Alveolar bone modeling and bone modeling/ tooth movement ratio during mandibular incisor retraction: a retrospective study

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Abstract

Background: The objective of this study was to explore the limit of orthodontic tooth movement by evaluating changes of alveolar bone during mandibular incisor retraction and comparing the bone modeling/tooth movement (B/T) ratio among patients with different vertical facial types. Methods: There were 103 patients with bimaxillary dentoalveolar protrusion evaluated with cephalograms in this study. The alveolar bone thickness (ABT) and cortical plate remodeling at cervical level (S1), middle level (S2) and apical level (S3) in Tip and Torque groups were measured, and B/T ratio in patients with different vertical facial types was calculated. Results: After excluding growth effect, buccolingual ABT at S1 and S2, as well as labial ABT at S1 in both Tip and Torque group decreased significantly. Cortical plate at three levels in Torque group remodeled to the lingual side. But in Tip group, cortical plate at S1 remodeled to the lingual side and cortical plate at S2 and S3 remodeled to the labial side. Regarding the B/T ratio, high-angle patients was smaller than average-angle and low-angle patients. Conclusions: In conclusion, resorption of alveolar bone was more than apposition during mandibular incisor retraction. The direction of alveolar cortical modeling was as same as tooth movement and the modeling amount was proportional to the distance of tooth movement. In addition, the B/T ratio was different among patients with different vertical craniofacial patterns. Close attention should be paid to high-angle patients with narrower ABT and smaller B/T ratio.
 Keywords: alveolar bone modeling, orthodontic tooth movement limit, incisor retraction, vertical facial patterns

Background

Bimaxillary dentoalveolar protrusion is one of the commonest malocclusions especially in Asian patients seeking orthodontic treatment[1, 2]. It is characterized by protrusion of maxillary and mandibular incisors with increased procumbency of the lips[3]. The treatment strategy of such condition is usually extraction of 4 first premolars with maximum or absolute anchorage to retract anterior incisors and improve facial profile[4].

However, the extent of alveolar bone modeling as response to orthodontic tooth retraction is still unclear. The classical theory is "bone traces tooth movement", which means the modeling of alveolar bone resulted from orthodontic force is to the same extent of tooth movement [5]. On the contrary, many investigators now agree with the concept that the ratio of bone modeling to tooth movement (B/T) of 1:1 does not hold true during incisor retraction, and the excessive lingual movement of maxillary and mandibular incisors should be prevented[1, 6-13]. If the alveolar bone models without balance of resorption and apposition, the area for movement will be limited[14, 15]. Moving the teeth beyond the limits of the alveolar bone carries the risk of iatrogenic sequelae, including root resorption, gingival recession, and alveolar bone loss[16, 17]. Consequently, the decision as to how much the incisors should be moved or how the bone may be affected with tooth movement is a critical consideration in treatment planning. Nevertheless, different results of alveolar bone thickness (ABT) changes during incisor retraction were reported, owing to differences of sample’s characteristics, research methodology, and orthodontic mechanics employed. Many researchers ignored the growth effect, which also affected ABT

during orthodontic treatment, especially for adolescents at their growth spurt. Moreover, whether B/T ratio will be affected by different vertical growth patterns has not been reported yet.

The objectives of this study were as follows: (1) to evaluate changes of alveolar bone during mandibular incisor retraction; (2) to compare the changes of alveolar bone between tip movement and torque movement after mandibular incisor retraction; (3) to estimate and compare the B/T ratio among patients with different vertical facial types.

Methods

This retrospective study was approved by the Biomedical Ethics Committee of West China Hospital of Stomatology and all subjects signed informed consents prior to the study. The study sample comprised 103 patients with Class I dentoalveolar protrusion (50 males and 53 females; mean age=15.30±5.31 years; treatment period=29.32±8.69 months; SNA=82.28°±3.32°; SNB=77.61°±3.35°; ANB=4.68°±1.74°; L1-MP=105.08°±3.62°). The inclusion and exclusion criteria were shown in Table 1 (Table 1). These patients were treated with extraction of 4 first premolars by straight wire orthodontic technique with sliding mechanics for anterior teeth retraction and space closure. Working wire was 0.019 x 0.025-inch stainless-steel wire with 0.022 x 0.028-inch straight-wire appliance.

According to cephalometric evaluation, these patients were divided into 2 groups, including Tip group (n=57) and Torque group (n=46). Refer to the grouping method of Vardimon, in the Tip group, the apex of the mandibular incisor moved anteriorly on the posttreatment cephalometric radiograph relative to its pretreatment position, while in the torque group, the apex of the mandibular incisor moved posteriorly posttreatment[7]. Mandibular plane angle (the angle between the anterior cranial base and the mandibular plane) was measured to divide patients into high-angle (n=33), average-angle (n=38) and low-angle (n=32) groups. The mandibular plane angle of average-angle patients was in the range of 32±5 degrees[18, 19].

Moreover, 57 Class I malocclusion patients without extraction and with little change of mandibular incisors after treatment were analyzed as a control group (25 males and 32 females; mean age=14.80±4.60 years; treatment period=24.10±8.85 months; SNA=81.30°±3.57°; SNB=77.60°±3.51°; ANB=3.64°±1.50°; L1-MP=93.7°±3.35°; △LI-MP=1.01°±2°) to eliminate the growth effect.

