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Original Article

Transverse compensation of first molars in different sagittal and vertical classifications: a retrospective study using cone-beam computed tomography

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Abstract: The aim of this study was to examine the buccolingual inclination and intermolar arch width of first molars related to sagittal and vertical discrepancies in the Chinese population. Cone-beam computed tomography (CBCT) data and medical records of 236 patients were analyzed with respect to gender, developmental stage, sagittal classification, and vertical growth pattern. Independent samples *t*-test, analysis of variance with post-hoc test, and regression analysis were performed. The study showed (1) no statistical significance among various developmental stages. (2) males' intermolar distances were wider than females' in both arches, while no gender difference was found in the angular measurements. (3) maxillary first molars were the most buccally inclined ($P < 0.000$) in skeletal Class III subjects, while the mandibular ones were the most buccally compensated ($P < 0.001$) in skeletal Class II subjects. The skeletal Class III showed the widest intermolar distances with significant difference. (4) varying compensations among the different growth patterns, which showed the most buccal inclinations in the maxilla ($P < 0.002$) and the most lingual inclinations in the mandible ($P < 0.000$) for subjects in the high angle group. This study demonstrated that (1) sagittal skeletal discrepancy can affect both the buccolingual inclination and the intermolar width of the first molars and (2) vertical skeletal discrepancy can affect buccolingual inclination of the first molars. These should be taken into consideration to avoid clinical complications when planning and treating different skeletal malocclusions.

Keywords: Transverse, compensation, first molar, cone-beam computed tomography

Introduction

As one of the criteria, buccolingual inclination is of fundamental importance in orthodontic treatment. In the 1970s, Andrews brought up the six keys after researching 120 Caucasian dental casts with ideal occlusion, laying the foundation for the preadjusted appliance [1]. However, even experienced orthodontists found it difficult to achieve all the keys without selecting suitable molar torque in certain cases. The American Board of Orthodontics (ABO) Objective Grading System also assessed the buccolingual inclination as a part of its final phase III clinical examination [2]. A list of clinical problems could occur without the concern of transverse discrepancies, such as relapse, occlusal interference, poor buccal interdigitation and periodontal risks (dehiscence and fenestration). Therefore, transverse compensation of the first molars needs to be explored to achieve acceptable treatment results and avoid relating clinical risks.

Several methods, such as dental casts [3] and two-dimensional (2D) radiographs [4-9], have been tried in measuring transverse dental compensations. However, each has its inherent clinical limitations. For the dental casts, the true long axis of each tooth was difficult to determine because of variations in dental crown anatomy [10]. It decreased reliability when selecting the crown's exact tangent point as the indicator for constructing the long axis of

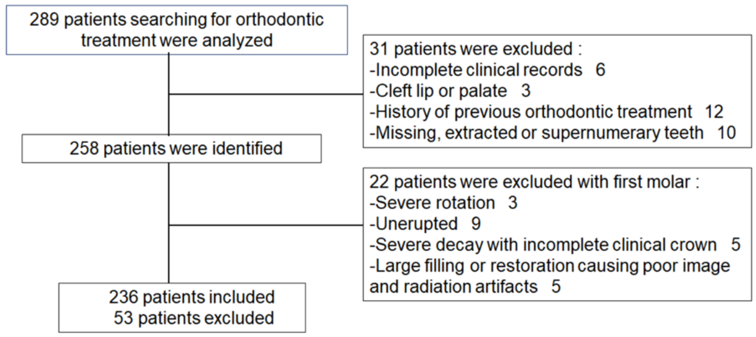

Figure 1. Detailed screening and exclusion protocol.

the crown. Furthermore, the crown and root inclinations often do not coincide. Panoramic radiographs have been shown to be of questionable reliability in indicating the true angulation or inclination [4, 5]. Lateral radiographs can only be used to measure mesiodistal but not buccolingual inclination [6]. Posteroanterior radiographs [7-9] can provide the buccolingual inclination of roots, but its accuracy is doubtful because of superimposed teeth and other landmarks.

The emergence of CBCT [11] has allowed dentists to reliably assess individual tooth positions in three dimensions with good accuracy [12, 13], specifically in the transverse direction.

