015 to december 2018, patients' age ranged from 8 to 15 yo and the average treatment duration was 18 months.

Each study group (CVM2 and CVM3) included 20 skeletal Class II growing patients each at T0. During the study, 1 patient dropped out for personal reasons, 3 patients dropped out because the family had to move to a different town.

The control groups (untreated subjects) included 15 patients (CVM2) and 17 patients (CVM3) at T0. Three subjects dropped out for lack of compliance in showing at follow-up visits. The control groups were composed of those patients whose parents decided to delay the beginning of the treatment for personal reasons. Untreated subjects were then kept in a monitoring stage before the beginning of therapy at the end of the observational study. According to the Guidelines of the Dental School – University of Turin (Italy), Radiology and Orthodontics Division, all X-rays at different stages of growth were taken 18 months after the first X-ray, for the monitoring phase.

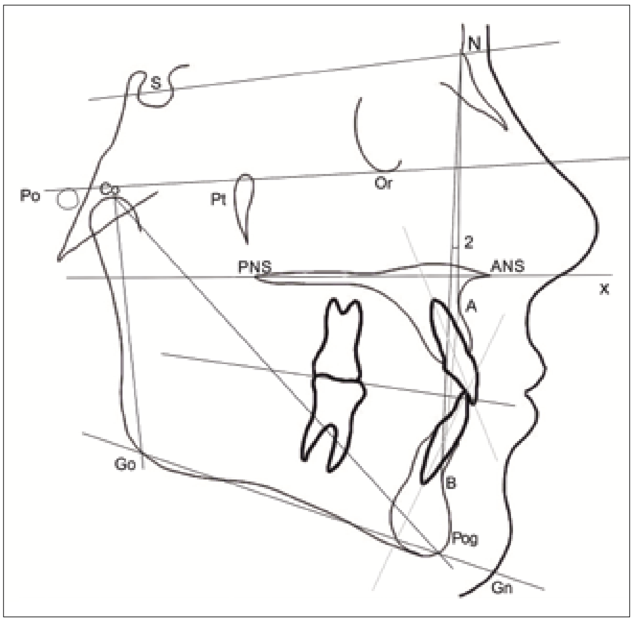

FIG. 2 Cephalometric analysis; skeletal angular variables: SN^GoGn (°), SpP^GoGn (°), SNA (°), SNB(°), ANB (°); skeletal linear variables: A-Pog (mm), Wits (mm), Go-Gn (mm), Co-Go (mm), Co-Gn (mm); dental angular variables: X11-SpP (°) as the angle between the 1.1 long axis and the Bispinal Plane SpP, X41-GoGn (°) as the angle between the 4.1 long axis and the Mandibular Plane GoGn, X11-X41 (°) as the angle defined by intersection of 1.1 and 4.1 long axes.

Cephalometric analysis

For each patient included in the study, lateral radiographs were collected both at the beginning (T0) and at the end of the mandibular advancement treatment (T1). Different X-ray devices for cephalometric radiographs were used, and for this reason, lateral cephalograms for each patient at T0 and T1 were standardised to life size using an X-ray ruler. The digital X-rays were stored in a computer, imported into a commercial software (Dolphin Imaging & Management Solutions, Version 11.95, at Patterson Technology, Chatsworth, CA, USA), in order to perform landmark identifications and cephalometric tracings. Cephalometric tracings of both study group and control group were randomly assigned (www.random.org) to 2 investigators (SR, FG), blinded about the study, and then perfomed using a customised digitisation set including landmarks and variables chosen from different cephalometric analyses [Downs, 1956; Angle, 1907; Franchi et al., 2000; Jacobson, 1975] (Fig. 2).

Inclusion and exclusion criteria

The inclusion criteria were: (1) skeletal Class II with mandibular retrusion according to Steiner (3°< ANB < 8°), Downs and Wits; (2) normal divergence (SN^GoGn < 37°); (3) moderate crowding in the upper arch (≤4 mm); (4) excellent radiographic record quality, with adequate cephalometric point display and head rotation control; (5) standardised treatment protocol.

