

ORIGINAL ARTICLE

Compensation trends of the angulation of first molars: retrospective study of 1 403 malocclusion cases

Hong Su¹, Bing Han¹, Sa Li², Bin Na³, Wen Ma⁴ and Tian-Min Xu¹

We investigated the compensatory trends of mesiodistal angulation of first molars in malocclusion cases. We compared differences in the angulation of first molars in different developmental stages, malocclusion classifications and skeletal patterns. The medical records and lateral cephalogrammes of 1 403 malocclusion cases taken before treatment were measured to evaluate compensation of molar angulation in relation to the skeletal jaw. The cases were stratified by age, Angle classification and skeletal patterns. Differences in the mesiodistal angulation of the first molars were compared among the stratifications. We observed three main phenomena. First, angulation of the upper first molar varied significantly with age and tipped most distally in cases aged < 12 years and least distally in cases aged > 16 years. The lower first molar did not show such differences. Second, in Angle Class II or skeletal Class II cases, the upper first molar was the most distally tipped, the lower first molar was the most mesially tipped, and opposite angulation compensation was observed in Class III cases. Third, in high-angle cases, the upper and lower first molars were the most distally tipped, and opposite angulation compensation was observed in low-angle cases. These data suggest that the angulation of the molars compensated for various growth patterns and malocclusion types. Hence, awareness of molar angulation compensation would help to adjust occlusal relationships, control anchorage and increase the chances of long-term stability.

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INTRODUCTION

In 1959, Steiner¹ proposed a ‘Cheveron analysis’ to evaluate malocclusion and to aid treatment planning. This analysis was based on the relationships between the relative position of the mandible to the maxilla, the incisors and the craniofacial position. Steiner stated that the harmony of the craniofacial relationship was dependent upon the degree of variation of the measured values. In other words, individuals should have compensation for variations and coordination among craniofacial relationships. Steiner made various treatment plans for malocclusions by analysing the compensatory position and inclination angle according to where the upper and lower incisors should be located. For orthodontists, incisors should not be the only concern. Molars, which are used as anchorage teeth, are also important, especially the first permanent molars, the compensatory differences of which have crucial roles in growth, development and anchorage control.

Crown angulation had been defined by Andrews² in ‘The six keys to normal occlusion’ based on his study of 120 adults with normal occlusion. Several orthodontists^{3–12} have found that the angulation of dentition can change appreciably according to certain factors and can exhibit regularities. Björk and Skieller⁴ found that teeth could change their direction of eruption to compensate for positional changes of the

jaws because the amount and direction of jaw growth showed considerable variability. Kim *et al.*⁷ carried out a longitudinal study focusing on molar relationships with regard to growth centres. They found that molar relationships in mixed dentition were highly significantly affected by the growth difference of jaws in the sagittal direction. They then tried to ascertain the compensatory changes of molars for sagittal malocclusions. Those studies were based on relatively small samples and had different objectives, so most of them could not provide clear and comprehensive conclusions about the compensatory trends of molar angulation for different skeletal patterns. A more far-ranging and in-depth study is clearly needed.

Changes in angulation of the first permanent molars are inextricably linked to changes in anchorage. Orthodontists have used various methods to make the correct changes in mesiodistal angulation of the first molars to influence anchorage preservation. Classic fixed appliances are used to put tip-backs on the posterior teeth for resisting the forward-tipping trend of the molars, as in the Begg or Tweed techniques. However, certain issues remain to be investigated: (i) molar angulation before treatment; (ii) the benefits of the compensatory condition of the molars themselves for anchorage preservation; and (iii) the natural pattern of differences in the axial angulation of the first molars in all types of malocclusions.

¹Department of Orthodontics, School and Hospital of Stomatology, Peking University, Beijing, China; ²Department of Stomatology, Shenzhen People’s Hospital, Shenzhen, China; ³Graduate from School and Hospital of Stomatology, Peking University, Beijing, China and ⁴Arrail International Dental Clinic, Beijing, China

Correspondence: Dr TM Xu, Department of Orthodontics, School and Hospital of Stomatology, Peking University, 22 Zhongguancun South Avenue, Beijing 100081, China
E-mail: tmxuortho@gmail.com

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We wished to investigate the natural state of mesiodistal angulation of the first molars in malocclusion cases without orthodontic treatment. By measuring and analysing the molar angulations of 1 403 cases, we aimed to contrast the compensatory differences of the angulation of the first molars among cross-sections at different growth stages, classifications of malocclusions and skeletal patterns. In this way, we hope to provide a reference for orthodontists to better understand the potential of molar anchorage, the effects of orthodontic appliances upon anchorage control, and promote technological innovations in orthodontic appliances.