With increasing clinical interest, continuously growing papers on transverse compensation of either inclination or width have been published in recent years [14-19]. However, inadequate information is common due to race, age, or gender differences, not to mention the reliability of measuring methodology or the sample size. Fewer studies have reported the comprehensive transverse discrepancies in both sagittal and vertical classifications, since compensations are mutually affected in three dimensions. To the best of our knowledge, a study concerning the transverse compensation in Chinese population has not been previously reported.

To address the aforementioned concerns, this study aimed to explore the buccolingual inclination and the intermolar widths of the first molars based on the 236 Chinese patients. Additionally, a reliable method using Simplant program was developed to measure transverse variables. Further in-depth three-dimensional (3D) study with a larger sample of various discrepancies is needed.

Materials and methods

The experimental protocol was approved with consent informed by the Ethics and Research Committee of Nanjing Medical University. CBCT images were taken of 289 patients seeking orthodontic treatment from 2016 through 2017 at the Department of Orthodontics, Affiliated Hospital of Stomatology, Nanjing Medical University.

Exclusion criteria of the patients were as follows: (1) incomplete clinical records, (2) syndromes or hereditary diseases, (3) history of previous orthodontic treatment, (4) poor quality of image, (5) missing, extracted or supernumerary teeth, (6) unerupted first molar, and (7) severe rotation, decay, large filling or restoration of first molars. Detailed screening and exclusions are described in **Figure 1**.

Besides the gender groups, the patients were divided into groups by developmental stage, sagittal and vertical skeletal classification. Based on the reported dentition stages in Chinese population, the patients were classified into mixed dentition (< 12 years old), early permanent dentition (12-16) and permanent dentition (> 16) [20]. According to the normal occlusions data in Chinese subjects [21], the sagittal and vertical skeletal groups were grouped by ANB angle and Frankfort horizontal (FH) plane/mandibular plane (MP) angle, respectively. Thus, there are three groups in the sagittal dimension: Class I (ANB angle of 0.7°-4.7°), Class II (> 4.7°) and Class III (< 0.7°). There are also three groups in the vertical dimension: low angle (FH/MP angle < 22°), average angle (22°-32°) and high angle (> 32°). Patients in the database who met the inclusion criteria formed the study cohort of 236 cases (**Table 1**).

All CBCTs were taken using a NewTom 5G Volumetric Scanner (NewTom QR, Verona, Italy) with the following operating parameters: 110 kV, 7.3 mA, 17-second exposure time, 18 ×

Table 1. Descriptive data of all samples

Variables	Group	N	%	Mean ± SD	Min	Max
Gender	M	88	37.29%			
	F	148	62.71%			
Developmental stage (Age)	< 12 years	33	13.98%	10.45 ± 1.00	7	11
	12-16 years	117	49.58%	13.59 ± 1.44	12	16
	> 16 years	86	36.44%	23.55 ± 6.00	17	48
Sagittal classification (ANB angle)	Class I	82	34.74%	2.69 ± 1.29	0.72	4.70
	Class II	107	45.34%	5.87 ± 1.33	4.71	10.45
	Class III	47	19.92%	-0.99 ± 1.66	-6.09	0.69
Vertical classification (FH/MP angle)	Low	41	17.37%	15.73 ± 2.88	8.33	21.96
	Ave	157	66.53%	24.40 ± 2.74	22.09	31.91
	High	38	16.10%	31.71 ± 3.23	32.12	42.72

N number; *M* male; *F* female; *Low* low angle; *Ave* average angle; *High* high angle.

Table 2. Definition of measuring variables

	Definition
Points	
S (Sella)	Midpoint of the sella turcica
N (Nasion)	Most anterior point on the frontonasal suture
A (A point)	Most posterior point on the anterior profile of the maxilla
B (B point)	Most posterior point on the anterior surface of the mandibular symphysis
PoR (right porion)	Most superior point of right external auditory meatus
PoL (left porion)	Most superior point of left external auditory meatus
OrR (right orbitale)	Most inferior point of right orbit's lower margin
OrL (left orbitale)	Most inferior point of left orbit's lower margin
Or (orbitale)	Midpoint of OrR and OrL
GoR (right gonion)	Most posterior and inferior point on the right angle of the mandible
GoL (left gonion)	Most posterior and inferior point on the left angle of the mandible
Gn (Gnathion)	Most anterior and inferior point on the bony chin
Crown center	Middle point of the central fossa
Root center	Middle point of the root apexes
Lines	
Long axis of first molars	Line connecting between the crown center and root center of first molars
Reference planes	
FH plane	Plane passing through points of PoR, PoL and Or
MP plane	Plane passing through points of GoR, GoL and Gn
Angular measurements	Angles between long axes of maxillary first molars to FH plane or mandibular first molars to MP plane
Linear measurements	Intermolar widths were calculated between the crown centers of first molars in maxilla/mandible