Lateral cephalograms of all patients were taken at the beginning of treatment (T1) and after treatment (T2) individually. And the image data were imported into the Dolphin imaging 11.0 (Dolphin Imaging company, USA）for analysis. The reference points, lines and measurement variables used in this study were modified from previous reports(Figure1, Figure 2 and Table 2)[6, 8, 10].

Independent t-test, paired t-test and one-way analysis of variance with Duncan’s multiple comparison test were performed with SPSS20.0 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilks normality test and Levene’s variance homogeneity test were applied to the data. Statistical significance was tested at α=0.05.

Results

In control group, we observed mandibular forward growth with decrease of ABT at three levels, but without significant changes of L1-MP angle (Table 3). In Tip and Torque groups, the ABT decreased significantly and the cortical plate modeled to the labial side after treatment (Table 4). Whereas results became slightly different when growth effect was excluded (Table 5, Figure 3 and Figure 4). Intergroup comparison demonstrated significantly different tooth movement and alveolar cortical bone modeling between two groups (Table 6 and Figure 5).

In addition, we confirmed that ABT of high-angle patients was the thinnest and ABT of low-angle patients was the thickest for almost all values measured at three levels (Table 7 and Figure 6). And the B/T ratios of three vertical patterns indicated less alveolar bone modeling in high-angle patients (Table 8).

Discussion

Up to now, there is no definite conclusion about the limit of tooth movement. Some hold the view that tooth movement takes place in coordination with bone resorption and apposition, that is tooth remains in the alveolar housing[20, 21]. But in fact, unlimited tooth movement is not possible during retraction of the incisors, especially the mandibular incisors restricted by the symphyseal bone. The main object of this study was to explore the limit of tooth movement.

The results of Control group confirmed the mandibular forward growth with age. As previously reported, the alveolar bone apposition took place at the labial side and the resorption took place at the lingual side. By comparison of posttreatment alveolar bone measurements with pretreatment in Tip and Torque group respectively, we found that the labial and lingual alveolar bone thickness at S1 reduced significantly. This result agreed with the results of Picanco and Sarikaya, who observed a reduction of lingual alveolar bone thickness due to lingual movement of maxillary and mandibular incisors[6, 12]. Moreover, Ahn also observed that alveolar bone area on the palatal side significantly decreased after retraction of maxillary anterior teeth[8]. But our finding for decrease of alveolar bone thickness in the direction of tooth movement was contrary to De Angelis, who claimed that alveolar bone had a bending capacity to coordinate bone apposition and resorption, thus the alveolar bone retained its structural characteristics and size as it moved[20]. Also, these results did not agree with the hypothesis of Hadelman regarding the limitation of tooth movement by alveolar cortical plates, showing that alveolar bone modeling is possible during tooth movement induced by biological forces[22, 23]. Moreover, the buccolingual ABT at three levels in both Tip and Torque groups decreased significantly due to combined results of growth effect and tooth movement. This finding was in consistence with the hypothesis of Sarikaya that suggested the apposition process in the inner cortical plate was somewhat slower than the resorption process in the outer cortical plate[6]. In other words, alveolar bone resorption was more than apposition during tooth movement.

When growth effect was excluded, changes of buccolingual ABT at S3 in Tip and Torque group, as well as labial ABT at S3 in Torque group became insignificant. We suggested the reason was whether by tipping or controlled tipping movement, the retraction force applied to the incisors was concentrated at the alveolar crest, leading to greater accumulation of pressure in the marginal region while less in the apical region[6]. In addition, labial ABT at S2 of Tip group and labial ABT at S2 and S3 of Torque group also decreased significantly, which agreed with the results of Vardimon that the labial cortical bone traced the tooth movement in a resorptive model[7]. With regard to the modeling of cortical plate, Edwards proposed the supporting alveolar bone did not model to the root's position and concluded that the apical zone is the limit for orthodontic tooth movement. On the contrary, our results demonstrated that although apical ABT did not change significantly, the alveolar cortical plate modeled to the same direction with tooth movement. Considering the results aforementioned, we suggest that not only the apical region, but the entire alveolar housing should be the therapeutic limitations for orthodontics.

Intergroup comparison indicated that lingual movement of incisors in Torque group was greater than that in Tip group. Although changes of ABT did not show any significant differences between two groups, the cortical bone modeling varied significantly. The cortical plate at S1 modeled toward lingual side in both groups, but the amount of modeling was smaller in Tip group. The cortical plate at S2 and S3 modeled toward labial side in Tip group, whereas toward lingual side in Torque group. These results indicated that the alveolar bone modeled to the same direction as tooth movement and the amount of modeling is proportional to the distance of tooth movement.

Furthermore, we confirmed the conclusion about relationship between vertical facial type and alveolar bone, which agreed with previous studies, that high-angle patients had the thinnest ABT while low-angle patients had the thickest[24-26]. It is loading exerted by muscles that altered cortical bone thickness, not only at the site of muscle insertion but also in the alveolar bone of tooth-bearing region[27, 28]. However, do patients with different vertical types have different B/T ratios? We finally found that B/T ratio of high-angle patients was less than average- and low-angle patients. Due to lower bone density, high-angle patients are more sensitive to orthodontic force and have more tooth movement, which leads to smaller B/T ratio[29, 30].