MATERIALS AND METHODS

Samples were taken from a database comprising >11 000 cases of malocclusion who had finished orthodontic treatment between 1997 and 2005 at the Peking University School and Hospital of Stomatology (Beijing, China). The Ethics Committee of Peking University School and Hospital of Stomatology approved the study protocol.

Inclusion criteria were: Han nationality; no hereditary diseases; complete medical records; availability of undamaged lateral cephalogrammes from before and after treatment obtained using the same X-ray machine; all first permanent molars present before treatment.

Patients in the database who met the inclusion criteria formed the study cohort of 1 403 cases (457 males, 32.6%; 946 females, 67.4%). The mean age of the study cohort was 13.85 (range: 7–45) years. There were 1 190 adolescent patients (84.8%) and 213 adult patients (15.2%). Angle Class I malocclusions were the most common (635 cases, 45.3%), followed by Class II (547 cases, 39.0%) and Class III (221 cases, 15.8%). According to the cephalometric data of normal occlusion in Chinese subjects (ANB angle = $2.7^{\circ} \pm 2.0^{\circ}$; MP/SN angle = $32.5^{\circ} \pm 5.2^{\circ}$),¹³ we classified the skeletal sagittal and vertical jaw relationships. Upon grouping based on the sagittal jaw relationship, the number of cases with skeletal class I ($0.7^{\circ} \leq \text{ANB} \leq 4.7^{\circ}$) was 588 (41.9%), the number of cases with skeletal class II ($\text{ANB} > 4.7^{\circ}$) was 646 (46.0%) and the number of cases with skeletal class III ($\text{ANB} < 0.7^{\circ}$) was 169 (12.1%). Upon grouping by the vertical jaw relationship, there were 703 (51.1%) average-angle patients ($27.3^{\circ} \leq \text{MP/SN} \leq 37.7^{\circ}$), 644 high-angle cases ($\text{MP/SN} > 37.7^{\circ}$) and 56 (4.0%) low-angle cases ($\text{MP/SN} < 27.3^{\circ}$).

Lateral cephalogrammes were provided by the radiology department of Peking University School and Hospital of Stomatology. All of the headfilms were taken using the same X-ray machine to exclude the influence of magnification. After the cephalogrammes were taken, landmarks were located thrice each by three senior residents in orthodontics who were blinded to the goals of our study. If the left and right projections were not matched in the cephalogramme, the midpoint of the two sides was located. According to studies of the reasonable range of the landmark position by Baumrind and colleagues,^{14–16} outlier landmarks could be detected automatically by the software. These outlier landmarks would be relocated again until all landmarks were within a reasonably good range. The average of three landmarks was used for subsequent calculations. Cephalometric landmarks were shown in a schematic plot (Figure 1). We selected six representative variables regarding growth and development from all measurement indicators: four skeletal variables and two dental variables (Table 1). The palatal plane (PP) and mandibular plane (MP, tangent from the menton to the average lower edges of the mandibular angle according to the description given by Downs¹⁷) were located. A line traced from the tip of the mesiobuccal cusp to the apex of the mesiobuccal root of the upper first molar (UM) was regarded to be the axis of the maxillary first molar, similar to the axis of the lower first molar (LM). The

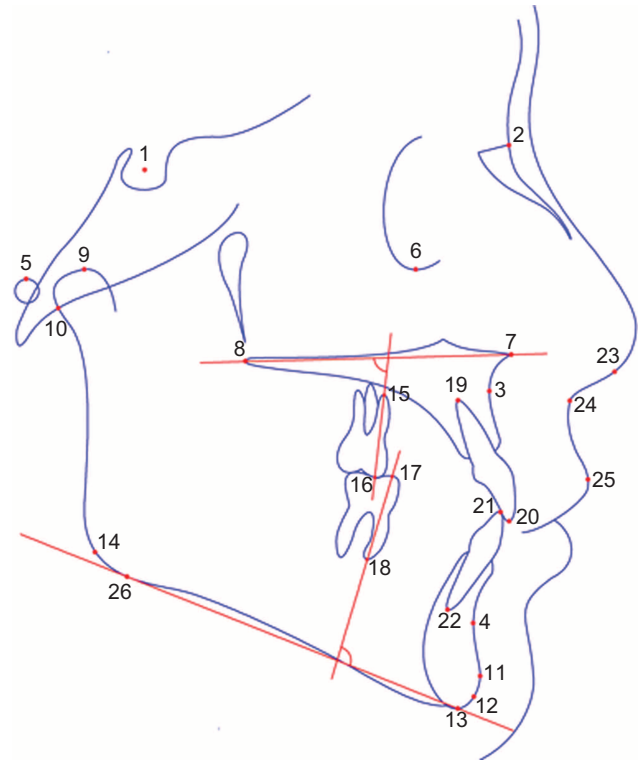


Figure 1 Cephalometric landmarks (schematic). 1: sella (S); 2: nasion (N); 3: subspinale (A); 4: supramental (B); 7: anterior nasal spine (ANS); 8: posterior nasal spine (PNS); 13: menton (Me); 15: apex of the mesial buccal root of the upper first molar (UMA); 16: mesial buccal cusp of the upper first molar (UMC); 17: mesial cusp of the lower first molar (LMC); 18: apex of the mesial root of the lower first molar (LMA).