16-cm field of view and voxel size of 0.5 mm. Images were obtained with an interval of 0.3 mm and a thickness of 0.3 mm. Planes were obtained with volume rendering, which renders every voxel in the 3D volume data directly without intermediate geometry conversion.

Scanned images were saved as digital imaging and communication in medicine (DICOM) files and reconstructed into 3D images using the Simplant program (Version16.0, Dentsply International, Salzburg, Austria) from the axial, sagittal and transverse dimensions by two trained observers. Landmarks, reference planes, and measurements are defined in **Table 2**. Images of the three coordinated planes and measurement points are shown in **Figure 2**.

Statistical analysis

To verify the reliability and reproducibility of our protocol, measurements on 80 randomly selected subjects were performed by two trained observers and repeated after a 3-week

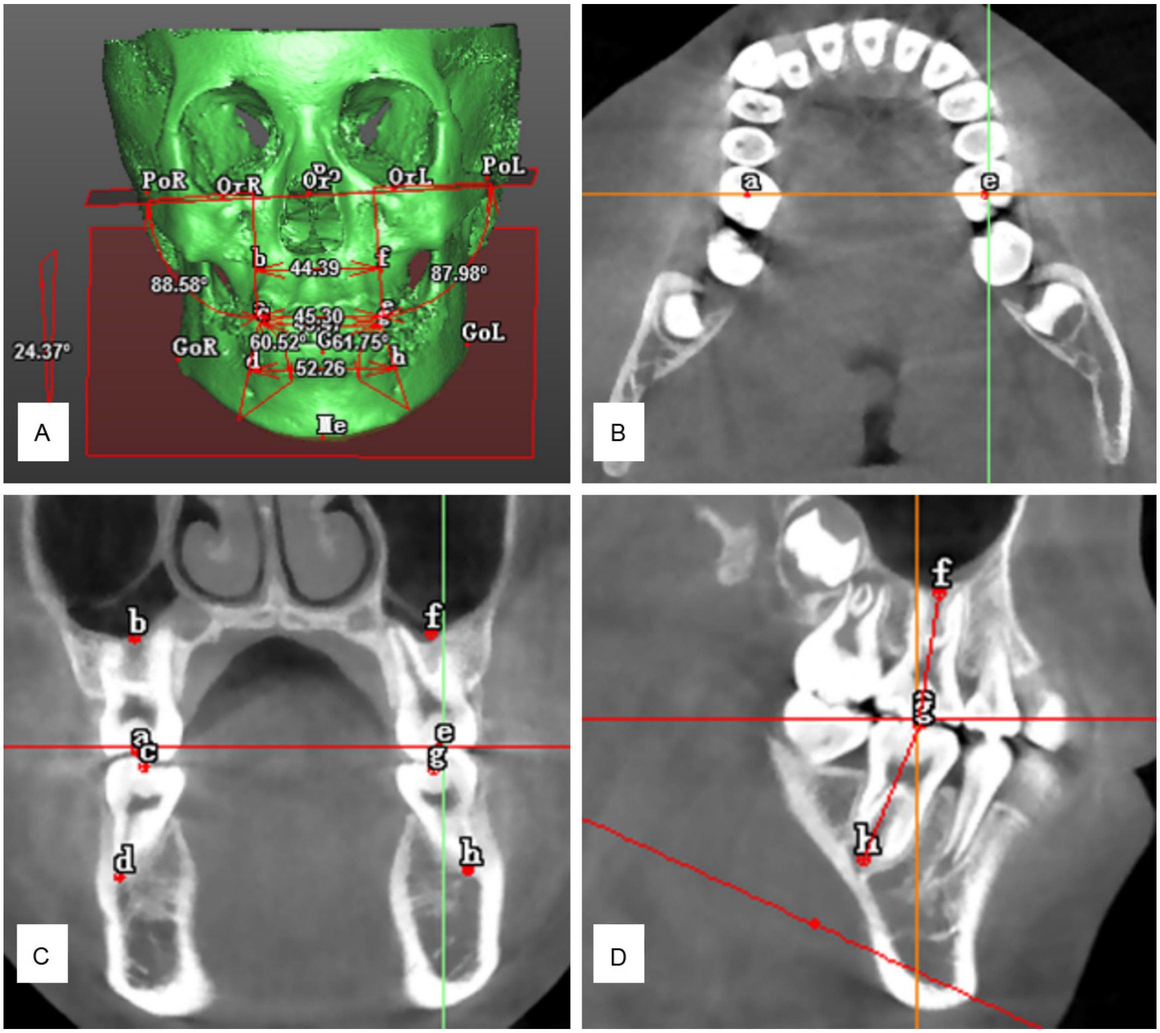

Figure 2. Images of the three coordinated planes and points of measurements. (A) 3D image of measuring points, lines and planes. The maxillary reference plane is the FH plane (determined by PoR, PoL and Or); the mandibular reference plane is the MP plane (determined by GoR, GoL and Gn). Locating the molar in (B) the axial view; (C) the transverse view; (D) the sagittal view.

interval. The consistency and precision of main landmarks' raw values were also quantified in 24 randomized patients. The average of both examiners locating each landmark at different times was defined as the centroid [22]. Numeric values of each landmark were recorded referring to the x-, y-, and z-axes. The mean distances from the centroid were used as a measure of consistency, whereas the standard deviation of the mean was used as a measure of precision.