The exclusion criteria were: Patients with severe transverse dental or skeletal discrepancies; Severe vertical dental or skeletal discrepancies; Extraction treatments; Patients with temporomandibular disorders (TMDs); Patients with craniofacial deformities.

On the lateral headfilms, the palatal plane/mandibular plane (SpP/GoGn) and the SN/mandibular plane angles were evaluated as indicators of skeletal posterior vertical dimension changes [McNamara Jr, 1984]. The overall craniofacial treatment changes were evaluated by superimposing on the stable structures of the anterior cranial base according to the structural method [Bjork and Skieller, 1983].

All the cephalograms were blindly traced by 2 investigators (SR, FG), then traced again after 3 months. If there was a discrepancy between the 2 cephalograms, a new tracing was obtained by mutual agreement with a third investigator (SR, FG, TC).

Statistical analysis

The sample size was computed considering $\alpha = 0.05$,

Group	Mean age at T0 (years, months)	Mean age at T1 (years, months)	Mean treatment duration (months)
CVM2 study group	9.2 ± 1.4	10.9 ± 1.8	18
CVM3 study group	12.10 ± 1.4	14.2 ± 1.0	17
			Mean follow up duration (months)
CVM2 control group	9.7 ± 0.10	11.2 ± 0.10	18
CVM3 control group	11.8 ± 0.11	13.6 ± 1.6	18

TABLE 1 Mean age of groups.

Variable	CVM2				CVM3			
	study group	control group	study group	control group	study group	control group	study group	control group
	T0		T1		T0		T1	
	Mean + SD	Mean + SD	Mean + SD	Mean + SD	Mean + SD	Mean + SD	Mean + SD	Mean + SD
SN_GoGn (°)	37.06 ± 5.32	31.68 ± 5.49	37.56 ± 5.92	32.83 ± 5.38	32.57 ± 5.70	32.53 ± 4.55	32.48 ± 6.33	30.81 ± 6.20
SpP_GoGn (°)	28.37 ± 4.83	24.92 ± 4.91	28.68 ± 5.48	26.32 ± 5.72	24.17 ± 5.71	26.6 ± 4.55	23.91 ± 5.28	24.26 ± 5.18
SNA (°)	80.44 ± 3.687	82.23 ± 3.48	79.38 ± 3.69	82.03 ± 4.08	81.84 ± 4.64	82.62 ± 3.75	81.34 ± 4.10	82.27 ± 3.37
SNB (°)	74.45 ± 3.10	77.00 ± 3.20	74.78 ± 3.06	76.99 ± 3.59	76.73 ± 4.25	77.53 ± 2.83	77.01 ± 4.08	77.11 ± 3.53
ANB (°)	5.99 ± 2.06	5.24 ± 1.93	4.53 ± 2.443	5.08 ± 2.32	5.12 ± 2.36	5.10 ± 2.19	4.28 ± 2.17	5.17 ± 1.79
A_Downs (mm)	1.66 ± 3.77	3.35 ± 1.97	0.52 ± 4.37	3.28 ± 1.79	0.25 ± 3.30	3.50 ± 1.57	1.20 ± 2.41	3.23 ± 1.51
Pog (mm)	-6.93 ± 5.24	-4.84 ± 2.46	-6.64 ± 5.57	-5.11 ± 2.86	-7.17 ± 5.29	-4.99 ± 2.70	-4.44 ± 8.26	-5.04 ± 2.48
B_Downs (mm)	-10.07 ± 4.15	-5.30 ± 1.57	-8.29 ± 5.43	-5.76 ± 1.87	-8.26 ± 4.43	-5.65 ± 1.87	-7.92 ± 5.59	-6.00 ± 1.79
A_Pog (mm)	8.59 ± 4.04	7.71 ± 4.46	6.06 ± 6.36	8.38 ± 4.59	7.41 ± 5.02	8.48 ± 4.23	5.64 ± 7.54	8.26 ± 3.92
Wits (mm)	3.62 ± 2.26	0.80 ± 3.70	1.62 ± 2.86	1.38 ± 3.62	3.29 ± 2.67	0.52 ± 4.19	1.83 ± 2.65	2.51 ± 3.32
X11_SpP (°)	114.27 ± 8.335	110.52 ± 4.94	107.93 ± 4.43	110.23 4.68	111.35 ± 8.88	109.80 ± 4.45	111.55 ± 4.41	106.07 ± 2.89
X41_GoGn (°)	93.89 7.80	96.64 9.06	94.13 7.09	97.30 ± 7.41	100.73 ± 5.60	97.23 ± 7.03	99.05 ± 6.13	98.34 ± 6.69
X11_X41 (°)	125.59 ± 9.05	126.5 ± 11.17	131.52 ± 6.88	126.1 ± 9.22	125.98 ± 12.29	126.07 ± 8.92	128.18 ± 7.87	124.74 ± 8.72
Go_Co (mm)	52.28 ± 11.62	52.12 ± 4.78	54.97 ± 12.37	55.96 ± 5.17	51.16 ± 5.38	56.13 ± 4.66	56.54 ± 11.04	56.32 ± 4.85
Gn_Co (mm)	111.22 ± 23.83	106.8 ± 6.40	117.15 ± 25.00	111.0 ± 6.80	107.93 ± 8.89	113.24 ± 6.18	117.39 ± 11.11	113.07 ± 6.04
Gn_Go (mm)	64.63 ± 14.39	68.46 ± 5.49	66.79 ± 15.54	71.12 ± 4.88	66.36 ± 6.19	71.36 ± 4.94	69.99 ± 9.85	73.02 ± 7.44