angulation of the axis of the maxillary first molar in relation to the PP (UM/PP) and the axis of angulation of the mandibular first molar in relation to the MP (LM/MP) were measured.

By measuring the pre-treatment values of UM/PP and LM/MP (in degrees) of all 1 403 malocclusion cases at various ages, of different malocclusion types and from different sagittal or vertical skeletal patterns, the mean values of mesiodistal angulation of the first molar were obtained. Compensatory trends and growth differences of first molar angulations were calculated and analysed according to the differences between the values measured in different malocclusion patterns or growth patterns.

Table 1 Definition of cephalometric variables

Variables	Definition
UM/PP	Inferoposterior crossing angle of the axis of the upper first molar with the palatal plane
LM/MP	Anterosuperior crossing angle of the axis of the lower first molar with the mandibular plane
SNA	Inferoposterior crossing angle of the NA line with the anterior cranial base plane
SNB	Inferoposterior crossing angle of the NB line with the anterior cranial base plane
ANB	Value of the SNA angle minus the SNB angle
MP/SN	Anteroinferior crossing angle of the mandibular plane with the anterior cranial base plane

Statistical analyses

Data were analysed using SPSS ver16.0 (SPSS, Chicago, IL, USA). Some of the variables were converted to classifications that were convenient for statistical analyses. $P < 0.05$ was considered significant.

The indicators UM/PP and LM/MP were regarded as dependent variables. All cases were classified into three groups according to age (<12 years, 12–16 years, >16 years). Similarly, they were classified into three groups (Angle classes I, II and III) according to molar relationships. Three groups (skeletal classes I, II and III) were created according to the ANB angle. Three groups (average angle, high angle, low angle) were created according to the MP/SN angle. The compensatory trends of angulation of the first molars to the different malocclusion types and skeletal patterns were analysed separately using analysis of variance (ANOVA).

To reduce possible systematic errors, all cephalogrammes were taken using the same X-ray machine, and all landmarks were located by three senior residents. To decrease the risk of random errors, we used a large sample (>1 400 cases), and landmark location was determined by taking the average of three values.

RESULTS

The angulation of the first molars compensated differently for various growth patterns and malocclusion types (Table 2). The mean values of UM/PP in the age groups of <12 years, 12–16 years, and >16 years were 77.022°, 79.112° and 84.311°, respectively, and were significantly different ($P < 0.01$). That is, for cases of mixed dentition (<12 years), the maxillary first molar was the most distally inclined. For cases of early permanent dentition (12–16 years), the maxillary first molar was inclined relatively distally. For cases of mature permanent dentition (>16 years), the maxillary first molar was inclined the least distally, with a difference of up to 7.2°. With respect to sagittal growth patterns, the dental indicator (Angle classification) and bone indicator (skeletal classification) showed the same patterns. That is, the maxillary first molars relative to PP were inclined the most distally in Class II cases,

followed by Class I cases and Class III cases, and the difference was significant ($P < 0.01$). It appeared that in the sagittal direction, the more the mandible retruded relative to the maxilla, the more the maxillary first molar tipped distally. With regard to vertical growth patterns, the axial angulation of the maxillary first molars showed different compensations. The UM tipped the most distally in high-angle cases, followed by average-angle cases and low-angle cases, and the difference was significant ($P < 0.01$). These results suggested that, in the vertical direction, the greater the angle in the MP, the more the UM tipped distally.

The axial angulation of the mandibular first molars showed different compensations with regularities between various growth patterns. According to the sagittal molar relationships, the mandibular first molars inclined the most distally relative to the MP in cases with Angle Class III, followed by Class I and Class II, and the difference was significant ($P < 0.01$). The sagittal skeletal indicator also showed that the axial angulation of the LM was the most distal in skeletal class III, and the least distal in skeletal class II, and the difference was significant ($P < 0.01$). That is, in the sagittal direction, the more the LM was located mesially relative to the UM or the mandible was located forward relative to the maxilla, the more the mandibular first molars were inclined distally, acting in opposition to the UM. With regard to vertical growth patterns, the axial inclination of the mandibular first molars also showed different compensations. The LM tipped the most distally in high-angle cases and the least distally in low-angle cases, and the difference was significant ($P < 0.01$). These results suggested that, in the vertical direction, the greater the MP angle, the more the LM tipped distally (similar to the UM). Interestingly, the angulation of the LM did not show significant difference ($P > 0.05$) between cases of different ages. This finding suggested that the axial angulation of the mandibular first molars remained stable with age (i.e., the opposite effect to that seen with the maxillary first molars).

