SCIENTIFIC SECTION

Morphological observation of the medial pterygoid muscle by the superimposition of images obtained by lateral cephalogram and MRI

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Objective: To observe the morphological relationship between the maxillofacial skeleton and medial pterygoid muscle by superimposing images constructed by MRI on a cephalogram.

Design: Cross-sectional study.

Setting: The Departments of Maxillofacial Orthognathics and Orthodontics, Tokyo Medical and Dental University.

Participants: Sixteen patients (5 males and 11 females, aged between 13.5 and 27.5 years) with various craniofacial skeletal patterns, who were about to start orthodontic treatment.

Methods: Lateral cephalometric radiographs and MRI scans were obtained and their images uploaded to a computer using a digitizer. The area of the medial pterygoid muscle was selected by binarization from the MRI. The mid-sagittal-plane MRI with a complete superimposed sagittal image of the medial pterygoid muscle was superimposed on the cephalogram using anatomical structures situated in the mid-sagittal plane of the head and shapes that could be identified from both the radiograph and the MRI image.

Results: These combined images showed various shapes of the medial pterygoid muscle. The inclination axis of the medial pterygoid muscle was correlated with various cephalometric variables including SNB ($r=0.658$), Facial angle ($r=0.601$), ramus inclination ($r=0.676$) and Ba-Po% ($r=0.585$).

The volume of the medial pterygoid muscle was also correlated with cephalometric variables such as ramus inclination ($r=0.453$), Ba-Nmm ($r=0.676$), Ba-Po% (depth) ($r=0.447$), Ar-Go% (depth) ($r=0.444$) and Ar-Go% (actual length) ($r=0.532$).

Conclusions: Morphometric analysis using a superimposed image of the medial pterygoid muscle produced from a cephalogram and MRI may help explain the influence of the medial pterygoid muscle inclination axis and volume on the shape of the mandibular bone, especially the shape of the ramus.

Key words: Medial pterygoid muscle, MRI, cephalogram, superimposition, ramus

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Introduction

The growth and development of the craniofacial skeleton is affected by functional factors involving muscle and soft tissue.[1–13] Various studies have investigated these mechanisms, including the relationships between jaw-muscle cross-sectional area and craniofacial morphology[1,2,9,11] and jaw-muscle volume and craniofacial morphology.[3–5,12,13]

The medial pterygoid muscle connects the inside angle of the mandible to the external plate of the pterygoid process of the sphenoid bone, and it functions with the masseter muscle to pull the mandible upward. Since the shape and orientation of the medial pterygoid muscle and masseter muscle are similar, both are considered to play an important role in the morphogenesis of the maxillary and mandibular bone.

The aim of the current study was to undertake morphological observations of the relationship between the shape and orientation of the medial pterygoid muscle and relate this to the craniofacial morphology in patients with various skeletal patterns. A second objective was to investigate whether the orientation and volume of the medial pterygoid is significantly

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correlated with craniofacial morphology by superimposing magnetic resonance imaging (MRI) images on the corresponding cephalograms.

Subjects and methods

The project was approved by The Ethical Review Committee of Tokyo Medical and Dental University (Ref. No. 344/2008).

Samples

The participants were selected from patients about to undergo treatment in the Orthodontic Department of Tokyo Medical and Dental University. To observe the morphological relationship between muscle and the craniofacial skeletal pattern, 16 patients (5 males and 11 females, aged between 13.5 and 27.5 years, mean: 26.2 years for males and 19.1 years for females) with various craniofacial skeletal patterns were approached. The purpose of the study was explained and informed consent obtained. No one refused to take part in the study.

The following examinations were carried out before the start of their orthodontic treatment.

Lateral cephalograms and magnetic resonance imaging (MRI)

The methods used to obtain and superimpose the lateral cephalogram and MRI images were those described by Higashino.[13] Prior to the examination, the patients were instructed to bite into paraffin wax in the intercuspal position, and a wax bite in this occlusal position was prepared. When undertaking the lateral cephalometric radiograph and MRI scan (1.5 T superconducting MRI system, Magnetom Vision, Siemens AG, Erlangen, Germany), the patients were instructed to occlude into the previously prepared wax bite so that the maxillo-mandibular positional relationship would not change during imaging. Lateral cephalometric radiography was performed in the sitting position using a standard method. The MRI scan was performed supine with the subject positioned so that the Frankfort plane and the mid-sagittal plane were at a right angle to the plane of the scanner bed. Magnetic resonance imaging scanning was executed in the sagittal direction. T1-weighted images (TR/TE=650/14 msec) were used. Scanning was conducted in three areas (mid-sagittal area and left and right areas of the medial pterygoid muscle), and in each area 20 3 mm-thick slices were scanned with 1-mm movement of the slice site.

