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RESEARCH

Noninvasive conservative management of anterior open bite treated with TADs versus clear aligner therapy

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Abstract

Objectives Anterior open bite can be treated non-surgically via molar intrusion using temporary skeletal devices (TAD). Clear aligner therapy (CAT) is recognized as a viable therapeutic modality for non-extraction treatment of adults with mild open bite. This study aimed to compare the treatment effect and mechanisms of open bite closure between patients treated with braces and TADs double arch intrusion and those treated with CAT. Treatment success at T3 was based on 1- positive overbite on ceph; 2- Change in the vertical dimension 3- post treatment POSI score equal to zero.
Material and Methods The TAD group includes 18 consecutively treated patients from the main author. The CAT group consisted of 16 selected patients from three different orthodontists. The observation time points were as follows: pretreatment (T1), end of molar intrusion and positive overbite achieved (T2), end of treatment (T3), at least 6-month follow-up (T4). Treatment changes were assessed by cephalometric analysis and frontal intraoral photo.
Results At the end of treatment, 100% of the patient of the TAD group and 78,6% of the CAT group had a posi score of 0. The TAD group showed a significant reduction in vertical measurements (SN-MPA: -1,55° $\pm$ 0.41, LAFH: -3,05 $\pm$ 0.51 mm, U6-PP: -1.48 $\pm$ 0.30 mm), but the CAT group did not have significant changes for these variables. Both groups had significant increases in overbite from T1 to T3 (TAD: 4,32 $\pm$ 0,5 mm; CAT: 2,33 $\pm$ 0.56 mm), and overbite remained stable at T4. The CAT group did not have a significant upper molar intrusion, but a significant extrusion of 1.22 $\pm$ 0.42 mm of the lower incisor occurred.
Conclusion The TAD group achieved bite closure by upper molar intrusion, lower molar and incisors vertical control, and mandibular plane counterclockwise rotation, resulting in an improved AP and vertical relationship.
The CAT group achieved bite closure through the lower incisor extrusion without significant change in the vertical dimension.
Clinical relevance This study provides relevant information about the skeletal and dental changes of open bite treatment with TADs double arch intrusion. The comparison with a control group treated with CAT confirms known information.

Keywords Open bite · TADs · Double arch intrusion · Clear aligner · Retention

Introduction

Anterior open bite (AOB) is the lack of vertical overlap of the anterior teeth in maximum intercuspation [1]. Two thirds of the patients with excessive anterior face height have an AOB [2] which is often combined with other problems, such as lack of chin prominence, and functional difficulty in speech, swallowing, incising food, and lip incompetence. The long face patient has rotation of the palatal plane down posteriorly, excessive eruption of maxillary posterior teeth, clockwise rotation of the mandible and compensatory eruption of the incisors [3]. Patients may be aware of their dental malocclusion but unaware of other dentoskeletal or functional characteristics [4]. Ascertaining the most important aspects leading a patient to seek treatment is crucial.

Treating and retaining AOB is challenging due to its multifactorial problem list [5].

Five treatment modalities can be identified [6].

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1- Clear Aligners Therapy only (CAT)
2- CAT with TADs
3- Fixed appliances only
4- TADs with fixed appliances
5- Orthognathic surgery

Nowadays, patients seek less invasive treatment modalities than surgery. Conventional fixed appliances or multiloop edgewise arch wire (MEAW) are successful but mainly extrude the anterior teeth which do little to improve facial esthetics as the vertical dimension remain unchanged [7].

CAT is recognized as a viable therapeutic modality for non-extraction treatment of adults with mild open bite. Bite closure is mainly achieved by a combination of the maxillary and mandibular incisor extrusion and some maxillary and mandibular molar intrusion and slight mandibular autorotation [8–10]. Garnett et al [11] showed that change in mandibular plane angle and the magnitude of overbite correction with the use of CAT compared to fixed appliances did not demonstrate a statistically significant difference in adult hyperdivergent patient. A recent study [12] comparing CAT versus mini-plate supported posterior intrusion (MSPI) found that both appliances were effective to improve overbite. MSPI achieve the correction via molar intrusion and counterclockwise (ccw) mandibular autorotation whereas CAT achieve bite closure anterior extrusion.

Molar intrusion with miniscrew or mini-plate anchorage can be a reasonable alternative to resolve an open bite malocclusion with vertical maxillary excess [13–18]. Chang et al [19] showed that post treatment stability of AOB was similar for surgical and non-surgical (TADs) methods. Kim et al [20] showed that for 1 mm of intrusion of the maxillary molar, it increases overbite by 2.6 mm, decrease anterior facial height by 1.7 mm, the mandibular plane by 2° and pogonion move forward by 2.3 mm. Scheffler et al [15] showed that vertical control of the mandibular molars so they do not erupt while intruding maxillary teeth is important in a decrease in face height. Paik and Kim [21] showed that double arch intrusion is the treatment of choice when the aim is to change the facial appearance by closing the mandibular plane angle, favour chin point advancement and reduce lower anterior facial height. When doing maxillary molar intrusion, it is important to control the vertical position of the maxillary incisor because any anterior extrusion will limit the mandibular rotation [21, 22].

The aim of the study is to evaluate the mechanisms and effects of these mechanical treatments comparing two groups of patients.

The primary objective of this study is to compare the treatment effect of TADs double arch intrusion with CAT. Success of treatment was based on the following outcome measure: 1- positive overbite on the post-treatment ceph; 2- Change in the vertical dimension; 3- post treatment POSI score equal to zero. Since a positive cephalometric overbite may lack clinically vertical overlap of all anterior, intraoral frontal photographs were used to verify the quality of the overbite.

The secondary objective is to assess which protocol has a higher success rate in achieving positive overbite and which treatment has greater stability at > 6-month follow-up. Stability of the treatment was assessed by intraoral photographs using the same criteria as T2 and the stability of the change of the vertical dimension.

H1: TADs and CAT allow change in the vertical dimension, ccw rotation of the mandibular plane.
H2: TADs and CAT are successful to close AOB.

Material and Methods

The sample population in this retrospective study consisted of patients who received one of the two methods of orthodontic treatment to address their anterior open bite: 1-comprehensive fixed appliances with skeletal anchorage (TAD group) or 2- clear aligner therapy (CAT group).

The inclusion criteria include:

1- Pretreatment open bite defined as no vertical overlap between maxillary and mandibular incisors. The POSI score should be ≥ 1.
2- Presence of pre- and post-treatment cephalogram and intraoral photograph.
3- Treatment was performed using exclusively one of the two described methods.
4- Treatment can include extraction of premolars to resolved crowding or dentoalveolar protrusion.
5- The anteroposterior dental correction did not exceed a half unit in any direction.

The exclusion criteria were patients lacking pre and post-treatment records.

The severity of the overbite was assessed by the Positive Open Bite Severity Index (POSI) score [1, 6, 23] that range from 1 to 6 (Fig. 1). A minimal score of 1 was necessary to meet the inclusion criteria [6]. The posi score was assessed by 2 examiners. Because some category had 0 patients, the posi score were grouped in 4 categories (0, 1–2, 3–4, 5–6).

The observation time points were as follows: pretreatment (T1), end of molar intrusion and positive overbite achieved (T2), end of treatment (T3), at least 6-month follow-up (T4). In the CAT group, only 6 patients had photographic progress records and 3 had cephalometric records.