We divided the sample into three age groups (<12 years, 12–16 years, >16 years) so that we could also study the compensatory differences to

Table 2 Compensatory differences of the axial inclination of maxillary and mandibular first molars between different malocclusion groups evaluated by ANOVA

Classification	<i>n</i>	UM/PP			LM/MP		
		(Mean±s.d.)/°	<i>P</i> value	Observed power ^a	(Mean±s.d.)/°	<i>P</i> value	Observed power ^a
Age/year			0.000**	1.000		0.858	0.074
<12	340	77.022±5.006			96.356±5.330		
12–16	788	79.112±5.327			96.457±5.592		
>16	275	84.311±5.693			96.610±6.347		
Angle classification			0.000**	1.000		0.000**	1.000
1	635	80.860±5.475			96.589±5.649		
2	547	77.539±5.704			95.535±5.490		
3	221	81.233±5.866			98.395±5.759		
Skeletal classification			0.000**	1.000		0.000**	1.000
1	588	80.412±5.444			96.936±5.623		
2	646	78.159±5.740			95.609±5.617		
3	169	82.482±6.209			98.080±5.635		
MP/SN classification			0.000**	0.995		0.000**	1.000
Low-angle	56	81.585±6.282			91.479±4.474		
Average angle	703	80.179±6.031			94.614±5.129		
High-angle	644	78.848±5.539			98.914±5.299		
Total	1 403	79.624±5.867			96.463±5.684		

ANOVA, analysis of variance; *n*, number of cases; s.d., standard deviation; UM/PP, inferoposterior crossing angle of the axis of the upper first molar with the palatal plane; LM/MP, anterosuperior crossing angle of the axis of the lower first molar with the mandibular plane.

** $P < 0.01$.

a: computed using $\alpha = 0.05$.

Table 3 ANOVA comparison of compensatory differences of the axial inclination of the maxillary first molars between groups within each stratification

Classification	<12 years		12–16 years		>16 years		P value
	<i>n</i>	(Mean±s.d.)/°	<i>n</i>	(Mean±s.d.)/°	<i>n</i>	(Mean±s.d.)/°	
Angle classification							
1	127	77.625±4.137	366	80.347±5.015	142	85.078±5.132	0.000**
2	145	75.645±5.055	309	77.041±5.130	93	82.147±6.085	0.000**
3	68	78.831±5.619	113	80.773±5.045	40	86.618±5.135	0.000**
P value		0.000**		0.000**		0.000**	
Skeletal classification							
1	132	77.805±4.384	350	79.907±5.026	106	85.329±4.895	0.000**
2	156	75.676±4.838	358	77.619±5.239	132	82.558±5.664	0.000**
3	52	79.070±5.888	80	82.311±4.879	37	87.647±5.855	0.000**
P value		0.000**		0.000**		0.000**	
MP/SN classification							
Low-angle	6	78.093±5.650	33	80.027±5.605	17	85.840±5.834	0.002**
Average angle	168	77.428±5.129	394	79.584±5.438	141	85.118±5.778	0.000**
High-angle	166	76.572±4.846	361	78.512±5.126	117	83.116±5.384	0.000**
P value		0.257		0.013*		0.010*	
Total	340	77.022±5.006	788	79.112±5.327	275	84.311±5.693	

ANOVA, analysis of variance; *n*, number of cases; MP/SN, antero-inferior crossing angle of the mandibular plane with the anterior cranial base plane.

* $P < 0.05$, ** $P < 0.01$.

malocclusion patterns at each growth stage. For children with mixed dentition (<12 years), the UM tipped the most distally in Angle and skeletal Class II cases, tipped the least distally in Class III cases, and the difference was significant ($P < 0.01$) (Table 3). These findings suggested obvious compensatory differences of axial angulation of the UM in the sagittal direction. Additionally, cases in the other two age groups showed similar compensatory changes. That is, the angulation of the UM showed significant compensatory changes to various sagittal malocclusion patterns at each growth stage. With regard to vertical growth patterns, the axial angulation of the UM did not show significant differences ($P > 0.05$) between high angle, average angle and low angle in cases aged <12 years. However, the UM tipped the most distally in high-angle cases and tipped the least distally in low-angle cases for early permanent dentition (12–16 years) and mature permanent dentition (>16 years), and the difference was significant ($P < 0.05$).

