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Original Paper

Relationship between the position of the maxillary molars and the infrazygomatic crest morphology

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Abstract

This study aimed to evaluate the morphological characteristics of the infrazygomatic crest with various jaw morphologies, occlusal forces, and maxillary first molar position in three dimensions to explore various factors that affect the morphology of the infrazygomatic crest, and to obtain knowledge regarding the ideal maxillary first molar position. Seventy-three Japanese subjects (32 males with a mean age of 22.50 ± 6.23 years and 41 females with a mean age of 25.17 ± 6.78 years) had their occlusal force measured and underwent cone-beam CT for orthodontic treatment. The subjects were categorized into the following three groups based on the mandibular plane angle (Mp): hypodivergent group (Mp<23°), normodivergent group (Mp 23°-30°), and hyperdivergent group (Mp ≥ 30°). Subjects were also divided into two groups based on the maxillary first molar positions: mesial and distal. The thickness of the infrazygomatic crest was evaluated using cross-sectional cone-beam CT images obtained in the coronal and axial planes. The thickness of the infrazygomatic crest in the coronal plane significantly differed among the hypodivergent, normodivergent, and hyperdivergent groups and between the mesial and distal groups. The thickness of the infrazygomatic crest in the axial plane significantly differed among the hypodivergent, normodivergent, and hyperdivergent groups. In conclusion, differences in the maxillary first molar position and the vertical skeletal pattern may affect the morphology of the infrazygomatic crest.

Key words: cone-beam CT, maxillary molars, jaw morphology, infrazygomatic crest

Introduction

The maxillary first molar was first considered to be the key to occlusion by Angle[1] and Helman[2], and the maxillary first molar was defined as a molar that does not need to be changed because its natural position was correct. However, Tweed[3] treated a case with incompatibility between the alveolar bone and tooth size by extracting a premolar, and set the incisor mandibular plane angle as a treatment goal. Later, Andrews[4] proposed six characteristics (molar relationship, crown angulation, crown inclination, rotation, spaces, and occlusal plane) for normal occlusion. At present, most orthodontic treatment is based on these goals, while the position of the first molar in relation to the maxillofacial morphology has not been adequately considered.

In recent years, with the advent of the temporary anchorage device, the concept of fixation in orthodontic treatment has changed and it is now possible to move molars significantly without considering the reaction forces applied to the teeth. We therefore need to better understand the influence of large tooth movement on maxillofacial bone morphology.

Atkinson[5] suggested that there is an inherent relationship between the position of the infrazygomatic crest and the maxillary first molars. Recently, several biomechanical studies have reported the dynamics of occlusal loading[6-9]. Finite element analysis has confirmed the importance of the infrazygomatic crest in the load transfer of occlusal forces to the maxilla[6,7]. However, the factors related to the three-dimensional morphology of the

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infrazygomatic crest are unknown.

Cone-beam CT (CBCT) is used not only for craniofacial analysis, but also for the evaluation and simulation of orthognathic surgery and implant treatment due to its high resolution and low radiation exposure[10–12]. Numerous studies have used CBCT to assess maxillofacial morphology; the morphology of the infrazygomatic crest has been assessed to determine the suitable placement of a temporary anchorage device and miniplates[13–16]. No studies, however, have focused on the relationship between the morphology of the infrazygomatic crest and the positions of the maxillary molars, or explored the factors that influence the morphology of the infrazygomatic crest. Previous studies have suggested that maxillofacial morphology is influenced by sex, bite force, masticatory muscle activity, and vertical skeletal patterns, and that these factors may also influence the infrazygomatic crest morphology[17–19].

The aims of this study were to evaluate the characteristics of the infrazygomatic crest with various jaw morphologies, occlusal forces, and maxillary first molar position in three dimensions, to identify the factors that affected the morphology of the infrazygomatic crest, and to investigate the ideal maxillary first molar position.

Materials and Methods

Subjects

The study cohort included 73 individuals 32 males with a mean age of 22.50 ± 6.23 years; 41 females with a mean age of 25.17 ± 6.78 years) who visited the Department of Orthodontics, Showa University Dental Hospital, and underwent occlusal force measurements and CBCT for the purpose of orthodontic treatment.