A similar study [12] estimated the sample size based on ANS-Me changes due to treatment. They found that 34 patients were required to detect a clinically meaningful

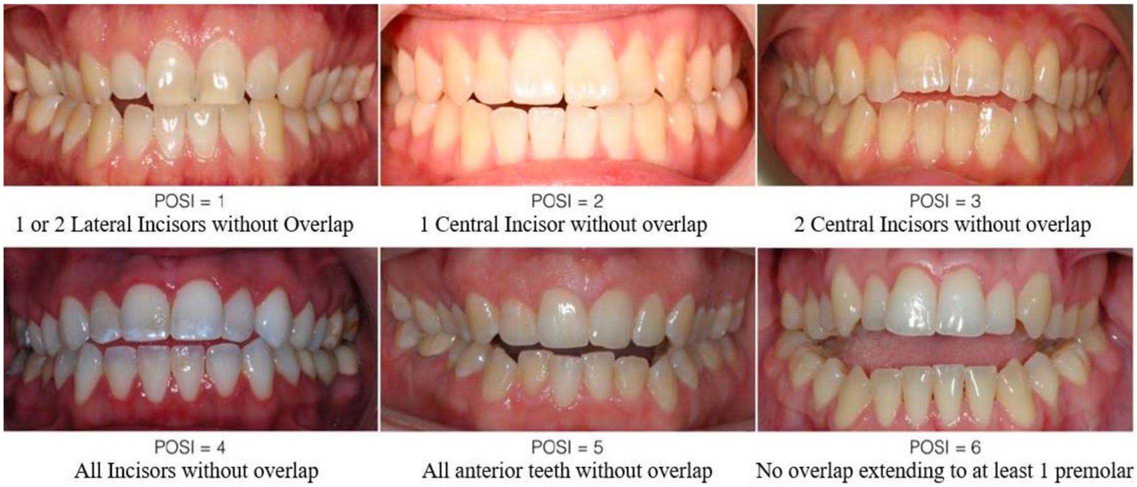

Fig. 1 Photographic Openbite Severity Index (POSI). Gu et al., Angle Ortho 2022 [6]. Reprinted with permission

difference of 3.4 ± 1.5 mm of ANS-Me changes were required to detect such difference with 95% of power and at 5% significance level. ANS-Me in their study is the same as LAFH in our study.

We did not calculate the sample size because we were limited by the number of patients available in the TAD group. Therefore, we tried to obtain a similar number of patients in the CAT group. The TAD group consisted of 19 consecutively treated patients from the senior author from 2010 to 2020, 18 of them met the inclusion criteria. Among those 18 patients, 5 of them had a functional genioplasty to reduce excessive lower anterior facial height and obtain lip competency in repose. The genioplasty was performed after a positive overbite was achieved and after space closure for patients who had extractions. This means that the genioplasty was performed less than 6 months before debonding. The genioplasty was considered in the statistical analysis as it affects the vertical measurement like the mandibular plane angle, the lower anterior facial height, and the lower anterior dental height. The CAT group consisted of 29 selected patients from three different orthodontists, 16 patients met the inclusion criteria and received their treatment from 2012 to 2020. Participating practitioners shared de-identified treatment records. This means that the total sample of the TAD-CAT study contains 34 patients and 4 observation time points. Peres et al [24] and Steele et al [12] has 2 observation time points.

The lateral cephs were traced by the main author with QuickCeph Studio (QuickCeph System®, California). A standard millimetric ruler in the lateral cephalogram was used to calibrate measurements. An x–y cranial base coordinate system was constructed through sella with the x-axis drawn 7° to the sella-nasion line and the y-axis passing through sella, perpendicular to the x-axis (Fig. 2). Table 1 shows landmarks and variable definition.

For the TAD group, Tomas® pins EP (Dentaurum Inc®, Germany) 8 mm was inserted palatally between upper 1st and 2nd molar at 8–10 mm apical to the contact point. To achieve parallel intrusion of the posterior teeth a Tomas pin 6 mm was inserted buccally between the root of the 1st and 2nd premolars. Some cases necessitate anterior intrusion to reduce gingival display on smiling or to counteract relative extrusion. A Tomas pin EP 6 mm was inserted

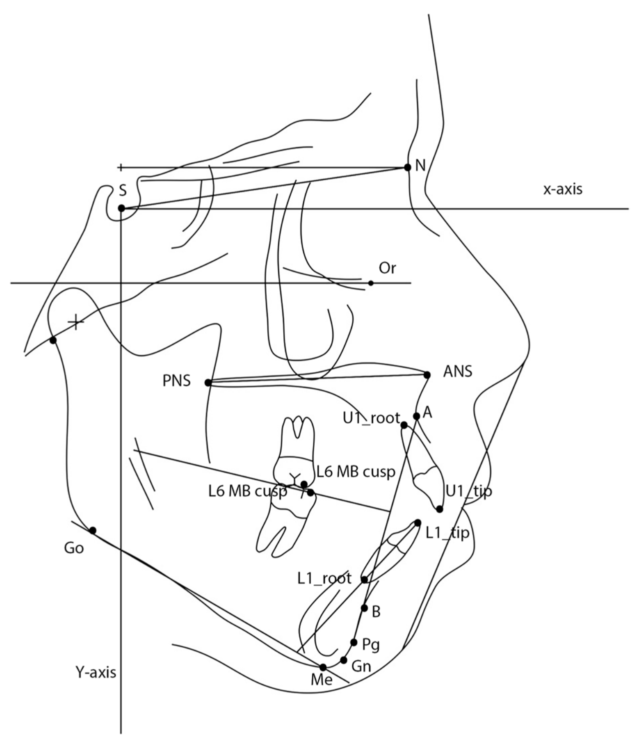

Fig. 2 Cephalometric landmarks

Table 1 Variable definition

Landmark	Definition	Variable	Definition
SN-MPA	Angle between SN plane and mandibular plane	Op-SN-7	Angle between the mandibular occlusal plane and a constructed plane Sella-Nasion minus 7°
LAFH	Distance between ANS and Me	U1-NA°	Angle between the long axis of the upper incisor (U1 tip-U1 root) and Nasion-A point plane
U1-NA°	Angle between the long axis of the upper incisor (U1 tip-U1 root) and Nasion-A point plane	U1-SN°	Angle between the long axis of the upper incisor (U1 tip-U1 root) and Sella-nasion plane
U1 tip-PP	Upper incisor height. Perpendicular distance between upper incisor tip and palatal plane (ANS-PNS)	U6-PP	Perpendicular distance between the mesiobuccal cusp tip of the 1st uppe molar and palatal plane (ANS-PNS)
L1 tip (ADH_Md_Mp)	Anterior dental height. Perpendicular distance from the tip of the lower incisor to the mandibular plane	L6-MP	Lower molar height. Perpendicular distance between the mesiobuccal cusp of the 1st lower molar and the mandibular plane
IMPA	Angle between the long axis of the lower incisor and the mandibular plane	OJ	Overjet
Md1-NB°	Angle between the long axis of the lower incisor and Nasion-B point plane	OB	Overbite

between the roots of the central and lateral incisors. The elastomeric module E-Links® (TP Orthodontics Inc®, LaPorte In) were used to deliver about 100 g of force per side for the posterior teeth and 50 g of force per side for the anterior teeth. In the mandible, Tomas® pin EP 8 mm was inserted buccally between the 1st and 2nd molars. A three-unit elastomeric chain was attached (mesial 1st molar-TAD-distal 2nd molar) to create the intrusive force. In some case, a Tomas pins SD 8 mm was placed between the 2nd premolar and the 1st molar was used. An intrusive force of 100 g per side was delivered by a custom-made 17 × 25 TMA (Ormco Corporation®, Orange Ca) cantilever spring of wire engaged in the cross head of the Tomas® pin. A 0.032X.032 beta-titanium TPA and lingual arch were tied to the upper and lower 1st molar respectively. The TPA incorporated 2–3 mm of expansion and the lower lingual arch 2–3 mm of constriction to counteract the expansion or constriction generated by buccal or lingual intrusive force in each arch (Fig. 3). Detailed mechanotherapy is described elsewhere [22, 25]. Intrusive forces were stopped once a positive overbite anteriorly and a posterior open bite between the molars were achieved.