Table 3 shows that the maxillary first molars tipped the most distally in cases aged <12 years and tipped the least distally in cases aged >16 years with each malocclusion group, and the difference was significant ($P < 0.01$). These findings suggested that the UM of each malocclusion group tended to tip forward with increasing age.

With respect to the sagittal direction (Table 4), the axial angulation of the LM varied significantly in different malocclusion patterns according to the Angle classification for cases aged <12 years ($P < 0.05$). However, the differences in angulation were $\leq 2^\circ$, i.e., not as large as for the UM. There were no significant differences in the axial angulation of LM between cases aged <12 years with different patterns of skeletal malocclusion. For cases aged 12–16 years or >16 years, LM/MP showed significant differences ($P < 0.01$) between each malocclusion group according to Angle or skeletal classifications. The LM tipped the most distally in Class III patients aged >12 years and tipped the least distally in Class II patients with early

Table 4 ANOVA comparison of compensatory differences of the axial inclination of the mandibular first molars between groups within each stratification

Classification	<12 years		12–16 years		>16 years		P value
	<i>n</i>	(Mean±s.d.)/°	<i>n</i>	(Mean±s.d.)/°	<i>n</i>	(Mean±s.d.)/°	
Angle classification							
1	127	96.310±5.512	366	96.539±5.605	142	96.969±5.901	0.614
2	145	95.754±5.173	309	95.648±5.306	93	94.815±6.486	0.376
3	68	97.722±5.139	113	98.405±5.857	40	99.513±6.414	0.297
P value		0.042*		0.000**		0.000**	
Skeletal classification							
1	132	96.766±5.626	350	96.929±5.484	106	97.171±6.103	0.859
2	156	95.812±5.038	358	95.548±5.544	132	95.532±6.442	0.874
3	52	96.944±5.359	80	98.461±5.568	37	98.852±6.053	0.205
P value		0.219		0.000**		0.009**	
MP/SN classification							
Low-angle	6	89.890±2.163	33	91.151±4.116	17	92.676±5.548	0.347
Average angle	168	94.648±4.807	394	94.398±5.000	141	95.177±5.809	0.300
High-angle	166	98.318±5.146	361	99.190±4.986	117	98.909±6.332	0.215
P value		0.000**		0.000**		0.000**	
Total	340	96.356±5.330	788	96.457±5.592	275	96.610±6.347	

ANOVA, analysis of variance; *n*, number of cases; MP/SN, antero-inferior crossing angle of the mandibular plane with the anterior cranial base plane.

* $P < 0.05$, ** $P < 0.01$.

permanent dentition (12–16 years) or those with relatively mature permanent dentition (>16 years). In the vertical direction, the LM tipped the most distally in high-angle cases and tipped the least distally in low-angle cases, at all growth stages, with a significant difference of $\leq 10^\circ$ ($P < 0.01$).

The data in Table 2 show that LM/MP did not vary with age in all cases ($P > 0.05$). After classification, LM/MP remained stable irrespective of age changes within each malocclusion group (Table 4) ($P > 0.05$). The mandibular first molars maintained the same degree of tipping after eruption without significant variations with age, which was different from the UM. LM/MP was affected primarily by the growth pattern, especially vertical growth (within which the difference in angulation was $\leq 10^\circ$).

DISCUSSION

Björk and Skieller⁴ stated that tooth position changed constantly to compensate for changes of jaw position during growth. Several studies on molar angulation have been carried out, but most have focused on a certain type of malocclusion or the effect of a single factor. Samples from such studies were usually limited to dozens of cases and longitudinal cephalometric analyses. The longitudinal study undertaken by Martinelli *et al.*¹⁸ analysed the angulation of the maxillary first molar of 30 skeletal Class II patients aged 9, 12, 14 and 16 years. Their study showed that the maxillary first molar had a certain regulation of growth, but that this regulation varied among individuals. Hence, studies on the effects of factors other than growth are necessary. In previous studies,^{19–21} we have described different sagittal jaw relationships (i.e., skeletal classification) and vertical jaw development (i.e., mandibular plane classification) as different jaw growth patterns. Here, the difference in compensation of the mesiodistal angulation

of the maxillary first molar was analysed among different jaw growth patterns and age groups. Cephalometric measurements were taken by working out the average landmark location according to three senior orthodontic residents. This method helped to ensure the accuracy of the results.