For dental variables there is a number indicating the FDA code for the considered tooth;
The X stands for tooth axis (X11; X41)
SN is for Sella Nasion Plane; SpP is for Palatal Plane; GoGn is for Mandibular Plane

TABLE 2 Mean Values and SD for all the variables at T0 and T1 for the groups.

CVM2					CVM3			
Variable	Estimate	Std. Error	95%CI	P value	Estimate	Std. Error	95%CI	P value
SN_GoGn (°)	-0,65	1,17	-2.94 | 1.65	0,585	1,41	1,24	-1.01 | 3.84	0,263
SpP_GoGn (°)	-1,08	1,09	-3.22 I 1.06	0,329	2,40	0,88	0.68 I 4.13	0.01065*
SNA (°)	-0,91	1,16	-3.18 I 1.35	0,435	0,30	1,15	-1.97 I 2.56	0,800
SNB (°)	0,35	0,91	-1.43 I 2.17	0,703	1,11	0,94	-0.73 I 2.95	0,247
ANB (°)	-1,30	0,50	-2.29 I -0.32	0.0138*	-0,91	0,69	-2.26 I 0.44	0,195
A_Downs (mm)	-1,06	0,67	-2.38 I 0.26	0,123	1,01	0,88	-0.71 I 2.72	0,260
Po (mm)	0,57	0,98	-1.34 I 2.48	0,563	3,12	1,71	-0.22 I 6.46	0,077
B_Downs (mm)	2,23	0,60	1.06 I 3.41	0.00067*	1,16	0,87	-0.54 I 2.85	0,193
A_Po (mm)	-3,20	1,31	-5.76 I -0.64	0.0195*	-2,12	1,22	-4.50 I 0.27	0,093
Wits (mm)	-2,59	0,87	-4.30 I -0.87	0.00542*	-3,65	1,29	-6.18 I -1.12	0.00845*
X11_SpP (°)	-6,05	1,53	-9.05 I -3.06	0.00034*	5,95	7,13	-8.02 I 19.92	0,410
X41_GoGn (°)	-0,41	1,30	-2.95 I 2.14	0,757	-2,97	1,50	-5.91 I 0.03	0,057
X11_X41 (°)	6,31	2,11	2.18 I 10.44	0.00491*	1,26	2,45	-3.52 I 6.07	0,606
Go_Co (mm)	-1,15	1,28	-3.65 I 1.36	0,376	3,82	2,49	-1.07 I 8.70	0,136
Gn_Co (mm)	1,69	1,63	-1.50 I 4.89	0,306	8,75	3,93	1.04 I 16.46	0.034*
Gn_Go (mm)	-0,51	1,18	-2.82 I 1.80	0,668	1,97	2,60	-3.12 I 7.06	0,455