The CAT group received a series of aligners (Invisalign system, Align Technology®, Santa Clara, CA, USA). Four patients had to change their aligners every two weeks because it was the requirement when they received their treatment. The other twelve patients changed their aligners weekly.

Attachments and IPR were tailored to each patient's needs, based on each of the three practitioner's clinical experience. Therefore, attachment location and IPR on teeth cannot be reported systematically. Moreover, attachment varies between series of aligners. Hence, we cannot draw up a precise guideline applicable to all cases of alignment.

Fig. 3 TAD placement

Statistical Analysis

Descriptive statistics are mean with standard deviation or frequency with percentages for continuous and categorical variables respectively. Characteristics at baseline were compared between groups with Student's t test or exact chi-square test accordingly. Inter evaluator reliability was verified with weighted kappa statistics. Intra evaluator reliability of cephalometric measures was assessed with intraclass correlation coefficients. Inter evaluator reliability for the posi score was assessed by a weighed kappa statistic. Associations between outcomes changes between visits 1 and 3 were illustrated with a heatmap of Pearson's correlation coefficients. Outcomes' differences between groups and over time were evaluated with two-way repeated measures ANOVA, estimated with linear mixed models. Multiple comparisons were adjusted with Bonferroni method.

Statistical analyses were done in SAS version 9.4 (SAS Institute®, NC).

Table 2 Demographic characteristics

	TAD group (1) N = 18*	CAT group (1) N = 16*	p-value (2)
Age (Mean, S-D)	20.3 ± 4.4	22.0 ± 8.7	0.4677
Tx Duration (weeks, S-D)	120.7 ± 30.7	102.8 ± 20.2	0.0888
Follow up (weeks, S-D)	69.51 ± 39.69	75.64 ± 44.62	0.7178
Extractions	7 (38.89%)	1 (6.25%)	0.0425
Genioplasty	5 (27.78%)	0 (0.0%)	0.0465
Aligners	N/A	63.6 ± 16.6	NC
Series of Aligner	N/A	2.6 ± 0.7	NC
Gender			
Female	13 (72.2%)	8 (50%)	0.2906
Growers	2 (11.1%)	3 (18.8%)	NC
Practitioner			
Practitioner A	18	0	
Practitioner B	0	8	
Practitioner C	0	4	
Practitioner D	0	4	

(1) Values are mean ± standard deviation or N (%)

(2) P value from Student's t test or exact chi-square test

* In presence of missing data, total N is presented in the 1st column.

NC: Not calculated. N/A: Not applicable

Results

Age and gender repartition, treatment duration and follow-ups were similar between the 2 groups (Table 2). There was a difference between the group for extraction and genioplasty. The CAT group received 63.6 ± 16.6 aligners in 2.6 ± 0.7 series (Table 3).

Posi score

Table 3 shows the POSI score of the TAD and CAT group at 4 different time points. The number of patients at the baseline with a posi score of 5–6 is significantly higher in the TAD group (83.3%) than the CAT group (37.5%), (p = 0.0122). At the end of treatment (T3), 100% of the patient of the TAD group and 78,6% of the CAT group had a posi score of 0. The outcome at the follow-up (T4) shows that 75% of the patient of the TAD group and 50% of the patient of the CAT group maintained a posi score of 0. The difference between TAD and CAT is nonsignificant at T3 (p = 0.0734) or at T4 (p = 0.2341).

The TAD group had a significantly greater mandibular plane angle, open bite, overjet, occlusal plane angulation (defined as plane tangent to the 1st lower molar and the tip of the lower incisor), smaller SNA, SNB, and upper incisor inclination than the CAT group at baseline (Tabls 4 and 5) indicating that the TAD group had a more severe discrepancy than the CAT group. There was no significant difference for the dentoalveolar vertical measurement at baseline.

Table 3 Posi score of the TAD and CAT groups at 4 different time points

POSI score	TAD				CAT			
	Patients N (%)				Patients N (%)			
	T1	T2	T3)	T4	T1	T2	T3	T4
0	0	18 (100%)	18 (100%)[a]	12 (75%)[a]	0	5 (83.3%)	11 (78.6%)[a]	5 (50%)[a]
1–2	2 (11.1%)[a]	0	0	3 (18.8%)	7 (43.75%)[a]	1 (16.7%)	3 (21.4%)	4 (40%)
3–4	1 (5.6%)[a]	0	0	0	3 (18.75%)[a]	0	0	1 (10%)
5–6	15 (83.3%)[a]	0	0	1 (6.3%)	6 (37.5%)[b]	0	0	0
	18	18	18	16	16	6	14	10

Comparison between groups (exact chi-square test). Different letters (e.g., a vs b) are significantly different at 5% significance level.

Table 4 Global tests from repeated measure ANOVA, with comparison between groups at each time point

	Global tests p values			p values for difference between groups per time point			
	Group	Time point	Group*Time point	T 1	T 2	T 3	T 4
SN-MPA (including patients with genio)	0.0424	0.0103	0.0370	0.0032	0.0918	0.1694	0.1061
SN-MPA (excluding patients with genio)	0.0804	**0.0162**	0.0788	0.0258	0.1534	0.0954	0.1317
LAFH (including patients with genio)	0.7247	0.0017	**< 0.0001**	0.2109	0.5839	0.2946	0.3548
LAFH (excluding patients with genio)	0.8648	0.0060	**< 0.0001**	0.2943	0.5037	0.5865	0.6568
U6-PP (mm)	0.3468	0.2008	**0.0004**	0.2767	0.0379	0.2196	0.2650
U1 crown tip PP(mm)	0.0676	0.1106	0.5952	0.0335	0.0896	0.0785	0.2279
OB (mm)	**0.0363**	**< 0.0001**	0.0949	0.0064	0.1985	0.9863	0.7420
ADH_Md1_MP (including patients with genio)	0.0133	0.3752	**0.0082**	0.3470	0.0467	0.0032	0.0066
ADH_Md1_MP (excluding patients with genio)	0.0213	0.0667	**0.0138**	0.2552	0.0039	0.0284	0.0179
L6-MPGoGn(mm)	0.1699	0.5895	0.4736	0.3999	0.1478	0.2292	0.1046
SNB	**0.0002**	0.0604	0.0775	< 0.0001	0.0007	0.0003	0.0009
Op-SN-7	**0.0021**	**0.0002**	0.2480	0.0107	0.0006	0.0058	0.0097
OJ (mm)	0.0003	0.2025	**< 0.0001**	< 0.0001	0.8540	0.0668	0.0118
SNA	**0.0113**	0.3581	0.1480	0.0264	0.0153	0.0056	0.0127
U1-SN°	**0.0054**	0.0950	0.6204	0.0412	0.0089	0.0232	0.0402
U1-NA°	0.1190	0.1142	0.6733	0.4129	0.0767	0.2821	0.3038
IMPA	**0.0033**	0.0840	0.2573	0.3028	0.0280	0.0239	0.0047
Md1-NB°	**0.0356**	**0.0080**	0.2748	0.5529	0.0598	0.1718	0.0180

The pairwise comparison at T2, T3, T4 show no significant difference between the two groups for SN-MPA, LAFH, overbite, lower molar and upper incisor height (Table 4).