In a longitudinal study of 40 patients, Kim *et al.*²² found that the maxillary first molar tipped mesially gradually. This finding was consistent with the findings of Björk *et al.*^{6,23} Similar results were noted by Martinelli *et al.*¹⁸ in skeletal Class II patients. In our retrospective study, the longitudinal development of individuals was not followed. Instead, a cross-sectional comparison between different ages was undertaken of 1 403 cases. We observed significantly different angulations of the maxillary first molar among the different age groups. In general, the younger the patient, the more backward tipping of the UM was observed. Given this information, the straight archwire in conventional 0° or 5° buccal tubes on UMs based on 'ideal' adult dentition should be reconsidered if it is used on adolescents (Figure 2). Forward-tipping of the UMs after orthodontic treatment has been noted.^{24–31} A natural, more backward-tipping molar angulation may (at least in part) explain the finding in our previous prospective randomised clinical trial²⁵ that UM anchorage is lost to a greater extent in younger patients.

In the Cheveron analysis by Steiner,¹ incisors were thought to incline to compensate for jaw discrepancies. However, molar compensation is not well documented in the literature. Table 2 and Figure 3 show clear differences in the angulation of the UM in relation to the PP for different patients. Maxillary first molars tended to be more distally inclined in cases of relatively distally positioned mandibular first molars or retrognathic mandibles. It seems that the

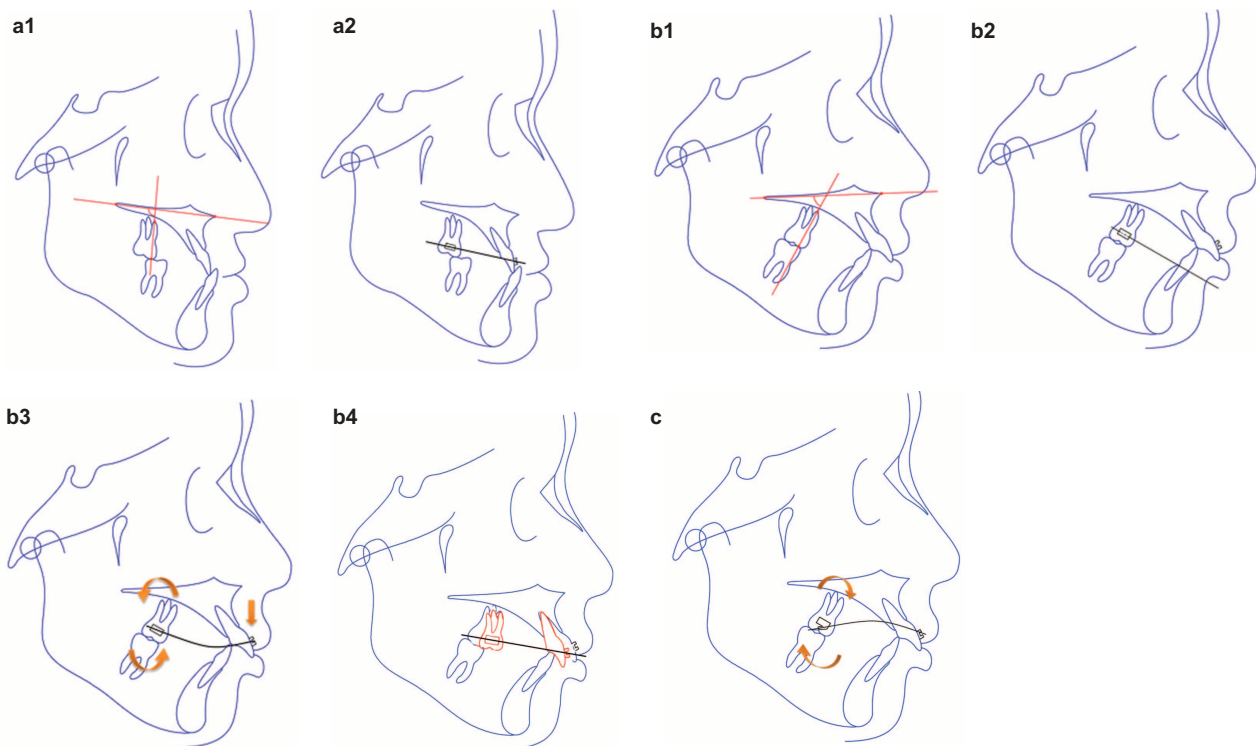


Figure 2 Simulation of alignment and levelling stage. (a) In cases with more mesially inclined maxillary first molars, a NiTi wire in a 0° buccal tube barely affected the molar (a1: tracing of a Class III patient; a2: straight wire in a 0° buccal tube and incisor bracket with no tip-back moment). (b) In cases with more distal-tipping maxillary first molars (especially in younger cases or Class II cases), under the mesial tipping moment from a NiTi wire in a 0° buccal tube, the first molar inclined mesially and anchorage loss occurred upon treatment onset (b1: tracing of a Class II patient; b2: Straight wire in a 0° buccal tube; b3: wire in the 0° buccal tube and incisor bracket with a mesial tipping moment on UM; b4: UM inclined mesially and anchorage loss occurred); (c) In the mechanical sense, adding a tip-back tube may be a good solution for a distal-tipping UM. UM, upper first molar.