The independent samples t-test was used to assess intra- and inter-observer differences, left- and right-side variables, and gender differences. One-way analysis of variance (ANOVA) and multiple comparison between the groups of post-hoc test were performed to evaluate the transverse molar relationship among groups of different ages, sagittal and vertical classifications. Since the ANB angle is widely used in clinical practice, linear regression analysis was also performed to detect its impact on the molars buccolingual inclination. $P < 0.05$ was used to assign statistical significance. All statistics were calculated using the SPSS (Version17.0, SPSS Inc, Chicago, IL, USA).

Results

The mean correlation coefficients of intra- and inter-observer between different measurement times were 0.942 and 0.953, respectively, indi-

Table 3. The consistency and rank of main landmarks in 3D axes

Landmarks	X-axis consistency		Y-axis consistency		Z-axis consistency	
	Mean ± SD (mm)	Rank	Mean ± SD (mm)	Rank	Mean ± SD (mm)	Rank
Sella	0.55 ± 0.37	8	0.46 ± 0.45	9	0.52 ± 0.44	11
Nasion	0.63 ± 0.48	11	0.46 ± 0.45	9	0.46 ± 0.33	7
A point	0.58 ± 0.50	9	0.59 ± 0.27	13	0.69 ± 0.54	13
B point	0.41 ± 0.31	6	0.16 ± 0.14	1	0.29 ± 0.05	1
Right porion	0.66 ± 0.43	12	0.41 ± 0.34	7	0.93 ± 0.13	2
Left porion	0.29 ± 0.23	4	0.39 ± 0.21	6	0.40 ± 0.35	8
Right orbitale	0.30 ± 0.03	5	0.41 ± 0.32	8	0.41 ± 0.15	3
Left orbitale	0.79 ± 0.30	13	0.32 ± 0.28	4	0.48 ± 0.42	10
Right gonion	0.13 ± 0.05	1	0.38 ± 0.30	5	0.43 ± 0.28	5
Left gonion	0.19 ± 0.10	3	0.30 ± 0.21	3	0.50 ± 0.36	9
Gnathion	0.59 ± 0.10	10	0.47 ± 0.34	11	0.46 ± 0.32	6
Right maxillary first molar central fossa	0.14 ± 0.09	2	0.58 ± 0.41	12	0.59 ± 0.48	12
Right maxillary first molar root apex	0.46 ± 0.43	7	0.17 ± 0.04	2	0.32 ± 0.28	4

Table 4. Comparison of buccolingual inclination of maxillary first molars among different groups