Method error

The posi score was evaluated independently by the two authors. The weighted kappa of 0.8971 shows an excellent inter-examiner reliability. The cephalogram of 6 patients were re-digitized by the main author. The intra evaluator reliability shows a score varying from 0.85 to 0.99 for the 15 variables used in the study.

Table 4 shows the interaction between groups and time point. If the interaction is significant, at a specific time point, it means that the 2 groups change differently at that time point. If there is no significant interaction at a time point, then we look at the global test. If there is a group effect only, this means that the groups were different and stay different for each time point observation. This is observed for the variable SNA, SNB, U1-SN° (TAD group always lower) and IMPA (TAD group always higher). If there is a time point effect only, this means that the 2 groups changed in the same manner. This is observed for the variable SN-MPA (excluding genio patients).

Change between time points

Tables 5 and 6, Figs. 4 and 5 shows the cephalometric measurement and mean changes at each time point per groups.

Table 5. Mean cephalometric measurements, per group and time points, from repeated measures ANOVA.

The result of the TAD group of patients who received a genioplasty is presented separately for the variable SN-MPA, LAFH, ADH-Md1-MP because a genioplasty changes the reference point for these measurements (Tables 5 and 6).

The TAD group at T2, excluding patients who had a genioplasty, shows a significant decrease of 1.98° ± 0.49° of SN-MPA. 3.5 ± 0.53 mm of LAFH and a significant intrusion of 1.87 ± 0.39 mm of the maxillary molars (Fig. 4A, B, C). The overbite shows a significant increase of 4.5 ± 0.42 mm (Table 6 and Fig. 4). At T3, SN-MPA decrease of 1.55° ± 0.41°, LAFH decrease of 3.05 ± 0.51 mm and the upper molar intrusion was 1.48 ± 0.3 mm. The overbite change at T3 is significant at 4.32 ± 0.5 mm (Fig. 5D). SNB shows a significant increase of 0.99° ± 0.25° (Fig. 5A).

The overjet in the TAD group has a significant decrease of 2.32 ± 0.38 mm. The occlusal plane angle decreases 1.59° ± 0.55° ($p = 0.0427$).

L6-MP shows a mild although nonsignificant intrusion of 0.71 ± 0.54 mm at T3 (Table 6 and Fig. 5C).

The lower incisors whose reference plane is influenced by the genioplasty show a vertical stability when the genioplasty is excluded and a reduction when the patient with a genioplasty is included.

At T2 and T3, the CAT group doesn't show significant vertical change for SN-MPA, LAFH, the upper and lower molar and the upper incisor height and no significant change

Table 5 Mean cephalometric measurements, per group and time points, from repeated measures ANOVA

	TAD					CAT				
	T 1 (N = 18)	T 2 (N = 18)	T 3 (N = 18)	T 4 (N = 16)	Time point p-value	T 1 (N = 16)	T 2 (N = 3)	T 3 (N = 10)	T 4 (N = 6)	Time point p-value
SN-MPA (including patients with genio)	44.14 ± 1.22^{a}	41.83 ± 1.33^{b}	41.12 ± 1.30^{b}	41.48 ± 1.31^{b}	< 0.0001					
SN-MPA (excluding patient with genio)	43.23 ± 1.50^{a}	41.25 ± 1.46^{b}	41.73 ± 1.50^{b}	42.15 ± 1.64^{ab}	0.0040	38.47 ± 1.35^{a}	38.24 ± 1.45^{a}	38.22 ± 1.38^{a}	38.67 ± 1.53^{a}	0.8736
LAFH (including patients with genio)	81.55 ± 1.46^{a}	77.89 ± 1.50^{b}	77.24 ± 1.45^{b}	77.71 ± 1.50^{b}	< 0.0001					
LAFH (excluding patients with genio)	81.31 ± 1.72^{a}	77.80 ± 1.74^{b}	78.25 ± 1.70^{b}	78.50 ± 1.84b	< 0.0001	78.83 ± 1.55^{a}	79.48 ± 1.77^{a}	79.53 ± 1.58^{a}	79.62 ± 1.70^{a}	0.3473
U6-PP (mm)	26.66 ± 0.63^{a}	24.79 ± 0.53^{b}	25.18 ± 0.55^{bc}	25.60 ± 0.58^{c}	< 0.0001	25.64 ± 0.67^{a}	26.82 ± 0.78^{a}	26.21 ± 0.61^{a}	26.63 ± 0.70^{a}	0.1757
U1 crown tip PP (mm)	34.67 ± 0.74^{a}	34.65 ± 0.68^{a}	34.98 ± 0.76^{a}	34.90 ± 0.78^{a}	0.5934	32.28 ± 0.78^{a}	32.65 ± 0.92^{a}	32.92 ± 0.84^{a}	33.41 ± 0.93^{a}	0.1315
OB (mm)	-2.86 ± 0.47^{a}	1.64 ± 0.36^{b}	1.46 ± 0.20^{b}	1.10 ± 0.27^{b}	< 0.0001	-0.87 ± 0.50^{a}	2.70 ± 0.72^{b}	1.47 ± 0.27^{b}	1.28 ± 0.45^{b}	0.0001
ADH_Md1_MP (including patients with genio)	44.84 ± 0.87^{a}	44.42 ± 1.12^{ab}	42.93 ± 0.94^{b}	42.81 ± 0.99^{b}	0.0314					
ADH_Md1_MP (excluding patients with genio)	44.50 ± 0.99^{a}	44.14 ± 1.04^{a}	44.13 ± 0.99^{a}	43.94 ± 1.02^{a}	0.5823	46.05 ± 0.89^{a}	48.96 ± 1.12^{b}	47.27 ± 0.92^{b}	47.49 ± 0.97^{ab}	0.0036
L6-MPGoGn(mm)	35.12 ± 0.93^{a}	34.64 ± 0.88^{a}	34.41 ± 0.83^{a}	34.16 ± 0.82^{a}	0.1280	36.27 ± 0.98^{a}	36.67 ± 1.05^{a}	35.93 ± 0.93^{a}	36.26 ± 0.96^{a}	0.8177
SNB	72.04 ± 0.93^{a}	73.02 ± 0.98^{b}	73.03 ± 0.95^{b}	72.64 ± 1.04^{ab}	0.0016	78.64 ± 0.98^{a}	78.72 ± 1.15^{a}	78.63 ± 1.02^{a}	78.26 ± 1.14^{a}	0.7825
Op-SN-7	15.96 ± 1.10^{a}	14.79 ± 1.05^{ab}	14.36 ± 1.11^{b}	14.27 ± 1.08^{b}	0.0138	11.59 ± 1.17^{a}	7.88 ± 1.50^{b}	9.46 ± 1.23^{b}	9.71 ± 1.25^{ab}	0.0024
OJ (mm)	5.71 ± 0.42^{a}	3.13 ± 0.30^{b}	3.39 ± 0.22^{b}	3.66 ± 0.25^{b}	< 0.0001	1.56 ± 0.45^{a}	3.26 ± 0.66^{a}	2.73 ± 0.27^{a}	2.50 ± 0.36^{a}	0.0492
SNA	78.31 ± 0.94^{a}	77.71 ± 0.97^{a}	77.88 ± 0.91^{a}	77.73 ± 0.94^{a}	0.0515	81.50 ± 1.00^{a}	81.57 ± 1.15^{a}	81.86 ± 0.98^{a}	81.41 ± 1.03^{a}	0.5820
U1-SN°	99.59 ± 1.66^{a}	94.42 ± 1.66^{a}	96.56 ± 1.97^{a}	95.65 ± 1.83^{a}	0.0133	104.74 ± 1.76^{a}	103.95 ± 2.99^{a}	103.70 ± 2.26^{a}	101.88 ± 2.27^{a}	0.5099
U1-NA°	21.29 ± 1.62^{a}	16.84 ± 1.53^{a}	18.67 ± 1.74^{a}	17.76 ± 1.56^{a}	0.0145	23.25 ± 1.72^{a}	22.85 ± 2.90^{a}	21.55 ± 1.98^{a}	20.36 ± 1.93^{a}	0.4710
IMPA	94.96 ± 1.52^{a}	93.08 ± 1.45^{a}	93.90 ± 1.51^{a}	95.42 ± 1.52^{a}	0.1782	92.64 ± 1.61^{a}	85.35 ± 3.03^{a}	88.28 ± 1.83^{a}	87.49 ± 2.12^{a}	0.0581
Md1-NB°	31.13 ± 1.65^{a}	28.16 ± 1.37^{a}	28.06 ± 1.30^{a}	29.36 ± 1.32^{a}	0.0463	29.69 ± 1.75^{a}	22.03 ± 2.82^{ab}	25.24 ± 1.54^{ab}	23.89 ± 1.75^{b}	0.0172