The vertical skeletal patterns of the maxillofacial morphology were used to classify the subjects into three groups based on the mandibular plane angle (Mp): hypodivergent group (Mp<23°; 13 males, 10 females), normodivergent group (Mp 23–30°; 11 males, 13 females), and hyperdivergent group (Mp ≥ 30°; eight males, 18 females)[20]. Furthermore, the anterior-posterior position of the palatal root of the maxillary first molar in the sagittal plane was used to categorize the subjects into two groups: mesial group (palatal root apex of the maxillary first molar located proximal to the coronal reference plane; 24 males, 32 females), and distal group (palatal root apex of the maxillary first molar located distal to the coronal reference plane; eight males, nine females; Fig. 1). The classifications of patients are shown in Table 1.

The subjects had no history of systemic diseases or jaw deformities. All subjects gave written informed consent and the study was approved by the Ethics

Table 1. Group classifications based on vertical skeletal pattern and maxillary first molar position

	Males	Females	Total
Skeletal pattern			
Hypodivergent	13	10	23
Mesodivergent	11	13	24
Hyperdivergent	8	18	26
Molar position			
Mesial	24	32	56
Distal	8	9	17

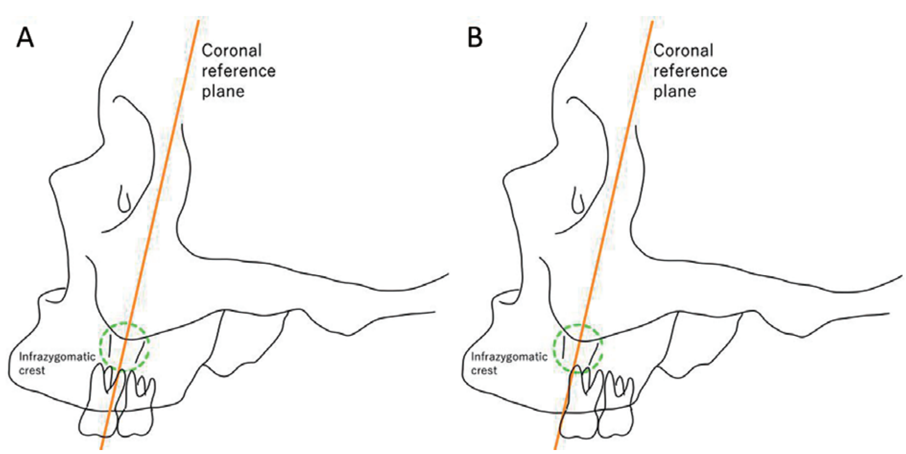

Fig. 1. Classification of the maxillary first molar position. A. mesial group: palatal root apex of the maxillary first molar located proximal to the coronal reference plane. B. distal group: palatal root apex of the maxillary first molar located distal to the coronal reference plane.

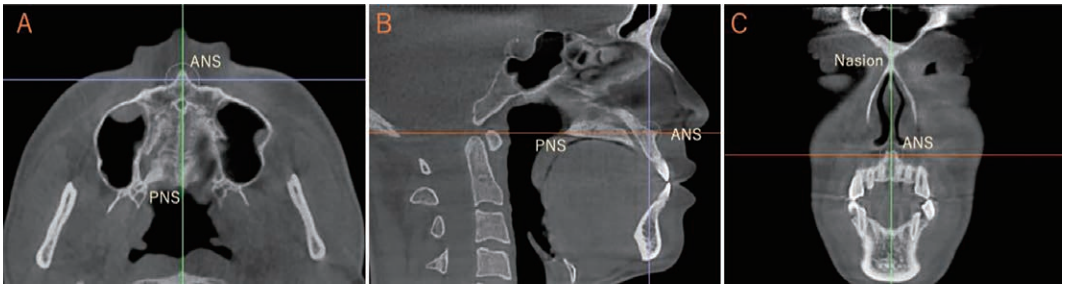

Fig. 2. Cone-beam CT sections used to obtain the measurements. A. axial section ; B. sagittal section ; C. coronal section.
ANS : anterior nasal spine ; PNS : posterior nasal spine.