In this study, lateral cephalogram instead of cone-beam computed tomography (CBCT) was used for measurement and analysis for the following reasons. First, based on European and American clinical practice guides, CBCT has not been recommended as a standard diagnostic and treatment planning method in the field of orthodontics, because of the ethical problem of radiation exposure[31-33]. And considering samples involved in this research were adolescents, who were more susceptible to harmful effects of radiation, CBCT was not recommended for this study. Although there actually were some studies using CBCT to detect alveolar bone changes, their sample size were so small that would limit the power of statistical test and lead to false-negative conclusions[6, 8, 11-13]. In addition, CBCT also has the risk of overestimating fenestration and dehiscence because thin bone below 1mm is difficult to be detected[34, 35].

However, there are some limitations in this study. First, the control group selection was limited by ethical problems of radiation exposure for patients without requirement for orthodontic treatment. Second, the accuracy of lateral cephalograms was not good enough. Moreover, due to lack of follow-up radiographs, we cannot estimate the repair of alveolar loss during retention period. Therefore, further investigations on changes of alveolar bone during retention period are needed, and widely application of CBCT in the future, with advances of technology and economy, will surely provide more comprehensive understanding of alveolar bone modeling in orthodontic treatment.

Conclusions

1. 1.During growth process, incisors move with mandibular forward growth through apposition on labial cortical plate and resorption on the lingual side.
2. During incisor retraction, alveolar bone loss is more evident at the marginal and midroot levels than apical level. Thus, close attention should be paid to the marginal and midroot regions in case of fenestration and dehiscence.
3. The modeling direction of alveolar bone is same as tooth movement and the amount of modeling was proportional to the distance of tooth movement.
4. High-angle patients have smaller B/T ratio than average- and low-angle patients. Therefore, clinicians should avoid excessive tooth movement of high-angle patients, especially considering the narrower alveolar bone of high-angle patients.

Abbreviations

B/T ratio: bone modeling/tooth movement ratio;

ABT: alveolar bone thickness;

PTMP plane: the plane perpendicular to MP through Go point;

CBCT: cone-beam computed tomography.

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Biomedical Ethics Committee of West China Hospital of Stomatology. Informed written consent was given by all subjects prior to the study.

Consent for publication

Not applicable.

Availability of data and materials

All data generated and analyzed in this review are included within the article.

Competing interests

None to declare.

Funding

None.

Authors' contributions

JCX contributed to the design of the work; JCX and JLZ contributed to the sample selection, lateral cephalometric evaluation, data analysis and interpretation; JCX drafted the paper; YYY, LC and SC revised the paper critically; all authors approved the final version of the manuscript to be published.

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Tables

Table 1. The inclusion and exclusion criteria for samples

Inclusion criteria	Exclusion criteria
eletal and dental Class I malocclusion; ntoalveolar protrusion; mplete permanent dentition with mild anterior crowding arch length of screpancy≤3mm; ere is no history of trauma, caries, endodontic treatment or abrasion of the andibular incisor; n-steroidal anti-inflammatory drugs were not taken before or during thodontic treatment; systemic disease, no periodontal disease, no obvious root resorption, no hiscence or fenestration before treatment; e medical records, dental casts, cephalograms and orthopantomograms fore and after treatment of patients were complete.	1. patients with history of orthodontic treatment; 2. treatment data of patients was not enough;

Table 2. Definitions of measurement used in this study

Measurement	Definition
Bx/Cx/Dx	The horizontal distance from incisor, cervical and apical point to PTMP plane*
Ex/Fx/Gx/Hx/Ix/Jx	The horizontal distance from point E/F/G/H/I/J to PTMP plane
T1/T2/T3	Buccolingual alveolar bone thickness at S 1/S 2/S 3 level
La1/La2/La3	Labial alveolar bone thickness on S1/S2/S3 plane
Li1/Li2/Li3	Palatal alveolar bone thickness on S1/S2/S3 plane

*PTMP planethe plane perpendicular to MP through Go point.

Table 3. Comparison between initial (T1) and final (T2) stages in Control group

Measurement	T1		T2		P
	x	SD	x	SD	
L1-MP	93.70	3.38	94.70	3.77	0.170
Bx	62.65	4.36	64.36	4.93	0.000*
Cx	62.53	4.11	63.97	4.84	0.000*
Dx	61.16	4.01	62.29	4.84	0.010*
T1	6.19	0.85	6.05	0.63	0.181
T2	6.51	0.98	6.14	0.74	0.000*
T3	8.12	1.67	7.43	1.61	0.000*
L1	0.65	0.39	0.72	0.59	0.366
L2	1.63	0.59	1.40	0.55	0.000*
L3	4.36	1.61	3.71	1.39	0.000*
P1	0.32	0.28	0.20	0.23	0.004*
P2	0.65	0.38	0.52	0.30	0.005*
P3	3.75	1.14	3.69	1.07	0.484
Ex	59.07	3.96	60.51	4.79	0.001*
Fx	65.26	4.21	66.57	4.90	0.001*
Gx	58.13	3.91	59.62	4.75	0.000*
Hx	64.64	3.96	65.76	4.88	0.005*
Ix	57.28	3.74	58.76	4.59	0.000*
Jx	65.40	3.91	66.19	5.07	0.038*

Table 4. Comparison between initial (T1) and final (T2) stages in Tip and Torque group