Values are means ± standard error

Separately for each group, time point with means with different letters (e.g., a vs b), are significantly different at 5% significance level with Bonferroni adjustment, whereas means with the same superscript letter are not significantly different at the 5% level (e.g., a vs a).

Table 6 Changes between time points for TAD and CAT group

	ΔT2T1	Adjusted p	ΔT3T1	Adjusted p	ΔT4T1	Adjusted p	ΔT2T3	Adjusted p	ΔT3T4	Adjusted p	ΔT2T4	Adjusted p
TAD												
SN-MPA	-2.31 ± 0.47	0.0002	-3.02 ± 0.68	0.0006	-2.66 ± 0.62	0.0001	-0.70 ± 0.67	1	0.36 ± 0.27	1	-0.35 ± 0.66	0.6028
LAFH	-3.66 ± 0.44	< 0.0001	-4.31 ± 0.66	< 0.0001	-3.84 ± 0.56	< 0.0001	-0.65 ± 0.56	1	0.47 ± 0.32	0.8747	-0.18 ± 0.60	0.7681
SNB	0.97 ± 0.26	0.0053	0.988 ± 0.25	0.0024	0.59 ± 0.29	0.2724	0.016 ± 0.19	1	-0.39 ± 0.18	0.2115	-0.37 ± 0.27	1
U6-PP (mm)	-1.87 ± 0.39	0.0002	-1.48 ± 0.30	0.0001	-1.06 ± 0.35	0.0320	0.39 ± 0.19	0.2769	0.42 ± 0.22	0.3948	0.81 ± 0.24	0.0101
U1 tip-PP(mm)	-0.01 ± 0.31	1	0.31 ± 0.29	1	0.23 ± 0.36	1	0.32 ± 0.27	1	-0.08 ± 0.34	1	0.24 ± 0.39	1
L6-MP(mm)	-0.48 ± 0.28	0.5579	-0.71 ± 0.54	1	-0.96 ± 0.50	0.3957	-0.23 ± 0.41	1	-0.25 ± 0.22	1	-0.48 ± 0.41	1
OB (mm)	4.5 ± 0.42	< 0.0001	4.32 ± 0.50	< 0.0001	3.96 ± 0.52	< 0.0001	-0.18 ± 0.44	1	-0.36 ± 0.24	0.89	-0.53 ± 0.36	0.8547
SNA	0.60 ± 0.27	0.194	0.43 ± 0.21	0.30	0.58 ± 0.20	0.45	-0.17 ± 0.20	1	0.15 ± 0.18	1	-0.02 ± 0.22	1
U1-SN°	5.18 ± 1.98	0.08	3.04 ± 1.68	0.48	3.95 ± 1.59	0.11	-2.14 ± 0.95	0.19	0.91 ± 0.63	1	-1.23 ± 1.15	1
U1-NA°	4.45 ± 1.83	0.13	2.62 ± 1.66	0.74	3.53 ± 1.62	0.22	-1.82 ± 0.85	0.38	0.90 ± 0.50	0.49	-0.92 ± 1.09	1
U1tip-PP	0.01 ± 0.31	1	-0.31 ± 0.29	1	-0.23 ± 0.36	1	-0.32 ± 0.27	1	0.08 ± 0.34	1	-0.24 ± 0.39	1
OJ	2.58 ± 0.48	< 0.0001	2.32 ± 0.38	< 0.0001	2.05 ± 0.35	< 0.0001	-0.26 ± 0.29	1	-0.27 ± 0.18	0.92	-0.53 ± 0.29	0.49
Md1-NB°	2.98 ± 1.69	0.53	3.07 ± 1.51	0.30	1.77 ± 1.53	1	0.09 ± 1.00	1	-1.30 ± 0.53	0.12	-1.20 ± 1.20	1
IMPA	1.88 ± 1.79	1	1.05 ± 1.76	1	-0.46 ± 1.72	1	-0.82 ± 1.26	1	-1.52 ± 0.74	0.29	-2.34 ± 1.37	0.59
Op_SN-7	1.17 ± 0.59	0.35	1.59 ± 0.55	0.04	1.69 ± 0.49	0.01	0.43 ± 0.37	1	0.09 ± 0.34	1	0.52 ± 0.45	1
ADH-Md1_MP	-0.42 ± 0.56	1	-1.91 ± 0.67	0.0466	-2.03 ± 0.64	0.0216	-1.49 ± 0.75	0.3356	-0.12 ± 0.22	1	-1.61 ± 0.73	0.0354
Excluding genioplasty patients												
SN-MPA	-1.98 ± 0.39	0.0002	-1.55 ± 0.41	0.0065	-1.08 ± 0.43	0.1019	0.48 ± 0.29	0.6701	0.42 ± 0.36	1	0.89 ± 0.44	0.0495
LAFH	-3.5 ± 0.53	< 0.0001	-3.05 ± 0.51	< 0.0001	-2.81 ± 0.39	< 0.0001	0.45 ± 0.23	0.3617	0.24 ± 0.43	1	0.70 ± 0.43	0.7071
ADH-Md1_MP	-0.36 ± 0.55	1	-0.37 ± 0.42	1	0.56 ± 0.47	1	-0.01 ± 0.29	1	-0.19 ± 0.17	1	0.19 ± 0.29	0.5151
CAT												
SN-MPA	0.23 ± 0.71	1	-0.25 ± 0.45	1	0.20 ± 0.55	1	-0.01 ± 0.82	1	0.45 ± 0.66	1	0.43 ± 0.66	1
LAFH	0.65 ± 0.95	1	0.70 ± 0.59	1	0.79 ± 0.51	0.7969	0.05 ± 1.08	1	0.09 ± 0.73	1	0.14 ± 0.89	1
SNB	0.078 ± 0.58	1	-0.018 ± 0.31	1	-0.39 ± 0.41	1	-0.09 ± 0.63	1	-0.37 ± 0.45	1	-0.47 ± 0.61	1
U6-PP (mm)	1.18 ± 0.67	0.5429	0.56 ± 0.37	0.8276	0.98 ± 0.51	0.3803	-0.61 ± 0.69	1	0.42 ± 0.54	1	-0.19 ± 0.57	1
U1 tip-PP(mm)	0.37 ± 0.67	1	0.63 ± 0.38	0.6375	1.12 ± 0.58	0.3703	0.27 ± 0.76	1	0.49 ± 0.67	1	0.76 ± 0.80	1
L6-MP(mm)	0.40 ± 0.57	1	-0.34 ± 0.64	1	-0.01 ± 0.67	1	-0.74 ± 0.78	1	0.33 ± 0.67	1	-0.41 ± 0.74	1
OB (mm)	3.56 ± 0.76	0.0003	2.33 ± 0.56	0.0014	2.14 ± 0.65	0.0024	-1.23 ± 0.76	0.7058	-0.19 ± 0.4993	1	-1.42 ± 0.76	0.0712
SNA	-0.06 ± 0.57	1	-0.36 ± 0.27	1	0.09 ± 0.32	1	-0.29 ± 0.62	1	0.45 ± 0.39	1	0.16 ± 0.55	1
U1-SN°	0.79 ± 3.20	1	1.03 ± 1.98	1	2.86 ± 2.06	1	0.24 ± 3.19	1	1.83 ± 1.99	1	2.07 ± 2.68	1
U1-NA°	0.40 ± 3.09	1	1.69 ± 1.90	1	2.89 ± 1.98	0.93	1.29 ± 3.03	1	1.19 ± 1.63	1	2.49 ± 2.73	1
U1 tip-PP	-0.37 ± 0.67	1	-0.64 ± 0.38	0.64	-1.12 ± 0.58	0.37	-0.27 ± 0.76	1	-0.45 ± 0.67	1	-0.76 ± 0.80	1
OJ	-1.70 ± 0.77	0.21	-1.17 ± 0.43	0.06	-0.94 ± 0.44	0.24	0.53 ± 0.69	1	0.23 ± 0.39	1	0.76 ± 0.67	1
Md1-NB°	7.66 ± 3.01	0.09	4.45 ± 1.74	0.09	5.80 ± 1.94	0.03	-3.221 ± 2.97	1	1.35 ± 1.66	1	-1.86 ± 2.84	1
IMPA	7.29 ± 3.23	0.19	4.36 ± 2.07	0.26	5.15 ± 2.29	0.19	-2.93 ± 3.34	1	0.79 ± 2.20	1	-2.14 ± 3.14	1