δ *(Tn – T0) means between group (control was used as reference) stratifying by CVM levels were considered. *, P-value <0.05*

TABLE 3 Linear regression analyses.

power=0.80, an effect size >= 1.10| (mean differences between group during follow-up) and a standard deviation of 1.00. Hence, a sample size of 28 (14 cases and 14 controls) subjects was determined to be adequate with T statistic and non-centrality parameter [Wang, 2017].

Normality assumption of the data was evaluated with the Shapiro-Wilk test; Linear regression analysis was performed to estimate the differences of δ (Tn – T0) means between group (control was used as reference) stratifying by CVM levels. Values were showed as Mean ± SD. The level of significance was set at $p < 0.05$.

Pearson's correlation was implemented simultaneously considering predictors matrix.

Statistical analyses were conducted using the R statistical package (version 3.5.3, R Core Team, Foundation for Statistical Computing, Wien, Austria).

Results

The average age of subjects in the CVM2 group at T0 was 9y2m while at T1 was 10y9m with an average treatment duration of 18 months (Table 1). The average age of subjects in the CVM3 group at T0 was 12y10m years, while at T1 was 14y2m years with an average treatment duration of 17 months (Table 1). Both samples composed of CVM2 and CVM3 patients were compared with the respective control groups (Table 2) and Table 3 shows the differences between T0 and T1 measurements of the study and control groups.

MA T0/T1 at CVM2

Analysing the patients in CVM2 stage of growth at T1, the following variables variation were significant with respect to T0 (Table 3): ANB reduction (-1.30 °, P=0.014); B Downs point advancement (+ 2.23 mm, P=0.0007); A:Po reduction (-3.20 mm, P=0.019); Wits index decrease (-2.59 mm, P=0.005); reduction of the inclination of the upper incisor with respect to the bispinal plane (-6.05°, P=0.0003); increasing of the interincisal angle 11^41 value (+6.31°, P=0.005).

In Figure 3 the intra-group variables correlations are described. 11^SpP angle decrease is associated with the reduction of the interincisor angle 11^41, as well as the the point B of Downs advancement is closely related to ANB, A:Po and Wits reduction.

MA T0/T1 at CVM3

In the CVM3 stage of growth the only significant data in common with the CVM2 patients' group at T1 (Table 3), is the reduction of the Wits index (-3.65 mm, P=0.008). Other significant results are the SpP^GoGn angle increasing (+2.40°, P=0.01), the linear measurement increasing of the total mandibular length CoGn (+8.75 mm, P=0.03). The inclination of the lower incisors on the mandibular plane shows a P-value very close to the limit of statistical significance (P=0.059) and patients treated with Invisalign® MA showed a reduction of this angular measurement of -2.97° when compared to control cases. From the plot analysis reported in Figure 4, the reduction of ANB, of Wits index and of A:Po measurements are correlated to point B of Downs and Po advancement. The latter two points are closely correlated with the linear growth of the mandible and the consequent increase in CoGn, CoGo and GoGn measurements.

Discussion

In this study, the short-term dental and skeletal effects resulting from the use of the Invisalign® MA appliance in patients with skeletal Class II malocclusion with mandibular retrusion, at different stages of growth, compared with untreated subjects, were evalueted on cephalometric tracings. When applied during the pubertal growth spurt, the appliance promotes a significant additional growth of the mandible.