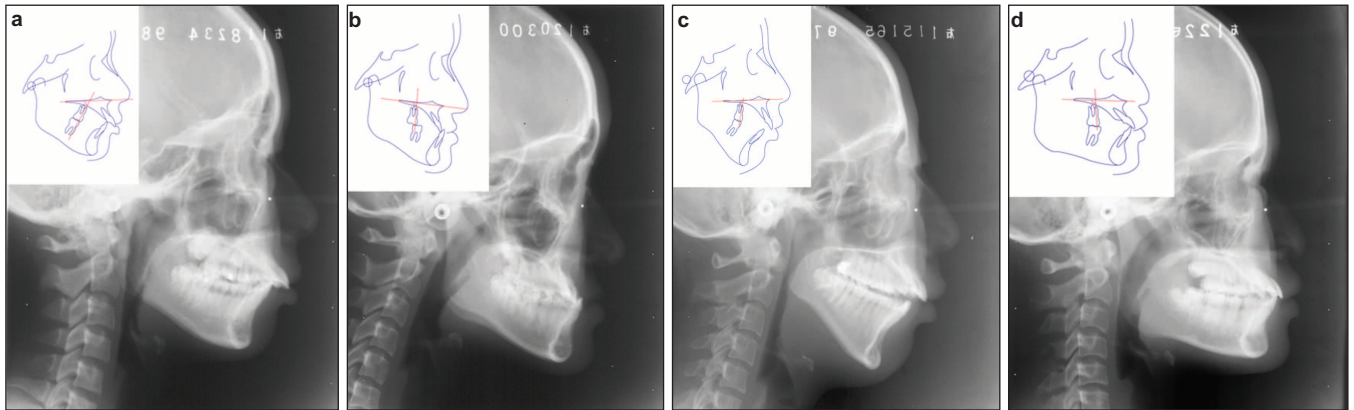


Figure 3 Cephalograms and tracings of patients. (a) Skeletal class II; (b) skeletal class III; (c) high angle; (d) low angle. Differences can be observed in the UM/PP between each group. UM/PP, inferoposterior crossing angle of the axis of the upper first molar with the palatal plane.

maxillary first molar would try to vary its angulation to 'chase' the first molar of the opposite jaw to establish occlusion, irrespective of whether the mandibular first molar or mandible was positioned distally or mesially in relation to it. This tendency for compensation was observed in all age groups. These results are in accord with those of Henry *et al.*³² (i.e., no mesially inclined maxillary first molars in Class II patients) and those of Martinelli *et al.*¹⁸ (i.e., distal inclination or upright molar patterns in Class II patients). Additionally, Kim *et al.*⁷ found that the relationship between molars was affected by differences between the two jaws (including changes in the basal bones, dentition and inclination of teeth). Therefore, the straight archwire in conventional 0° or 5° buccal tubes on UMs should be considered more carefully if it is used on the more distally tipped molars in Class II cases. As shown in Figure 2b, under the mesial tipping moment of a NiTi wire, the first molar tips mesially and then occupies the extraction space, resulting in loss of anchorage. This result implies that molars also compensate for the jaw relationship just as incisors do; it also implies that prescription of the buccal tube based on the ideal final angulation of molars may not apply to cases whose molars have not grown to their final angulation in adolescence or whose basal bones are not in an ideal relationship. From a mechanical perspective, adding a tip-back tube³³ may be a good solution for the compensatory backward-tipping molars (Figure 2c).

In the present study, the vertical classification was made according to MP angles. High-angle cases had the most distally angled first molars, followed by average-angle cases, and low-angle cases had the most mesially angled molars. The differences between high, average and low angles were significant. This result shows that, apart from sagittal compensation, the position of the maxillary first molar also has vertical compensation, with a greater degree of distal inclination in cases of larger MP angles and *vice versa*. Our findings are in accord with those of Björk *et al.*,⁴ who observed a tendency of posterior teeth in clockwise-rotated mandibles to incline distally. Additionally, Chang and Moon³⁴ found that in long faces and open-bite cases, UMs were more distally inclined in relation to the PP and the occlusal plane. Liao *et al.*³⁵ also showed increased inclination of the maxillary molars with increased MP angle, but Kim *et al.*³⁶ and several orthodontists^{37–38} did not. This observation might provide an additional explanation regarding why high-angle cases tend to lose anchorage more easily,³⁵ in addition to the explanation of weak masticatory forces.