Table 6 (continued)

	ΔT2T1	Adjusted p	ΔT3T1	Adjusted p	ΔT4T1	Adjusted p	ΔT2T3	Adjusted p	ΔT3T4	Adjusted p	ΔT2T4	Adjusted p
Op_SN-7	3.71 ± 1.18	0.02	2.13 ± 0.70	0.03	1.87 ± 0.72	0.08	-1.58 ± 1.30	1	-0.25 ± 0.86	1	-1.83 ± 1.12	0.66
ADH-Md1_MP	**2.91 ± 0.78**	**0.0057**	**1.22 ± 0.42**	**0.0445**	1.44 ± 0.52	0.0604	-1.68 ± 0.77	0.2231	0.22 ± 0.48	1	-1.46 ± 0.63	0.1666

Values are means ± standard error.

for angular measurement SNB, SNA, U1-SN°, U1-NA° (Tables 5 and 6, Figs. 4 and 5). The overbite shows a significant increase of 2.33 ± 0.56 mm while the change in overjet is nonsignificant. The occlusal plane angle decreases 2.13° ± 0.7° (p = 0.0275). The lower incisors show a mild but significant extrusion of 1.22 ± 0.42 mm at T3.

At T3 and T4, the upper incisors for the TAD group are more upright than the CAT group, whereas the lower incisors of the CAT group are more retroclined than the TAD group and the difference is significant.

Stability

In the TAD group, the upper molars show a slight nonsignificant relapse of 0.39 ± 0.18 mm from the maximum intrusion point (T2) to the end of treatment. Another mild nonsignificant re-eruption of 0.42 ± 0.22 mm is measured at the follow-up.

However, if we consider from maximum intrusion point (T2) to follow up (T4), the total relapse of 0.81 ± 0.24 mm is significant (p = 0.0101).

The vertical change SN-MPA, LAFH does not show a significant relapse.

SNB show slight nonsignificant decrease of 0.39° ± 0.18° at the follow-up (Table 6 and Fig. 5A).

The CAT group did not show significant changes throughout treatment for most variables. Therefore, the relapse at follow-up doesn't show significant value.

The CAT group does not show a significant change of SNB over time (Table 6 and Fig. 5A).

Correlation between the outcome measures

Figure 6 shows the correlation between the change of the variable for both groups combined between T3T1. It shows that the mandibular plane angle change is significantly positively correlated with LAFH, U6-PP, L6-MP, anterior dental height and negatively with SNB. LAFH is positively correlated with U6-PP and ADH-Md1-MP. SNB is negatively correlated with LAFH, SN-MPA, U6-PP, L6-MP, and ADH-Md1-MP. The overbite is negatively correlated with the upper molar and the occlusal plane changes.

Discussion

Our study confirms that both treatment modalities achieved a positive overbite at T3 quantitatively and qualitatively and obtained a POSI score of 0. There was no significant difference between the TAD group and the CAT group. The null hypothesis 2 is accepted.