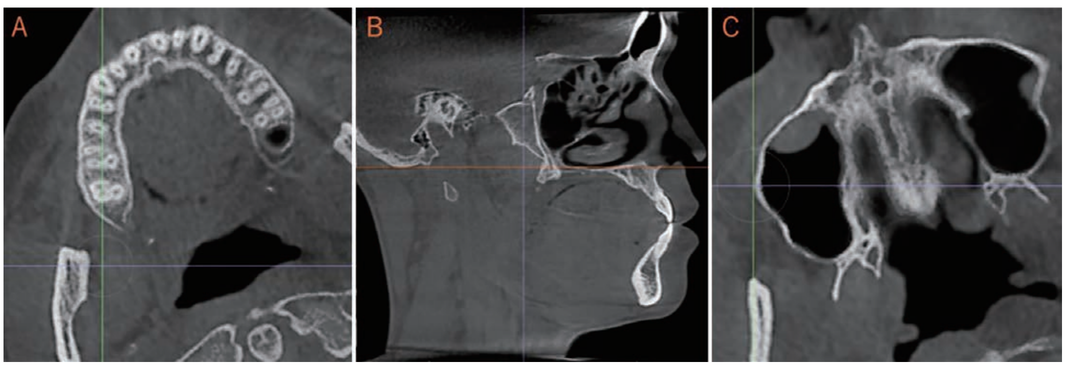

Fig. 3. Setting the axial and coronal reference planes. A. The green line passes through the furcation of the maxillary right molar and maxillary right canine root. B. The red line passes through the anterior nasal spine (axial reference plane). C. The blue line crosses the most prominent point of the infrazygomatic crest (coronal reference plane).

Committee of Showa University Dental Hospital (approval number : SUDH0056).

Occlusal force measurement

The bite force was measured using a film consisting of pressure-sensitive sheets (Dental Prescale II, G.C. Corporation, Tokyo, Japan) and analyzed with specified software (Bite Force Analyzer ver. 1.01, 2018, G.C. Corporation).

CBCT measurement of the infrazygomatic crest

CBCT images were acquired using a KaVo 3DeXam (KaVo, Dental, Biberach, Germany) in the Department of Radiology, Showa University Dental Hospital. The scanning conditions were : 120 kV and 5 mA, voxel size 0.4 mm, scan time 7.0 s. CBCT images were converted to Digital Imaging and Communications in Medicine format and analyzed using Invivo5 software (Anatomage, San Jose, CA).

The measurement method was based on a previous study[13]. The volume data were uploaded into the software, and the 3D images were manually oriented with respect to the anterior nasal spine (ANS), posterior nasal spine (PNS), and nasion points on the CBCT images (Fig. 2).

The axial plane was oriented so that the root furcations of the maxillary right molar and canine root became collinear with the green line (Fig. 3A). The axial reference plane was defined as the plane parallel to the axial plane that passed through the ANS (Fig. 3B). In the axial reference plane, the most prominent point of the surface of the infrazygomatic crest was selected to draw the coronal reference plane (Fig. 3C). The coronal reference plane was defined as the plane passing through the most prominent point and parallel to the coronal plane.

In the coronal reference plane, the most inferior border of the zygoma to the alveolar crest process was vertically divided into eight equal sections, with each height defined as H1 to H7 (Fig. 4A). In the vertical reference plane, the thickness of the cortical bone was measured perpendicular to the bone surface at H3 to H7. In the axial plane from H3 to H7, the thickness of the cortical bone at the most protruding part was measured perpendicular to the bone surface (Fig. 4B).