Measure -ment	Tip group			Torque group		
	T1	T2	P	T1	T2	P
L1-MP	106.04±4.17	94.83±5.28	0.000*	103.89±2.39	94.46±4.37	0.000*
Bx	65.30±5.24	63.32±4.92	0.040*	66.64±5.26	61.37±5.37	0.000*
Cx	63.18±4.84	63.26±4.82	0.786	64.88±5.09	60.81±5.19	0.000*
Dx	59.53±4.59	61.82±4.90	0.000*	61.77±4.95	59.36±5.27	0.026*
T1	7.47±1.06	6.15±0.71	0.000*	6.80±1.12	5.92±0.69	0.000*
T2	7.61±1.15	6.59±1.27	0.000*	6.92±0.91	6.15±1.01	0.000*
T3	8.82±1.51	8.28±1.92	0.001*	8.43±1.38	7.67±1.75	0.024*
L1	1.10±0.65	0.70±0.30	0.000*	1.02±0.57	0.71±0.29	0.001*
L2	1.96±0.83	1.58±0.76	0.002*	1.94±0.71	1.40±0.67	0.000*
L3	4.74±1.26	4.45±1.69	0.112	4.61±1.11	4.04±1.63	0.007*
P1	0.59±0.37	0.46±0.31	0.011*	0.51±0.31	0.38±0.24	0.025*
P2	1.13±0.60	1.00±0.64	0.127	0.96±0.47	0.85±0.58	0.305
P3	4.08±1.24	3.83±1.42	0.124	3.821.16	3.63±1.71	0.322
Ex	58.371±4.49	59.33±4.59	0.002*	60.66±5.08	57.45±4.96	0.000*
Fx	65.83±4.95	65.48±4.83	0.754	67.45±4.95	63.37±5.11	0.000*
Gx	56.69±4.27	59.07±4.68	0.000*	59.04±4.81	56.94±4.82	0.000*
Hx	64.30±4.71	65.65±4.85	0.000*	65.95±4.80	63.20±5.00	0.000*
Ix	55.46±4.16	57.87±4.33	0.000*	57.60±4.57	56.27±4.70	0.000*
Jx	64.28±4.66	66.14±4.76	0.000*	66.03±4.73	63.89±4.70	0.000*

Table 5. Comparison between initial (T1) and final (T2) stages excluding growth effect

Measure -ment	Tip group			Torque group		
	T1	T2	P	T1	T2	P
L1-MP	106.04±4.17	94.83±5.28	0.000*	103.89±2.39	94.46±4.37	0.000*
Bx	67.01±5.24	63.32±4.92	0.000*	68.15±5.26	61.37±5.37	0.000*
Cx	64.58±4.84	63.26±4.82	0.000*	66.28±5.09	60.81±5.19	0.000*
Dx	60.66±4.59	61.82±4.90	0.000*	62.90±4.95	59.36±5.27	0.001*
T1	7.33±1.06	6.15±0.71	0.000*	6.66±1.12	5.92±0.69	0.006*
T2	7.24±1.15	6.59±1.27	0.000*	6.55±0.91	6.15±1.01	0.707
T3	8.13±1.51	8.28±1.92	0.376	7.74±1.38	7.67±1.75	0.000*
L1	1.17±0.65	0.70±0.30	0.000*	1.09±0.57	0.71±0.29	0.003*
L2	1.79±0.83	1.58±0.76	0.084	1.71±0.71	1.40±0.67	0.756
L3	4.11±1.26	4.45±1.69	0.078	3.98±1.11	4.04±1.63	0.943
P1	0.47±0.37	0.46±0.31	0.888	0.39±0.31	0.38±0.24	0.882
P2	1.00±0.60	1.00±0.64	0.965	0.83±0.47	0.85±0.58	0.498
P3	4.02±1.24	3.83±1.42	0.241	3.76±1.16	3.63±1.71	0.000*
Ex	59.81±4.49	59.33±4.59	0.108	62.10±5.08	57.45±4.96	0.000*
Fx	67.14±4.95	65.48±4.83	0.000*	68.76±4.95	63.37±5.11	0.000*
Gx	58.18±4.27	59.07±4.68	0.000*	60.53±4.81	56.94±4.82	0.000*
Hx	65.42±4.71	65.65±4.85	0.005*	67.07±4.80	63.20±5.00	0.000*
Ix	56.94±4.16	57.87±4.33	0.001*	59.08±4.57	56.27±4.70	0.000*
Jx	65.07±4.66	66.14±4.76	0.000*	66.82±4.73	63.89±4.70	0.000*

Table 6. Intergroup comparison of the changes after mandibular incisors retraction(T2-T1)

Measurement	Tip		Torque		P
	x	SD	x	SD	
Bx	-3.7	2.90	-6.78	2.16	0.000*
Cx	-1.32	2.35	-5.47	1.97	0.000*
Dx	1.16	1.96	-3.54	2.23	0.000*
T1	-1.18	1.01	-0.74	1.33	0.059
T2	-0.75	1.08	-0.4	0.92	0.204
T3	0.15	1.21	-0.07	1.17	0.380
L1	-0.47	0.72	-0.38	0.57	0.479
L2	-0.15	0.89	-0.31	0.67	0.292
L3	0.34	1.36	0.06	1.37	0.437
P1	-0.01	0.36	-0.01	0.36	0.966
P2	0	0.62	0.02	0.74	0.924
P3	-0.13	1.15	-0.13	1.27	0.992
Ex	-0.48	2.21	-4.65	2.24	0.000*
Fx	-1.67	2.35	-5.39	1.84	0.000*
Gx	0.89	2.29	-3.48	2.02	0.000*
Hx	0.23	2.24	-3.87	2.02	0.000*
Ix	0.93	1.95	-1.06	1.52	0.000*
Jx	1.07	0.35	-2.94	2.26	0.000*

Table 7. Comparison of alveolar bone thickness among different vertical craniofacial morphology