The improvements due to an orthodontic treatment based on mandibular advancement, are still a controversial topic; many studies describe the positive effects of this procedure [Cozza et al., 2006; Perinetti et al., 2015], while others report no significant dentoskeletal effects [Koretsi et al., 2015].

In this study, at CVM2 growth phase, the use of the Invisalign® MA appliance showed mainly dentoalveolar effects. There was a significant reduction in the interincisal angle (11^41), due to retroclination of the upper incisors with respect to the palatal plane. The reduction of proinclination of the upper incisors and overjet is beneficial to reduce the incidence of incisor trauma and bullying among children [Batista et al., 2018], preserving a healthy psychological development. These factors should be considered when assessing interceptive therapy in the pre-pubertal growth phase.

Important skeletal results emerge in patients treated with Invisalign® MA during the CVM3 stage of growth. The Wits index was reduced of about 3.65 mm with respect to the untreated control group. Using the efficiency measurment described by Cozza et al. [2006], our study demonstrated a coefficient of 0.48 mm per month for the Invisalign MA appliance. The annualised rate of change previously described for a sample of consecutive patients treated with the Twin Block appliance was 5.6 mm per year [Mills and McCulloch, 2000]. In the current study the annualized rate of change was 5.8 mm per year, thus very close to the Twin Block skeletal effects. Step-by-step mandibular advancement has been demonstrated to be more effective than single jump forward repositioning of the mandible [Wang et al., 2018; Patil et al., 2012; Aras et al., 2017]. A minimal thereshold of strain must be exceeded to promote an ideal response [Rabie and Al-Kalaly, 2008; Rabie et al., 2003]. In order to reduce patient discomfort, the initial advancement with the appliance used in the current study was set at 2 mm, with subsequent adavancements of 2 mm every 2 months to repeatedly maximise the number of replicating cells in the condyle and glenoid fossa [Aras et al., 2017]. Appliance comfort is a crucial issue when considering patient compliance with removable appliances [El-Huni et al., 2019]. An increase of the intermaxillary angle was observed in the anlysed sample. The presence of the lateral wings guiding the forward posturing of the mandible discloses the arches. The upper arch expansion guided by the aligners, in order to create room for the forwarded position of the mandible, can promote posterior teeth buccal tipping as resulted by previous studies [Zhou and Guo, 2020; Deregibus et al., 2020; Quinzi et al., 2020]. Relative extrusion of the lingual cusps can explain the final increase of the intermaxillary angle despite the occlusal coverage provided by the aligners.

Several criticisms raised from the orthodontic community regarding the retroclination of upper incisors and the proclination of lower incisors in Class II treatment with functional appliances [Mills, 1983; Janson et al., 1983; Van Der Plas et al., 2017; Joss-Vassalli et al., 2010; Ravera et al., 2020]. Our results indicate an average decrease of incisor proclination of almost 3°: the advantage of using active clear aligners is represented by the possibility of controlling orthodontic tooth movement while the MA feature is moving the mandible forward.

A factor that should be considered when planning Class II treatment with removable functional appliances is represented by patient compliance. In this study patient compliance was set at 20-22 hours per day: however, the advantages of clear aligners in terms of comfort and aesthetics supported the excellent participation of each patient during the entire study [Al-Moghrabi et al., 2017].