The thinnest measured values were specified as the

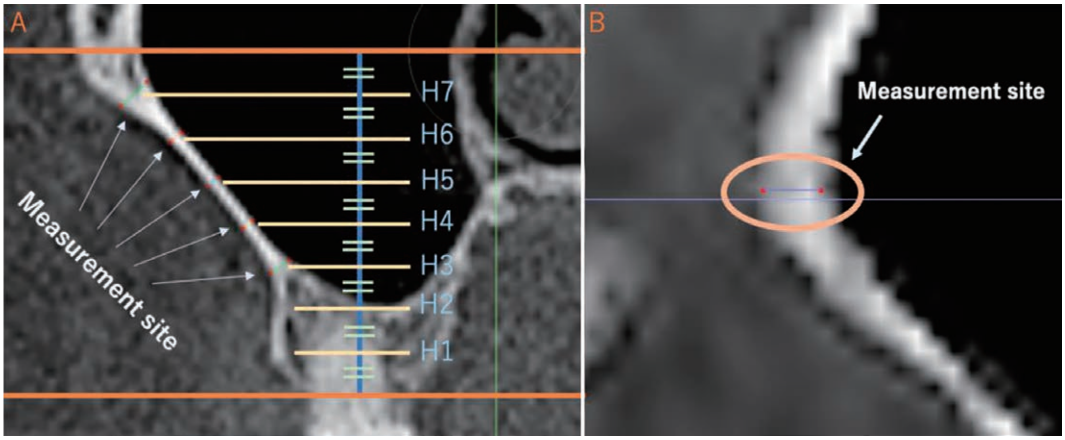

Fig. 4. Morphological measurement of the infrazygomatic crest. A. Measurement of the cortical bone thickness at H3 to H7 in the coronal reference plane. B. Measurement of the cortical bone thickness at H3 to H7 in the axial plane.

Table 2. TICC and TICA measurements in all groups

	TICC	TICA
Hypodivergent group	1.40 ± 0.65 mm	2.00 ± 0.60 mm
Mesodivergent group	1.01 ± 0.36 mm	1.63 ± 0.36 mm
Hyperdivergent group	1.10 ± 0.45 mm	1.70 ± 0.63 mm
Mesial group	1.24 ± 0.56 mm	1.84 ± 0.60 mm
Distal group	0.90 ± 0.24 mm	1.55 ± 0.34 mm

Data are presented as the mean ± standard deviation
TICC : thickness of the infrazygomatic crest in the coronal plane
TICA : thickness of the infrazygomatic crest in the axial plane

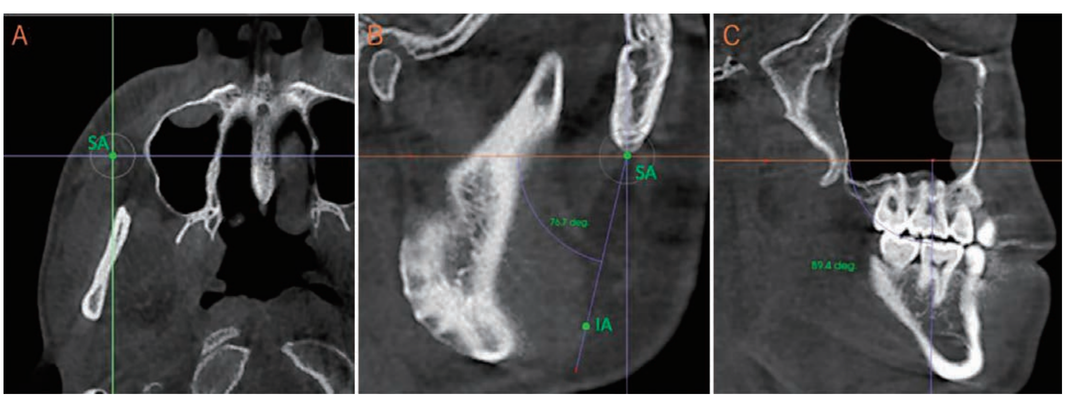

Fig. 5. Setting the landmarks of the masseter muscle and measuring the angle of the masseter muscle and maxillary first molar. A, B. SA and IA points. B. Measurement of the angle of the masseter muscle to the palatal plane. C. Measurement of the angle of the maxillary first molar to the palatal plane.
SA : most superior and anterior part of the masseter muscle ; IA : most inferior and anterior part of the masseter muscle.

thickness of the infrazygomatic crest in the coronal plane (TICC) and the thickness of the infrazygomatic crest in the axial plane (TICA), respectively. The CBCT measurement parameters for each group are shown in Table 2. Only symmetrical patients were selected, and only the right side was measured because the cortical bone thickness was similar bilaterally.