Measurement	High-angle		Average-angle		Low-angle		F	P
	x	SD	x	SD	x	SD		
T1	6.66	1.23	6.79	1.07	7.10	1.10	1.467	0.234
T2	6.64	1.01	7.06^{a}	1.02	7.55^{ab}	1.31	6.450	0.002*
T3	7.93	1.45	8.47a	1.43	9.24^{ab}	1.66	7.088	0.001*
L1	0.81	0.60	0.95	0.52	0.97	0.66	1.051	0.352
L2	1.59	0.58	1.86^{a}	0.72	2.16^{ab}	0.78	6.356	0.002*
L3	4.04	1.03	4.61^{a}	1.20	5.18^{ab}	1.78	7.103	0.001*
P1	0.38	0.33	0.46	0.32	0.59^{a}	0.37	3.454	0.034*
P2	0.8	0.46	0.91	0.48	1.06^{a}	0.69	2.179	0.116
P3	3.88	1.00	3.86	1.17	3.98	1.41	0.116	0.891

a: There was statistical difference with high-angle group

b: There was statistical difference with average-angle group.

Table 8. Intergroup comparison of B/T ratio among different craniofacial morphology

B/T	High-angle	Average-angle	Low-angle
Tip group	77.98%	80.30%	82.74%
Torque group	79.16%	82.74%	84.98%

Figures

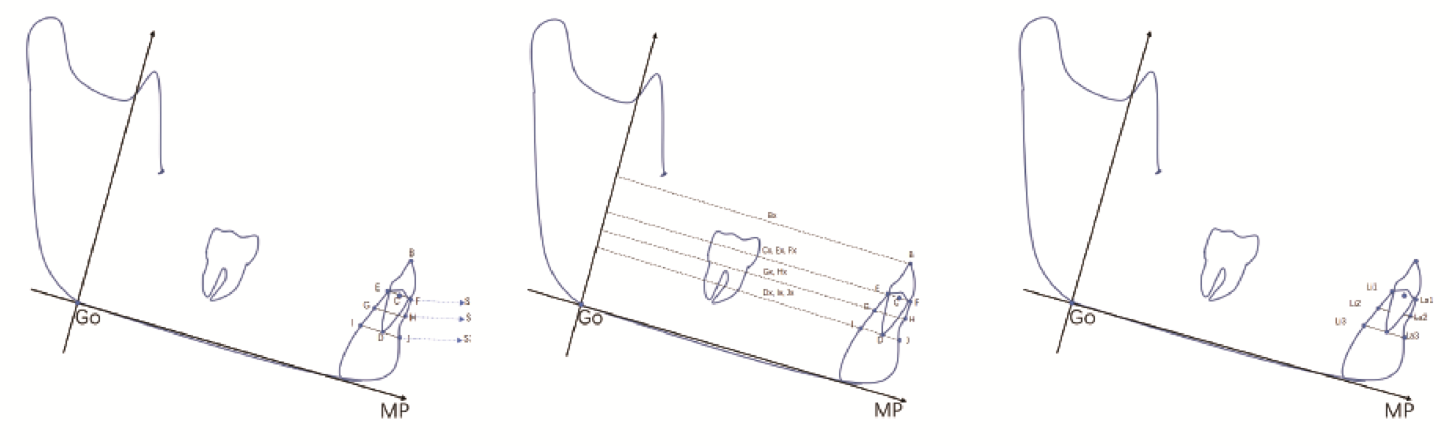

Figure 1

Landmarks and reference planes. MP: the mandibular plane; Go: the gonion point; S1/S2/S3: intersecting line parallel to MP plane at cervical, middle and apical level of root; B: incisor point; C: cervical point; D: apical point; E/F/G/H/I/J: the intersection point of S1/S2/S3 plane and alveolar cortical plate; E-F: alveolar bone thickness at S 1; G-H: alveolar bone thickness at S 2; I-J: alveolar bone thickness at S 3.