	Maxillary Molar Inclination (°)				
	N	Min	Max	Mean ± SD	*P*
Gender					
M	176	90.14	121.61	99.06 ± 5.47	0.163
F	296	90.73	116.79	98.36 ± 5.05	
Developmental stage					
< 12 years	66	90.14	121.61	99.12 ± 6.00	0.703
12-16 years	234	90.73	118.96	98.52 ± 4.90	
> 16 years	172	91.05	116.79	98.57 ± 5.33	
Sagittal skeletal classification					
Class I	164	90.14	116.79	97.66 ± 4.31	< 0.001**
Class II	214	90.73	116.45	98.33 ± 5.04	
Class III	94	91.09	121.61	100.96 ± 6.29	
Vertical skeletal classification					
Low	82	91.16	116.79	98.06 ± 5.41	0.002**
Ave	314	90.14	121.61	98.31 ± 5.08	
High	76	92.16	112.13	100.52 ± 5.19	

N number; *M* male; *F* female; *Low* low angle; *Ave* average angle; *High* high angle; $^{**}P < 0.01$.

cating good reliability and reproducibility. The raw 3D values of main landmarks showed high consistency and precision with a deviation less than 0.50 mm in **Table 3**. The rank revealed B point with the highest consistency, while A point with the lowest consistency.

There was no significant difference in values of buccolingual inclination between right and left sides ($P > 0.05$). Therefore, both sides were added together for subsequent group comparison.

Tables 4-7 show the overall measurements of maxillary and mandibular first molars among different groups. Post hoc tests were performed to identify the cause of significant differences between each group (**Tables 8** and **9**).

There were no significant differences among the different developmental stages, for either angular or linear measurements. Nor were there any gender differences in buccolingual inclination. However, intermolar distances were wider in males than in females in both arches ($P < 0.001$).

Tables 4, **6** and **8** indicated that the first molars were more buccally inclined in the skeletal Class III group than those found in skeletal Class I or Class II group in the maxilla, while the ones were more buccally compensated in skeletal Class II group than other groups in the mandible. Various compensations were also found among different vertical growth patterns,

Table 5. Comparison of intermolar widths between maxillary first molars among different groups

	Maxillary Intermolar Width(mm)				
	N	Min	Max	Mean ± SD	*P*
Gender					
M	88	41.65	55.00	47.96 ± 2.75	< 0.001**
F	148	39.36	55.31	46.28 ± 2.81	
Developmental stage					
< 12 years	33	43.53	54.52	47.46 ± 2.88	0.108
12-16 years	117	40.75	52.74	47.12 ± 2.64	
> 16 years	86	39.36	55.31	46.40 ± 3.18	
Sagittal skeletal classification					
Class I	82	40.74	55.00	47.01 ± 2.77	0.027*
Class II	107	39.36	55.31	46.44 ± 2.98	
Class III	47	41.89	52.74	47.78 ± 2.76	
Vertical skeletal classification					
Low	41	40.74	55.31	46.85 ± 3.55	0.675
Ave	157	39.36	54.52	46.83 ± 2.80	
High	38	42.83	54.05	47.29 ± 2.53	

N number; *M* male; *F* female; *Low* low angle; *Ave* average angle; *High* high angle; **P* < 0.05; ***P* < 0.01.

Table 6. Comparison of buccolingual inclination of mandibular first molars among different groups

	Mandibular Molar Inclination (°)				
	N	Min	Max	Mean ± SD	*P*
Gender					
M	176	55.75	86.38	72.68 ± 5.78	0.091
F	296	55.21	86.60	71.73 ± 5.95	
Developmental stage					
< 12 years	66	55.21	86.16	72.71 ± 6.14	0.125
12-16 years	234	55.75	84.02	71.38 ± 5.40	
> 16 years	172	55.97	86.60	72.94 ± 5.95	
Sagittal skeletal classification					
Class I	164	55.75	86.60	71.73 ± 5.77	0.001**
Class II	214	58.15	86.38	73.07 ± 5.60	
Class III	94	55.21	86.38	70.46 ± 6.41	
Vertical skeletal classification					
Low	82	64.50	86.60	76.86 ± 5.02	< 0.001**
Ave	314	55.21	86.38	71.60 ± 5.17	
High	76	55.75	84.02	68.93 ± 6.63	

N number; *M* male; *F* female; *Low* low angle; *Ave* average angle; *High* high angle; ***P* < 0.01.

which demonstrated the most buccal inclination in the maxilla (P < 0.002) and the most lingual inclination in the mandible (P < 0.001) for subjects in the high angle group. No linear difference was revealed among different growth patterns.