Table 3. Classifications based on the vertical skeletal pattern and maxillary first molar position

Hypodivergent group: Mp angle $<$ 23°
Normodivergent group: Mp angle 23–30°
Hyperdivergent group: Mp angle ≥ 30°
Mesial group: palatal root apex of the maxillary first molar located proximal to the coronal reference plane
Distal group: palatal root apex of the maxillary first molar located distal to the coronal reference plane

Mp angle measured by CBCT
Mp: mandibular plane

Measurement of the angle between the masseter and the maxillary first molar (AMM)

The measurement of the angle of the masseter muscle was based on a previous study[20]. The 3D image was manually oriented with respect to the ANS, PNS, and nasion points on the CBCT image. Landmarks were then placed at the most superior and anterior parts of the masseter muscle (SA) and most inferior and anterior parts of the masseter muscle (IA; Fig. 5A, B).

The angle of the masseter muscle was measured as the angle formed by the line extending from SA and IA to the palatal plane. The angle of the first molar was determined by measuring the angle formed between the line passing through the root furcation of the mesiobuccal and distobuccal roots and the central fossa to the palatal plane (Fig. 5C). The AMM was calculated by subtracting the angle of the masseter muscle from the angle of the first molar.

Statistical analyses

The following factors related to the morphology of the infrazygomatic crest were analyzed to determine whether they had a statistically significant effect on the TICC and TICA: bite force, vertical skeletal patterns, AMM, and sex or age.

At the start of the study, the required sample size was calculated using G*Power (Heinrich-Heine-Universität, Düsseldorf, Germany) based on research by Santos *et al.*[14]. The expected TICC was 0.698 ± 0.134 mm for males and 0.789 ± 0.127 mm for females. To detect significant differences between males and females, the required sample size was calculated as 34 subjects per group and 68 subjects in two groups. Therefore, 32 males and 41 females were enrolled.

The normality of continuous data (such as the bite force, AMM, TICC, and TICA) was confirmed using the Shapiro-Wilk test. As these data were non-normally distributed for most factors, the analysis was performed using a nonparametric statistical method (Spearman's correlation coefficient) while assessing potential sex differences.

For categorical data (such as the vertical skeletal pattern and maxillary first molar position), factors with three or more categories were analyzed using the Kruskal–Wallis test, and factors with two categories were analyzed using the Mann–Whitney U test. The criteria used for these classifications are shown in Table 3.

SPSS Statistics 25 (IBM Corporation, Armonk, NY, USA) was used for statistical analyses. The significance level was set at $\alpha = 0.05$ (two-sided), and $p < 0.05$ was considered significant.

All digital measurements were performed by a single previously calibrated operator under identical conditions at two different times, with the second following a two-week interval. The mean intraclass correlation coefficient was 0.97, and the random error evaluation showed that the magnitude of measurement error was small.

Results

Factors related to the TICC

Statistical results are shown in Tables 4 and 5.

Sex or age

The TICC was significantly larger in females than males ($p = 0.012$), and was significantly correlated with age ($p = 0.048$). Therefore, sex and age were included in the analysis of factors that affected the TICC.

Bite force

The bite force was not significantly correlated with

Table 4. Analysis of the factors related to the TICC

Factors	Categories	*p* value
Sex	Male, female	0.01
Age	Years	0.05
Bite force	Measured values (N)	0.71
Vertical skeletal pattern	Classification	0.04*
Maxillary first molar position	Classification	0.02*
AMM	Measured value (degrees)	0.52

*$p<0.05$
TICC: thickness of the infrazygomatic crest in the coronal plane
AMM: angle between the masseter and the maxillary first molar

Table 5. Multiple regression analysis of the variables related to the TICC

Variable	Unstandardized coefficients		Standardized coefficients	t value	*p* value
	B	Standard error	Beta		
Constant	1.62	0.4		4.07	0
Sex	0.16	0.12	0.15	1.33	0.19
Age	0.01	0.01	0.17	1.47	0.15
Vertical skeletal pattern	−0.15	0.07	−0.23	−2.04	0.05
Maxillary first molar position	−0.32	0.14	−0.27	−2.39	0.02

Dependent variable: thickness of the infrazygomatic crest in the coronal plane (TICC)

the TICC ($p = 0.706$) or sex of the patient.