Our results show that the maxillary first molars (which are usually employed as anchorage teeth) have varied mesiodistal angulations that are affected by growth stages, malocclusion classification, and jaw

growth patterns. Almost all UM buccal tubes have the same angulation based on ideal normal occlusion as demonstrated by Andrews.² Hence, the forward tipping moments on molars may be larger for growing adolescents, Class II cases and/or high-angle cases than for adults, Class III cases and/or low-angle cases if using the same straight archwire (Figure 2b) due to differences in the initial molar angulation. Tipping compensatory molars into ideal molar angulation with a straight archwire might cause early loss of anchorage, exaggerate the Class II molar relationship and reduce the natural occlusal curve, which could increase the risk of instability.³⁹ Within single sagittal or vertical malocclusion classifications, the angulation of the mandibular first molar did not show significant differences in the different age groups evaluated. This result shows that the LM/MP retains a certain angulation that is affected by malocclusion classification and jaw growth pattern but not by growth stages.

From the results described above, we can deduce that the driving force for upper molar compensation is growth of the mandible. Maxillary growth lags behind that of the mandible. Hence, through intercuspation, the upper teeth will experience forward tipping forces. These tipping forces are in accord with the direction of tooth growth, so the upper dentition moves ahead of the basal bone. The upper incisors and posterior teeth tip forward. The lower teeth experience opposite intercuspation forces. However, because they oppose the direction of tooth growth and there is no room for the lower teeth to move backward, they seldom vary their angulation with age. This hypothesis could enable a new treatment strategy to be developed if it can be validated in future studies.

In the 1 403 cases evaluated in the present study, significant differences were observed among LM angulations in different Angle classifications and sagittal skeletal classifications, with a more mesially angled LM in retrognathic mandible cases or relatively distally located LM cases and *vice versa*. All age groups showed sagittal compensation of the LM, and apart from the <12 year group, the differences among the sagittal classifications were significant. In all subjects and age groups, LM angulation was strongly affected by vertical variations. The higher the mandibular angle, the more the molars tipped distally, and this difference was significant. The maximum difference in angulation could reach ~10°. Therefore, compensation of the LM is obvious in the different types of malocclusions and jaw growth patterns. These findings are in accord with those of Chang and Moon,³⁴ and Liao *et al.*³⁵

Our results also show that the compensation between the UM and the LM in different malocclusion classifications is linked. This linkage is similar to the finding of compensation of the anterior teeth

in the study by Steiner *et al*. In the sagittal direction, Class II cases or retrusive-mandible cases have a more distal-tipping UM and more mesial-tipping LM. In Class III cases or protrusive-mandible cases, the compensation of molar angulation is reversed. Vertically, UM and LM are more distal-tipping in high-angle cases, whereas in low-angle cases, they are both more mesial-tipping. These results show that teeth self-adjust their angulation to reach and establish occlusion with the opposing counterpart if insufficient or excessive jaw growth is present.

This retrospective study explored the positional differences and dental compensations of maxillary and mandibular first molars at different developmental stages in 1 403 cases. Björk and Skieller⁴ investigated the compensatory changes of teeth during development, and many studies on this topic have been carried out in anterior teeth. However, studies on molar compensation have been limited due to few samples, few results and contradictory conclusions. A better understanding of molar compensation in different growth stages, malocclusion classifications and jaw growth patterns is necessary for clearer diagnosis and better treatment.

CONCLUSIONS

Maxillary and mandibular first molars experience differences in angulation at different growth stages. The maxillary first molar was more distal-tipping in adolescents and became relatively mesial-tipping in adults. This difference was significant. For mandibular molars, the angulation was relatively stable and was maintained at certain angulations during different developmental stages.

The compensation of molar angulation varied among different classifications of sagittal malocclusion. Variations of the UM and LM with malocclusion patterns were linked to each other. In Angle Class II and skeletal Class II cases, if the lower teeth or bone were in a relatively distal position compared with the opposing counterpart, the maxillary first molar would be more distally inclined, whereas the mandibular first molar would be more mesially inclined. The opposite was true in Class III cases.

The compensation of molar angulation also varied among different vertical jaw relationships, with linkage between variations in the UM and the LM. In high-angle cases, both molars were more distal-tipping. In low-angle cases, both molars were mesial-tipping.

Clinicians must avoid using a straight archwire in a 0° buccal tube on more distal-tipping first molars with regard to anchorage control.

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