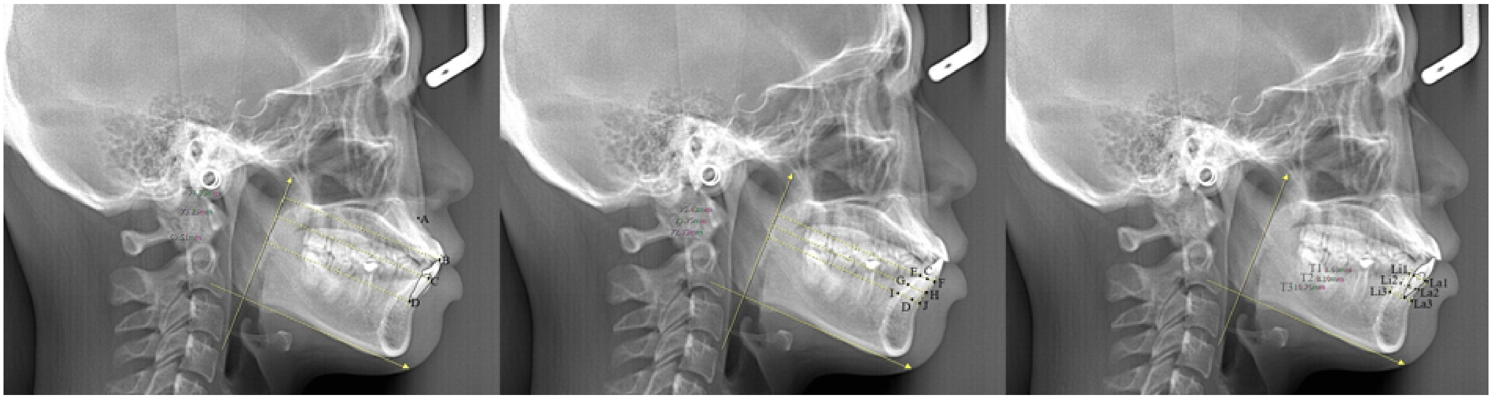

Figure 2

Measurements on the lateral cephalograms

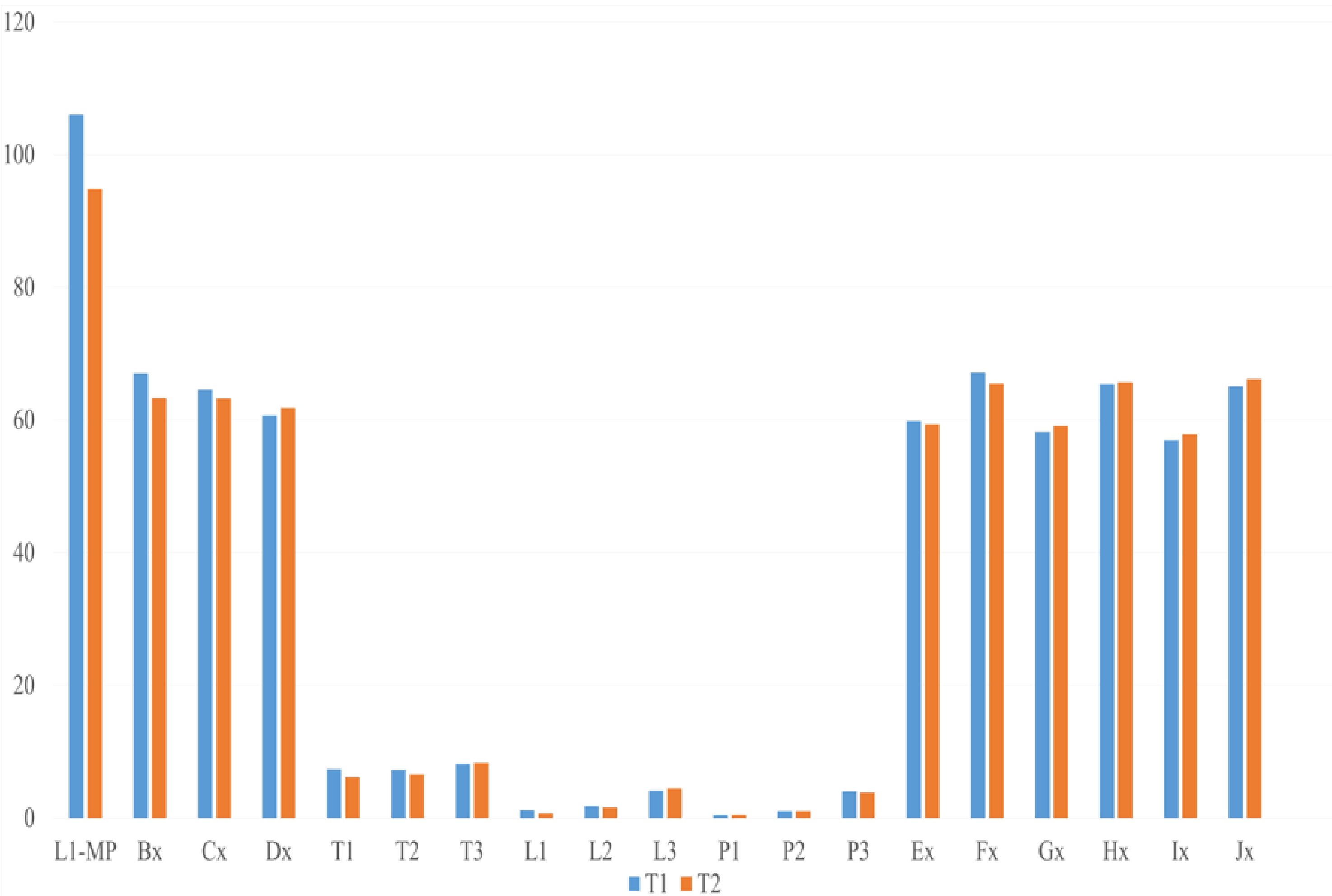

Figure 3

Comparison between initial (T1) and final (T2) stages excluding the growth effect in Tip group