Vertical skeletal pattern

The TICC differed significantly among the hypodivergent group, normodivergent group, and hyperdivergent groups ($p = 0.039$: Kruskal–Wallis test). Furthermore, the TICC differed significantly between the normodivergent and hypodivergent groups ($p = 0.045$: Bonferroni's method).

Maxillary first molar position

The TICC differed significantly between the mesial and distal groups ($p = 0.017$).

Measured AMM

The measured AMM was not significantly correlated with the TICC ($p = 0.518$) or sex of the patient.

Subsequently, the factors that were significantly correlated in the univariate analysis (sex, age, vertical skeletal pattern, and maxillary first molar position) were used as explanatory variables, and associations were examined using multiple regression analyses with the TICC as the objective variable. The vertical skeletal pattern and maxillary first molar position were significantly related to the TICC, even after adjustments for age and sex.

Factors related to the TICA

Statistical results are shown in Table 6.

Sex or age

The TICA did not significantly differ between males and females ($p = 0.058$) or in accordance with age ($p = 0.068$). However, as the differences in the TICA were marginally significant for both sex and age ($p<0.1$), the effects of sex and age were also considered in the analysis of factors that affected the TICA.

Bite force

The bite force was not significantly correlated with the TICA ($p = 0.711$) or sex of the patient.

Table 6. Analysis of the factors related to the TICA

Factors	Categories	*p* value
Sex	Male, female	0.06
Age	Years	0.07
Bite force	Measured values (N)	0.71
Vertical skeletal pattern	Classification	0.05*
Maxillary first molar position	Classification	0.08
AMM	Measured values (degrees)	0.51

*$p < 0.05$
TICA: thickness of the infrazygomatic crest in the axial plane
AMM: angle between the masseter and the maxillary first molar

Vertical skeletal pattern

The TICA differed significantly among the hypodivergent, normodivergent, and hyperdivergent groups ($p = 0.048$; Kruskal–Wallis test). However, there was no significant difference between any two of the three groups.

Maxillary first molar position

The TICA did not significantly differ between the mesial and distal groups ($p = 0.083$).

Measured AMM

The AMM was not significantly correlated with the TICA ($p = 0.514$) or sex of the patient. As only the vertical skeletal pattern classification showed a significant association with the TICA, multiple regression analysis was unnecessary.

Discussion

We evaluated the morphology of the infrazygomatic crest to investigate the factors that affect the morphology of the infrazygomatic crest and to gain knowledge about the ideal maxillary first molar position.

The measurement results showed a significant difference in the TICC between groups classified according to vertical skeletal morphology and between groups classified according to the maxillary first molar position, and a significant difference in the TICA between groups classified according to the vertical skeletal morphology.

Our results showed no significant difference between the magnitude of occlusal force and the thickness of the infrazygomatic crest. A study on the amount of secondary bone generated by mechanical loading in crab-eating monkeys suggested that the incidence of bone remodeling may be closely related to the frequency of mechanical loading rather than the magnitude of bone strain[21]. The thickness of the infrazygomatic crest is therefore expected to be strongly influenced by the frequency of occlusion and the duration of the occlusal force that was exerted. Further investigation of these factors is needed.

The present study focused on the masseter muscle, which has the largest volume among the masticatory muscles, excluding the temporalis muscle[22]; measurements were conducted based on the assumption that the closer the masseter muscle runs parallel to the first molar, the greater the occlusal force transmitted to the infrazygomatic crest and the greater the thickness of the infrazygomatic crest. However, there was no significant relationship between the AMM and the thickness of the infrazygomatic crest. Maki *et al.*[10] reported that the direction of growth of the mandibular head is related to the vector of reaction force applied to the mandibular head calculated from the strength and the vector of masticatory muscles such as the masseter, temporalis, medial pterygoid, and lateral pterygoid muscles. This suggests that not only the masseter muscle but also the strength and vector of the masticatory muscles may be involved in the vector of the occlusal force transmitted to the infrazygomatic crest.