TADs double arch intrusion therapy is effective to reduce the vertical dimension by intrusion of the

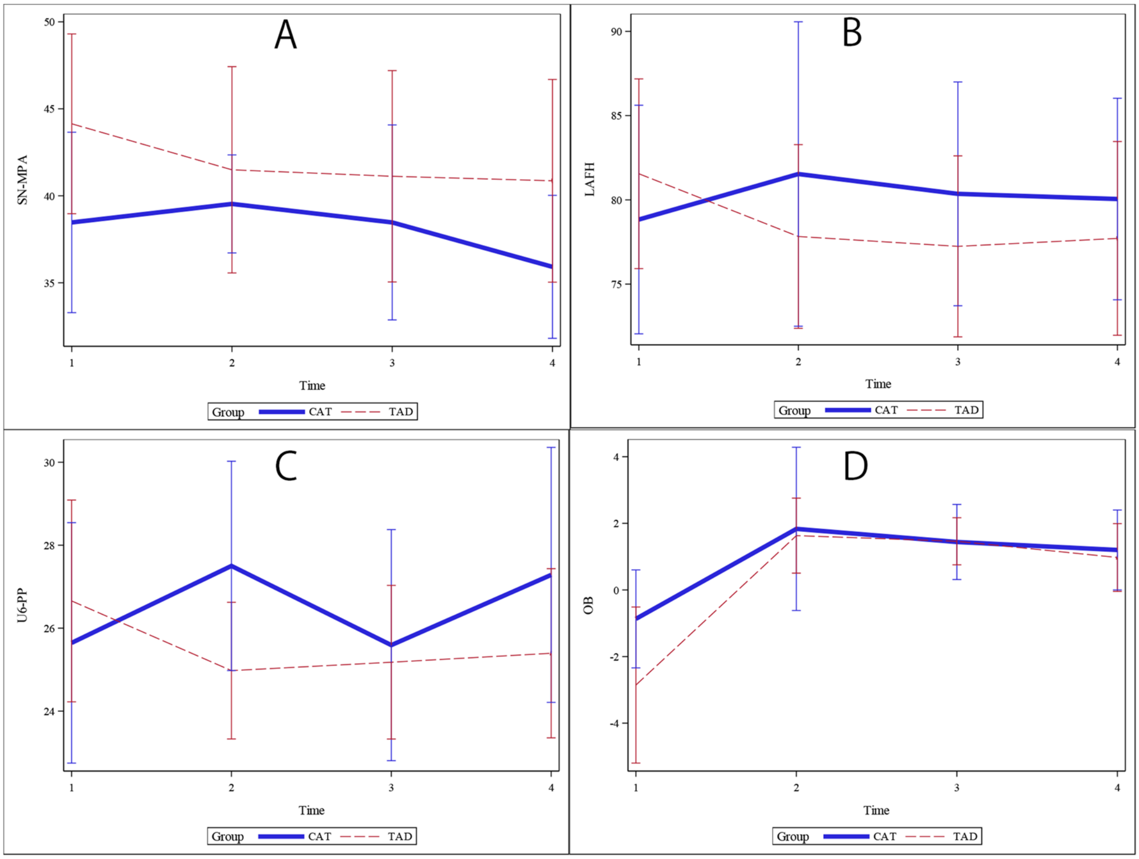

Fig. 4 Evolution of measures SN-MPA, LAFH, U6-PP, OB, over time according to the group

maxillary molars and controlling the vertical position of the lower molars and the maxillary and mandibular incisors as noted by the reduction of the mandibular plane angle and LAFH. The change in the vertical dimension of the TAD group help explain the significant change of SNB because of mandibular counterclockwise rotation.

As expected, the genioplasty has an impact in the measurement of the anterior dental height because the reference point change with the genioplasty.

The CAT group does not show any significant intrusion of the maxillary and mandibular molars, MPA and LAFH, but a mild nonsignificant extrusion of upper incisors and a significant extrusion of lower incisors.

Therefore, the null hypothesis H1 is rejected

The heatmap helps to explain how a positive overbite can be achieved. It shows that, if the aim of the treatment is to reduce the mandibular plane, one must control the vertical position of the maxillary and mandibular molars and the lower incisors.

Our study confirms the findings of Steele et al [12], the TAD double arch intrusion achieved correction of an open bite via molar intrusion and ccw rotation of the mandibular plane whereas CAT achieved correction via incisors extrusion.

Fixed appliance tends to open the bite as some molar extrusion can occur when levelling the curve of Spee. Moreover, it is shown that lower molars can extrude while the upper molars are intruding [15, 17]. Paik and Kim [21] showed that molar intrusion may result in premature traumatic contact of the anterior teeth as the mandible rotates ccw. Therefore, if the aim of the treatment is to maximize the change in the vertical dimension and improve the chin projection, the vertical position of the upper and lower incisors must be controlled to allow maximum rotation of the mandible.

Our study found a decrease of the occlusal plane relative to SN in both groups. This can be explained by maxillary molar intrusion and vertical control of the lower molar for the TAD group and extrusion of the lower incisors in the CAT group. This finding for the TAD group is contrary to the findings of Peres et al [24] who found steepening

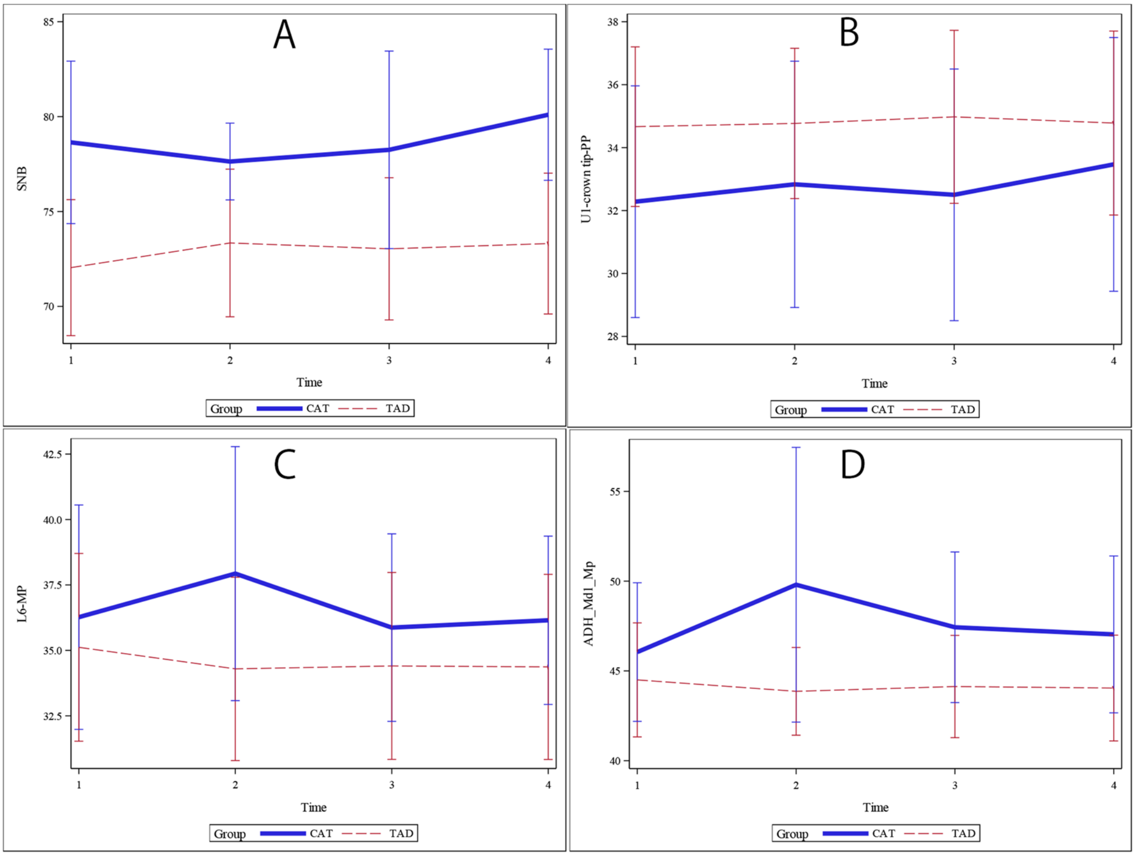

Fig. 5 Evolution of measures SNB, U1 crown tip-PP, L6-MP, lower anterior dental height (ADH-Md1_MP), over time according to the group