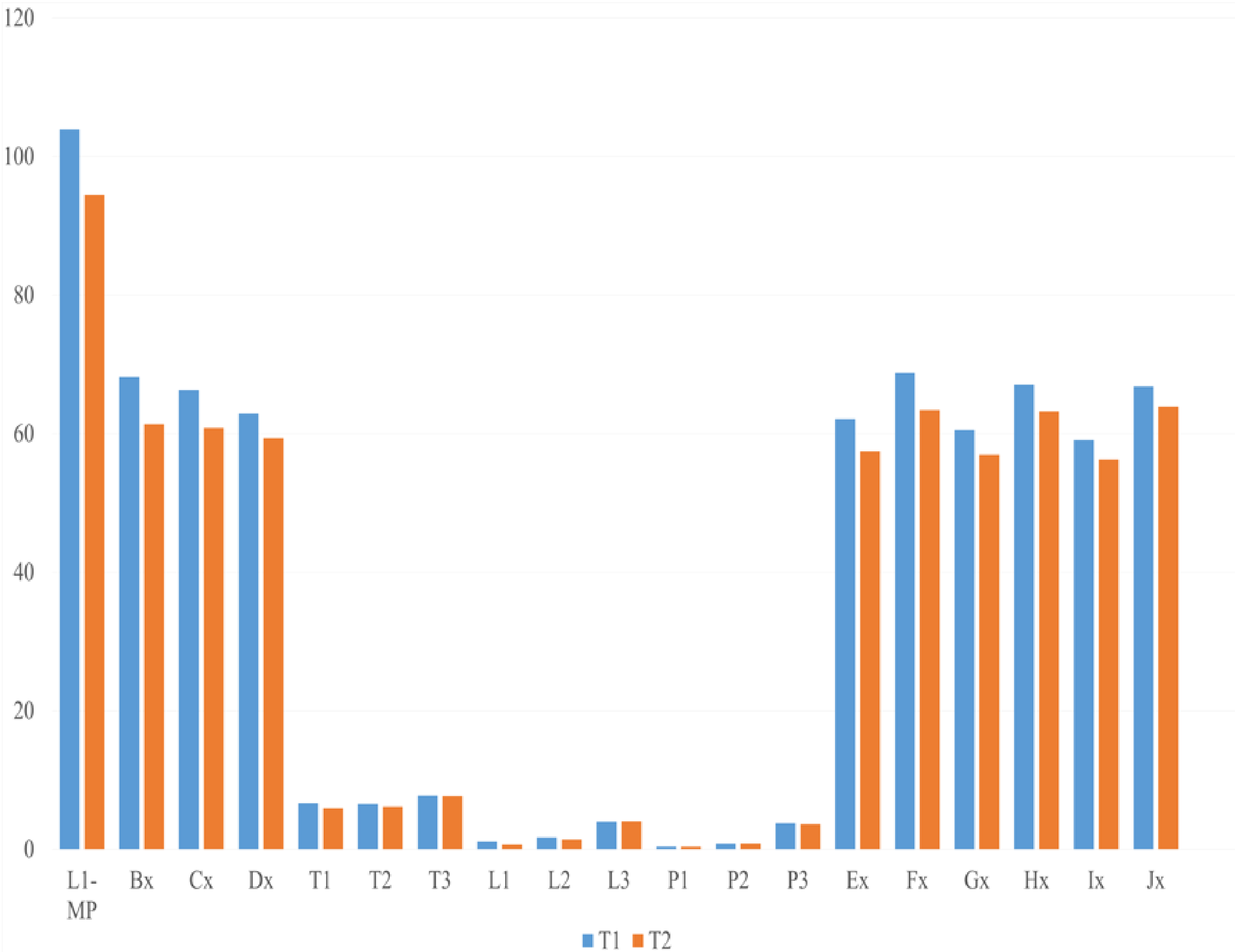

Figure 4

Comparison between initial (T1) and final (T2) stages excluding the growth effect in Torque group