Tables 5, **7** and **9** revealed significant differences in intermolar widths, indicating that patients with skeletal Class III feature wider arches than Class I and II in terms of molar segment.

Linear regression analysis also demonstrated the ANB angle was negatively correlated with the maxillary first molar inclination but positively correlated with the mandibular first molar inclination (**Table 10**).

Discussion

In order to establish proper occlusion in maximum intercuspation, avoid balancing interferences and maintain the long-term stability, the transverse relationship has been proven to be significantly interesting to clinicians. In the present study, these discrepancies related to different dental developmental stages, sagittal, and vertical skeletal classifications in Chinese population were firstly demonstrated. The sample size (236 patients) is three times compared with the latest reported studies [14, 15]. This research is also one of the first reports exploring molar transverse discrepancies, combining not only the vertical but also the sagittal classifications.

In this study, the method of evaluating first molar inclinations was proved effective by Tong et al. [23]. The long axis of first molar is defined as the line passing through the center of the crown and apex. The measured angles correspond to the actual long axis of the teeth regardless of the different crown anatomies. The occlusal plane was used as the refer-

Table 7. Comparison of intermolar widths between mandibular first molars among different groups

	Mandibular Intermolar Width(mm)				
	N	Min	Max	Mean ± SD	*P*
Gender					
M	88	37.55	54.08	44.43 ± 3.24	< 0.001**
F	148	36.15	54.49	42.70 ± 2.84	
Developmental stage					
< 12 years	33	39.42	54.08	44.28 ± 3.03	0.138
12-16 years	117	37.21	52.29	43.34 ± 2.75	
> 16 years	86	36.15	54.49	43.01 ± 3.53	
Sagittal skeletal classification					
Class I	82	36.15	49.95	43.10 ± 2.89	0.017*
Class II	107	37.20	54.49	43.03 ± 3.03	
Class III	47	38.01	54.08	44.50 ± 3.40	
Vertical skeletal classification					
Low	41	36.15	54.49	43.35 ± 3.89	0.266
Ave	157	37.08	54.08	43.17 ± 2.87	
High	38	38.94	52.29	44.08 ± 3.07	

N number; *M* male; *F* female; *Low* low angle; *Ave* average angle; *High* high angle; $^{*}P < 0.05$; $^{**}P < 0.01$.

Table 8. Post-hoc tests of the molar inclination differences between groups

Maxillary Molar Inclination	Groups	Class I	Class II
	Class II	0.201	-
	Class III	< 0.001**	< 0.001**
	Groups	Low	Ave
	Ave	0.699	-
	High	0.003**	0.001**
Mandibular Molar Inclination	Groups	Class I	Class III
	Class II	0.028*	< 0.001**
	Class III	0.095	-
	Groups	Low	Ave
	Ave	< 0.001**	< 0.001**
	High	< 0.001**	< 0.001**

Low low angle; *Ave* average angle; *High* high angle; $^{*}P < 0.05$; $^{**}P < 0.01$.

ence plane in Ross's study of dental casts [24] while the MP and FH planes were used in this study. Unlike the occlusal plane, the latter two are both reproducible and less likely to be influenced by tooth movement, which makes them suitable to compare pre- and post-treatment changes. Ritter et al. [25] reported that age and the amount of dental restorations appear to have a negative influence on CBCT image quality in a sample of patients aged 18-73 years old. They observed the lower image quality happened as the age increased with the explanation of older patients receiving more dental restorations. In this study, patients with large fillings or restoration in the first molars were excluded to ensure the image quality.

With regard to the sagittal skeletal malocclusions, the subjects in the skeletal Class III group had the most buccally inclined maxillary first molars, which was partially consistent with Ahn's results [14], suggesting the original existence of transverse angular compensation in different sagittal classifications. If the clinical intervention exceeds the potential of the transverse compensation, the molar root was moved out of the alveolar bone boundary, which may deteriorate the original structure and cause unstable treatment results. Yagci et al. [26] also pointed out that the incidence of alveolar dehiscence and fenestration is higher in skeletal Class III malocclusion than skeletal Class I and II malocclusions.