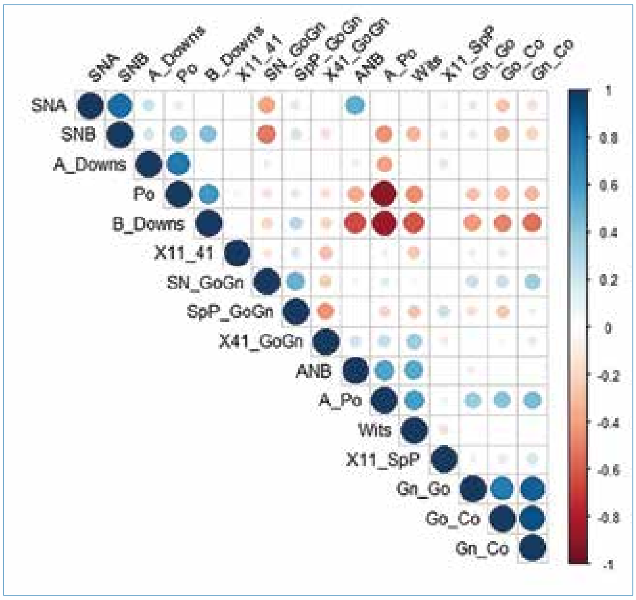

FIG. 3 Variables correlation in CVM2 sample

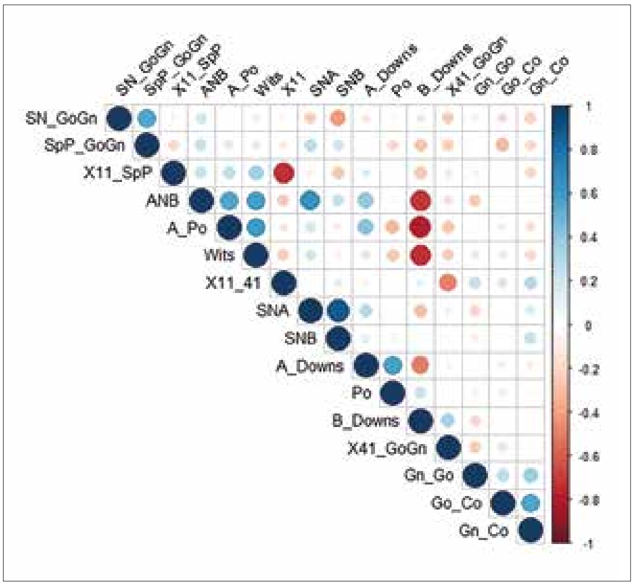

FIG. 4 Variables correlation in CVM3 sample

The CVM method used in this study to identify the growth stages could be questionable, accordingly to several reviews [Zhao et al., 2012; Santiago et al., 2012]. As stated by McNamara and Franchi [2018], the CVM method is not a perfect rating system. The method is ordinal in nature while the nature of the growth process is continuous. Therefore, accordingly to Contardo and Perinetti [2017], while no growth indicator may be considered to have a full diagnostic reliability in the identification of the pubertal growth spurt, their use may still be recommended for increasing efficiency of functional treatment for skeletal Class II malocclusion.

A limitation of this study is the lack of a long-term follow-up in order to evaluate the stability of the correction. Future studies investigating this issue are necessary.

Conclusion

When used in the pre-pubertal stage of growth, Invisalign® aligners, with Mandibular Advancement feature, have mainly dentoalveolar effects in the short-term period.

When used in the pubertal growth phase, the short-term effects of Mandibular Advancement feature are dento-skeletal. Although considering removable appliances, it is possible to observe an additional growth of the mandible, with an annual rate of change comparable to what has been previously described for the Twin Block appliance

The use of clear Invisalign® aligners with Mandibular Advancement feature is effective in skeletal Class II growing patients, with different outcomes according to the growth stages.

Authors' contributions

S.R. has made substantial contributions to conception and design of the study, acquisition and interpretation of data, has been involved in drafting the manuscript and revising it critically for important intellectual content.

T.C. has made substantial contributions to conception and design of the study, collection and interpretation of data, has been involved in drafting the manuscript and revising it critically for important intellectual content., has given final approval of the version to be published.

Fa.G. has made contributions to acquisition of data, has been involved in drafting the manuscript.

G.C. carried out the statistical analysis and interpretation of data.

Fr.G. has made contributions to collection of data.

A.D has been involved in revising the manuscript critically for important intellectual content.

V.Q. has been involved in drafting the manuscript and revising it critically for important intellectual content, has given final approval of the version to be published.

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