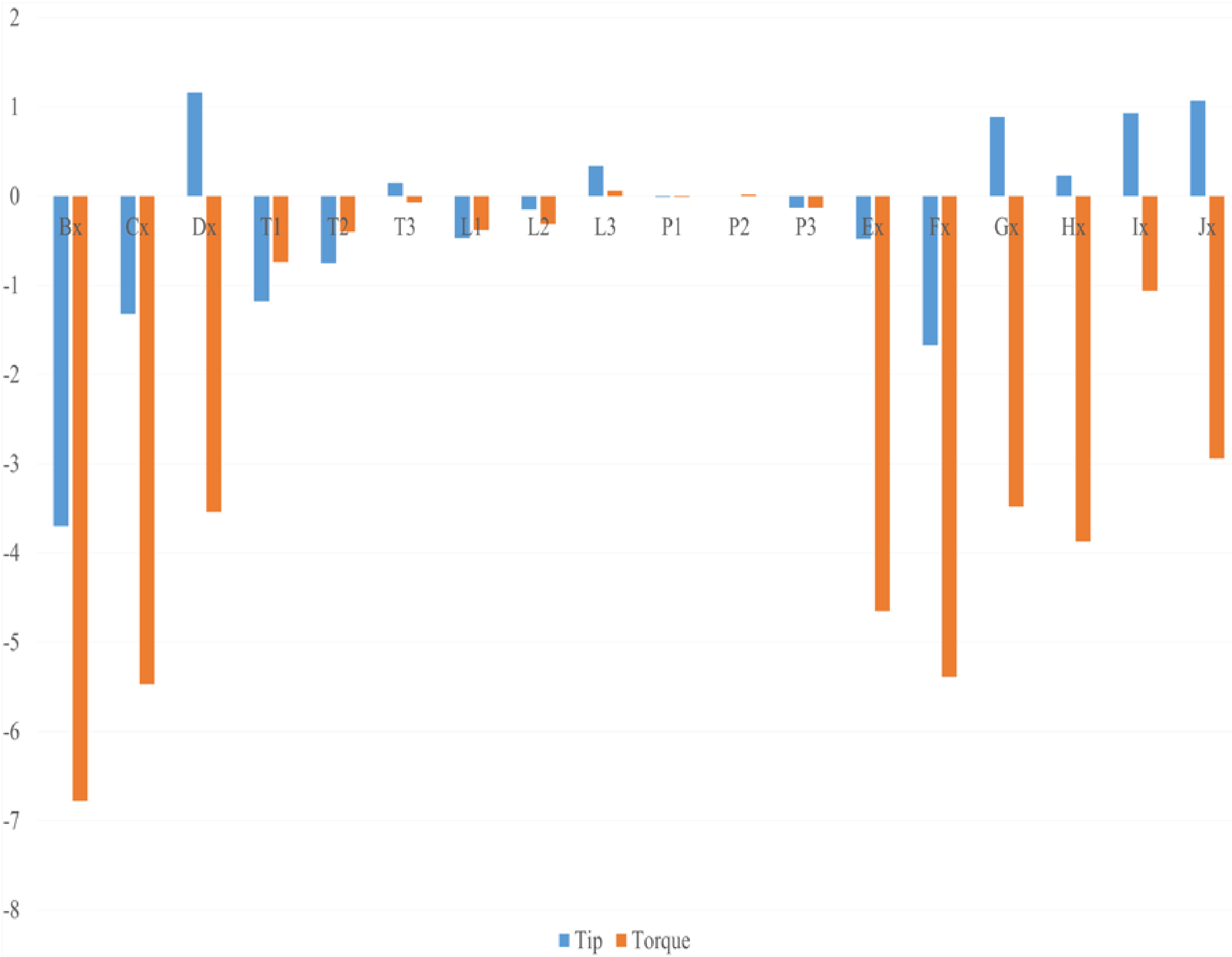

Figure 5

Intergroup comparison of the changes after mandibular Incisor retraction(T2-T1)

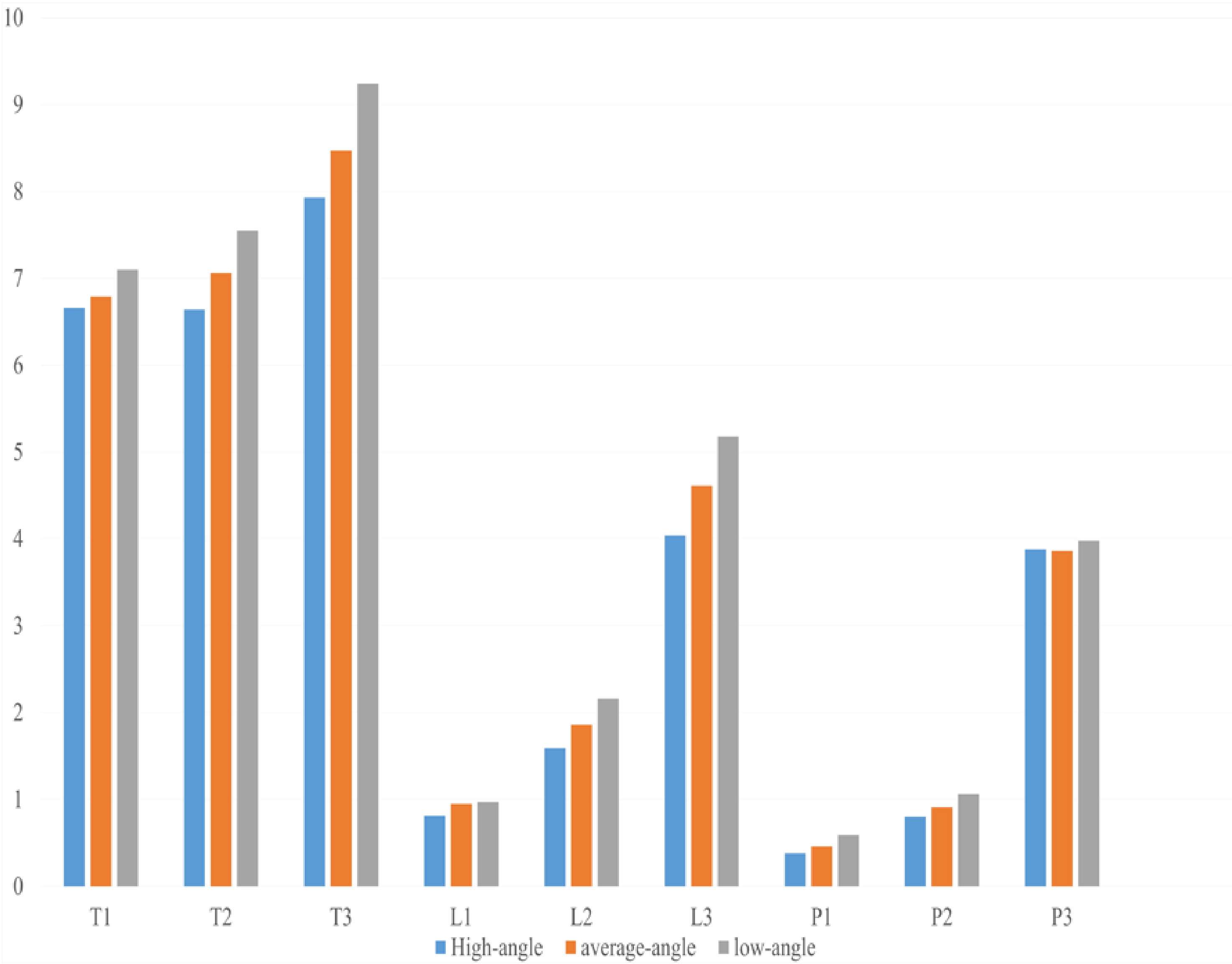

Figure 6

Comparison of alveolar bone thickness among different vertical craniofacial morphology