The lower intermolar widths are larger in the Chinese population (male: 44.43 ± 3.24 mm, female: 42.70 ± 2.84 mm) compared to the Caucasian population (male: 41.4 ± 2.3 mm, female: 40.4 ± 3.0 mm) [15]. Studies suggest racial differences be taken into account to achieve stable outcome. The comparison of intermolar widths was in accordance with the result of Tyan [19], who studied 45 Class III patients with facial asymmetry and 33 Class I patients as the control group, concluding that transverse linear compensation also exists for sagittal discrepancies. Patients with Class III malocclusion

Table 9. Post-hoc tests of the intermolar width differences between groups

Maxillary Intermolar Width	Groups	Class I	Class II
	Class II	0.140	-
	Class III	0.087	0.003**
Mandibular Intermolar Width	Groups	Class I	Class II
	Class II	0.880	-
	Class III	0.013*	0.007**

*$P < 0.05$; **$P < 0.01$.

Table 10. Linear regression analysis between the ANB angle and molars buccolingual inclination

	Correlation Coefficient	P
Maxillary Molar Inclination	-0.157	0.016*
Mandibular Molar Inclination	0.144	0.027*

*$P < 0.05$.

showed a high tendency to have wider arches. Considering the molar inclination and width, thorough decompensation suited to the basal bone is suggested in the early stage of Class III treatment when orthognathic surgery is planned.

With regard to the vertical growth patterns, the result of maxillary transverse compensation of first molars in high angle subjects was the same as those of Janson et al. [27], while mandibular compensation was in the opposite direction with significant difference. Interestingly, the result was in contrast to Ross's study [24], which compared the buccolingual inclination of the first molars of 72 white patients using 2D cephalograms and dental casts. The reason might be variations in the efficiency of methods used, not to mention the racial differences. The present results demonstrated vertical discrepancy also affects the transverse angular-but not linear-measurement of the first molars.

For the clinical implication, since individualized preadjusted appliances are widely used nowadays, it is fundamental to take transverse compensation into consideration in patients with different diagnoses. Universal prescriptions are not the gold standard for every case [28]. The clinicians select variable torque values not only for the anterior teeth as the digital era arrives. For example, it is inappropriate to select appliances with high torque for skeletal Class III or high angle patients since their maxillary first molars are already buccally inclined. Customized brackets are cut at an angle to compensate for the loss of torque from wire play. Thus, the torque value assigned to the bracket will be expressed and the molar will be driven all the way to its desired final transverse position.

Related complications including periodontal risk could happen without transverse consideration. When making plans on whether to expand or extract in borderline cases, this study provides the evidences that expansion may be more applicable for low angle cases while extraction seems more appropriate for high angle cases. Nonsurgical palatal expansion can accentuate the buccal inclination of the maxillary first molars, thus jeopardizing the periodontal condition and increasing the probability of relapse [29]. Especially when camouflaged treatment is planned for mild or moderate skeletal malocclusions, the potential of molar compensation needs to be clearly defined. Otherwise, surgery assisted expansion should be considered to avoid dehiscence or fenestration.

The clinicians also realize that transverse discrepancies are reasonable for bimaxillary relationship in 3D. For example, as the maxillary molars' palatal cusp descend followed by the backward rotation of the mandible, difficulty arises from obtaining a good sagittal relationship due to the transverse discrepancy.

Skeletal classifications in transverse dimension will be explored in the following study, which would be better to illustrate why the dental compensations occurred in some groups since the dental compensation is to coordinate and camouflage the skeletal discrepancy. In further studies, we will also investigate differences in the intermolar widths not only at the crown level but also at the apex level.

Conclusions

As shown in this Chinese population, sagittal skeletal discrepancy can affect both the buccolingual inclination and the intermolar width of the first molars, while vertical skeletal discrepancy can only affect the inclination of the first molars. Racial and gender differences of the intermolar width also should be considered. With a reliable method using a commercially available imaging program to investigate the transverse discrepancy, we provide clinical hints on how to select suitable preadjusted appliances in different cases. This study contributes to a better understanding of transverse compensation in different classification, which is fundamental for more precise planning, less periodontal risk, improved outcome and a long-term stability.

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Disclosure of conflict of interest

None.

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