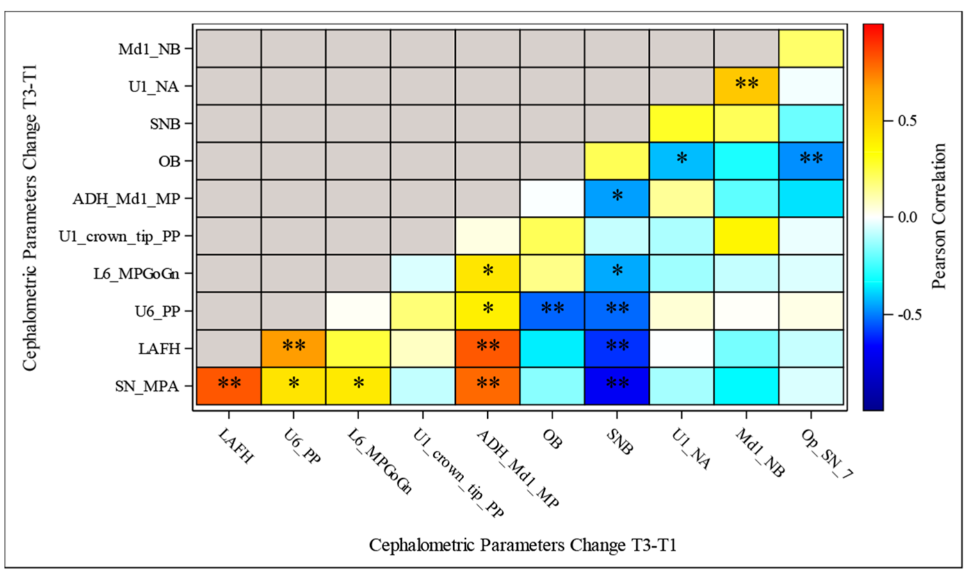

Fig. 6 Pearson's correlation heatmap. Positive correlation has yellow to red shade. Negative correlation has a green to blue shade. **$p < 0.01$, * $0.01 \le p < 0.5$

of the occlusal plane. In their study, the lower molars had a nonsignificant extrusion of 0.26 (CI95% 2.35; -1.82). In our study, the lower molars were intruded by 0.71 mm (95% CI: -5.4; 1.9). Although it does not reach the level of significance one can assume intruding, on average 0.71 mm the lower molars help explain why the mandibular occlusal plane decreased significantly in our study compared to Peres et al [24] study.

Our findings for the CAT group do not support the findings of Harris et al [8] and Moshiri et al [9] in terms of change of the mandibular plane, reduction of the anterior face height and molar intrusion or upper incisor extrusion.

Stability

The posi score at T3 and T4, although the TAD group has more patients having a posi score of zero, is not significantly different between the TAD and the CAT group. However, this data should be interpreted with caution because the numbers of patients in each group (particularly the CAT group) with a posi score greater than 1 is too small at T3 and T4 to find a significant difference. But one can see a tendency of poor stability for the CAT group.

The re-extrusion of the maxillary molars form T2 to T3 of the TAD group can be explained by the fact the molars were over intruded during the intrusion phase.

The open bite relapse tendency in the TAD group from the end of treatment (T3) to follow up (T4) is explained by further extrusion of the intruded molars and condylar remodeling in the patient having signs of arthrosis of the joint. The relapse tendency in the CAT group can be explained by intrusion of the extruded incisors.

Anterior open bite is not only accompanied by a tongue dysfunction or thumb sucking habit but often time there is condylar resorption or deformation that causes CW rotation of the mandible and bite opening. Then the tongue adapts to this acquired open bite caused by condylar resorption. One patient hat persistent thumb sucking habits at age 21…

Therefore, the TAD group has a mix of patients who had signs of condylar deformation/resorption, tongue thrusting, interdental sigmatism. The patients who had a tongue dysfunction and sigmatism were referred to a speech therapist, but only 3 patients accepted to follow a myofunctional therapy. The patient with thumb thrusting stopped his habit when fixed appliances were placed. Among those who relapse, it is not clear if the relapse can be explained by the persistence of the tongue dysfunction or further condylar remodeling. But it is clear reeruption of the intruded molars of the TAD group, from the maximum intrusion point (T2) to follow up (T4), is significant and likely played a role in the reduction of the overbite.

We could not obtain the information about tongue dysfunction from the 3 providers of patients for the CAT group. We cannot draw a conclusion on the tongue dysfunction for that group.

The strength of this study is that the TAD group was composed of all the consecutively treated patients between 2010 and 2020 by the one practitioner (the senior author). Also, we have the data at 4 different time points. Scheffler et al [15] study had 5 observation time points. Having more observation time points gives a better understanding of the evolution of the measures compared to other studies that have only 2 observation time points [8, 11, 12, 24].

The weakness of our study is the small sample size and likely a selection bias. The CAT group was "selected" patients from 3 different practices during about the same period (2012–2020). Moreover, among the 29 cases provided, only 16 (55%) met the inclusion criteria of having sufficient records. The direction of this bias is unknown and create a degree of uncertainty. The other weakness for the CAT group is the lack of complete cephalometric records for time point T2 ($n = 3$), T3 ($n = 10$), T4 ($n = 6$) and photographic records for time point T2 ($n = 6$), T3 ($n = 14$), T4 ($n = 10$).

In our study, we estimated that 1 mm of maxillary molar intrusion increases the overbite by 2.9 mm and the vertical position of both upper and lower incisors was controlled and the lower molars, although it was nonsignificant, were intruded by 0.71 mm. This likely helps to achieve greater overbite change than previous study [20, 24].

Conclusion

The aim of the treatment of open bite malocclusion should not be only obtaining a positive overbite, but also reducing the vertical dimension to improve facial balance.

The CAT group close the bite by lower incisor extrusion and has a non-significant change in the vertical dimension throughout treatment for most variables.

At the end of treatment, the TAD group showed SN-MPA decrease of $1.55° \pm 0.41°$, LAFH decrease of 3.05 ± 0.51 mm and the upper molar intrusion was 1.48 ± 0.3 mm. The overbite showed a significant increase 4.32 ± 0.5 mm.

The TAD group close the bite by upper molar intrusion and vertical control of the lower molars, upper and lower incisors and allow a significant ccw rotation of the mandibular plane and improvement of the AP relation (SNB increased).

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Authors' contribution SC contributed to conceptualization, original draft preparation, methodology, validation, resources original draft preparation, manuscripts review and editing, visualization, supervision, and project administration; NN contributed to methodology, validation, data curation manuscript reviews and editing, and visualization

All authors have read and approved the manuscript.

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Data Availability The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethical and consent to participate As the study was retrospective, the research was not reviewed by an ethic committee.

All the patients completed a written informed consent to use their data for publication.
The consent was written. See the following paragraph.

Consent for publication The patients agreed that the **data relating** to diagnosis, **treatment** may be used for educational purposes of teaching, examinations, **research**, conferences, **and scientific publication.**

Competing interest Each of the authors certifies that he has no affiliation with or involvement in any organization or entity with a financial interest.

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