We also evaluated the relationship between the vertical skeletal morphology and the thickness of the infrazygomatic crest. The hypodivergent group tended to have a thicker infrazygomatic crest than the normodivergent group. This may be because the hypodivergent group had more active masticatory muscles overall. It is assumed that not only the masseter muscle but also factors related to other masticatory muscles (such as the occlusal force, occlusal frequency, and occlusal time) tended to increase the thickness of the infrazygomatic crest,

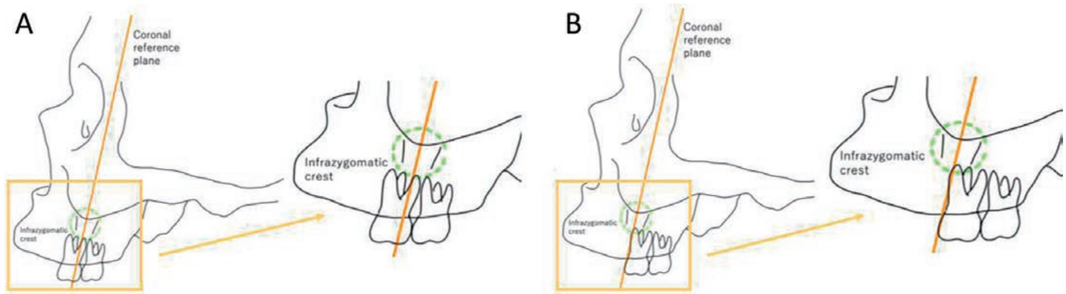

Fig. 6. Illustrations showing the molar positions in the mesial and distal groups. A. In the mesial group, the maxillary first and second molars are located just below the infrazygomatic crest. B. In the distal group, the maxillary second molar is far from the infrazygomatic crest.

which is the occlusal support area. Our results differed from those reported by Vargas, Lima, and Nojima[15] who found no significant difference in the thickness of the infrazygomatic crest between subjects classified by vertical skeletal patterns[13]. This discrepancy may be due to differences in the measurement sites. Vargas, Lima, and Nojima[15] performed morphometric measurements at the site of miniscrew implantation in the infrazygomatic crest; however, this area of the infrazygomatic crest is close to the roots of the maxillary molars, which affects the infrazygomatic crest morphology. In the present study, the infrazygomatic crest measurements were made at a site that was far from the roots of the maxillary molars, so the morphology of the infrazygomatic crest was not affected by the roots of the maxillary molars.

The difference in the anterior-posterior position of the maxillary first molars and the thickness of the infrazygomatic crest were also evaluated. In the mesial group (Fig. 6A) with the maxillary first molar located anterior to the infrazygomatic crest, both the maxillary first and second molars were close to the infrazygomatic crest. In contrast, in the distal group (Fig. 6B), the maxillary second molar was more distant from the infrazygomatic crest. Furthermore, according to a previous study, the occlusal force is greatest in the maxillary first molar, followed by the maxillary second molar, and these occlusal forces are greater than those of other tooth types[23]. This suggests that the large occlusal forces exerted by the maxillary first and second molars near the infrazygomatic crest are easily transmitted to the infrazygomatic crest in the mesial group more than in the distal group, and that there is a tendency for the infrazygomatic crest to be thicker in the mesial group than the distal group.

The present study has one main limitation. There was a relatively large difference in the sizes of the groups based on the maxillary first molar position, with 56 patients (24 males, 32 females) in the mesial group and 17 patients (eight males, nine females) in the distal group. However, we measured the morphology of the infrazygomatic crest, which is considered the main occlusal force support area in the maxillofacial region, in detail in three dimensions and showed the factors related to the morphology of the infrazygomatic crest.

The morphology of the infrazygomatic crest may be affected by the morphology of the crown and root of the maxillary first molar. Further investigation is warranted.

It remains challenging for orthodontists to determine the optimal maxillary first molar position in relation to the craniofacial morphology, periodontal tissues, and soft tissues to improve malocclusion by orthodontic treatment. The present results suggested that excessive distal movement of the maxillary molars may result in a posteriorly deviated occlusal force-bearing area and increased occlusal force-bearing posterior to the infrazygomatic crest. The maxilla with distally moved molars is thought to undergo greater compressive deformation at the posterior of the maxilla[8]. Further investigation is needed to determine the effect of this change in the occlusal support area on the craniomaxillofacial skeleton and stability after orthodontic treatment.

Conflict of interest disclosure

The authors declare that there are no conflicts of interest.

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