Selection and construction of images of the medial pterygoid muscle

The image files of the cephalograms (in bmp format) and MRI scans (in dicom format) were uploaded to computer using a digitizer. The area of the medial pterygoid muscle was selected by binarization (two-level thresholding: a method to convert image with various grey-level into 2 grey-level by choosing threshold values) from the MRI images, using Volume Rugle image-processing software (Medic Engineering, Kyoto, Japan), that were input in layers, and these layers were superimposed using the scale-line displayed on each MRI screen as a reference-axis so that all medial pterygoid muscle images could be projected on the mid-sagittal plane of the MRI.

Superimposition of MRIs and cephalograms

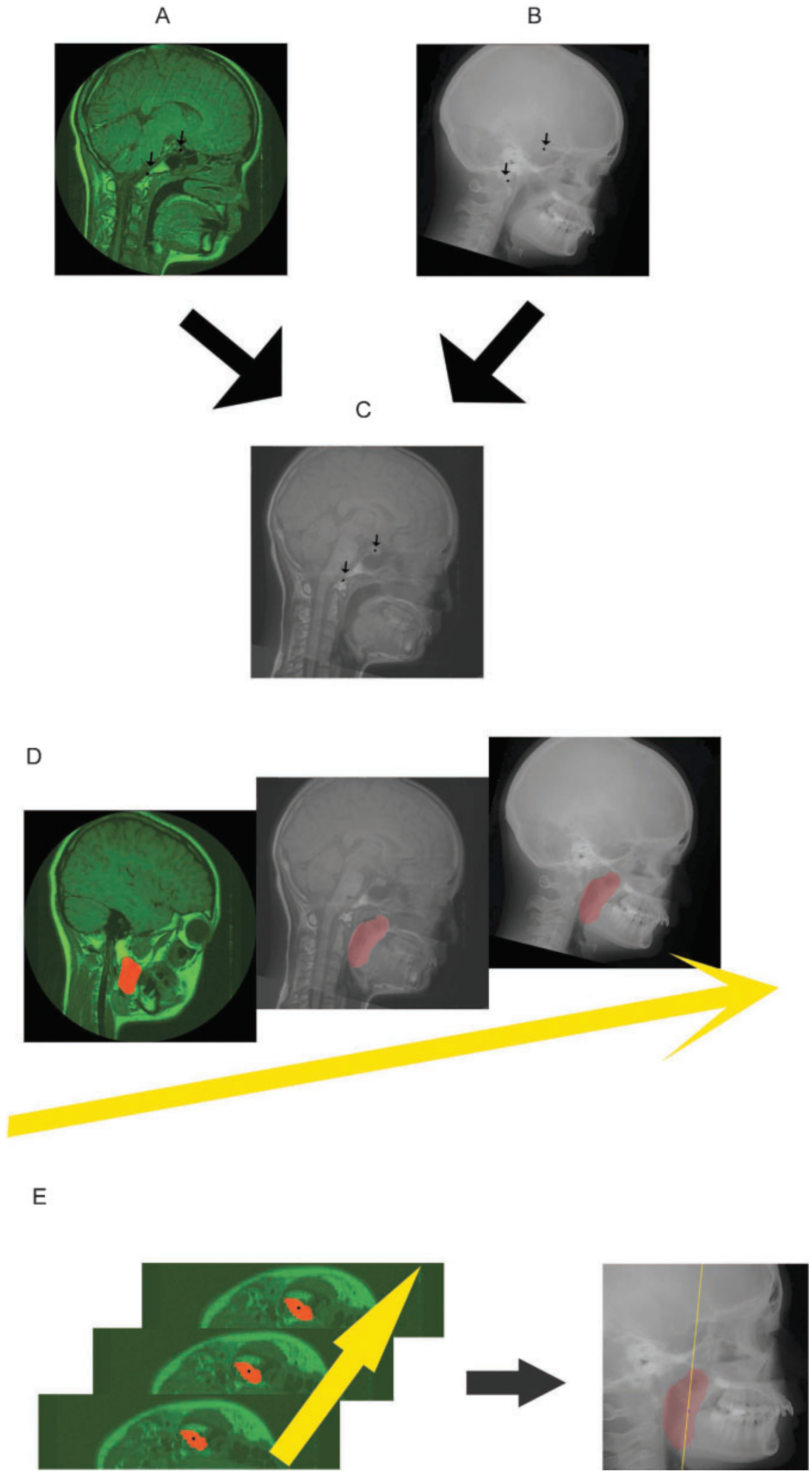
The mid-sagittal-plane MRI with a complete superimposed sagittal image of the medial pterygoid muscle was superimposed on the cephalogram. Hard and soft tissues were shown in black and white inverted in the radiograph and MRI images. Anatomical structures situated in the mid-sagittal plane of the head and shapes that could be identified from both the radiograph and the MRI image were used as references for superimposing the images. The following structures were used for superimposition:

- The round structure of the hypophysial fossa observed from the cephalogram and the pituitary gland tissue identified from the MRI image.
- The contour of the basilar bone observed from the cephalogram and the bone marrow of the basilar bone identified from the MRI scan.

The cephalogram and MRI images were superimposed as follows. First, Sella and point Ba were marked in the cephalogram. Next, both images were superimposed by aligning the centre of the pituitary from the MRI image with Sella. Then the centrifugal edge of the bone marrow of basilar bone from the MRI image was aligned with the line connecting Sella and Ba (Figure 1A–D). Hence, a superimposed image composed of the cephalogram image and the MRI image in the mid-sagittal plane, including the medial pterygoid muscle was acquired. A superimposed image of the cephalogram and medial pterygoid muscle was then obtained by eliminating the MRI in the mid-sagittal plane.

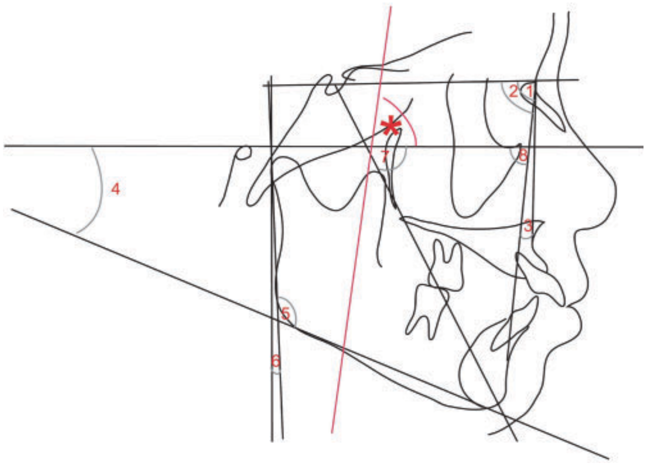
Determination of the inclination axis and the volume of the medial pterygoid muscle

The inclination axis of the medial pterygoid muscle was determined by the centroid from the cross-section of the



(A) MRI; (B) cephalogram radiograph; the images were superimposed as follows. First, the Sella and point Ba were marked in the cephalograms. Next, the images were superimposed by aligning the centre of the pituitary in MRI images with the Sella, and aligning the centrifugal edge of the bone marrow of basilar bone in MRI with the line connecting the Sella and Ba; (C) superimposition of MRI and cephalogram; (D) medial pterygoid muscle projection to the cephalogram; (E) determining the muscle inclination axis. The inclination axis of the medial pterygoid muscle was determined by the centre of gravity on its cross-section

Figure 1 Superimposition of MRI and cephalograms



1: SNA; 2: SNB; 3: ANB; 4: mandibular plane angle; 5: gonial angle; 6: ramus inclination; 7: Y-axis; 8: facial angle; *: inclination axis of the medial pterygoid muscle

Figure 2 Angular measurements in the lateral cephalogram

medial pterygoid muscle, and the size of the cross-sectional area was taken into account to estimate the inclination axis of muscle. The least-squares method was used to obtain a best-fitting straight line (Figure 1E). The volume of the medial pterygoid muscle was calculated by adding the sequential cross-sectional areas of the individual muscles, multiplied by the slice thickness.

The images were masked and assessed in a random order. The lateral cephalometric radiographs were also measured (Figure 2). All the measurements were repeated three times by a single observer after a period of 3 weeks.

Statistical analysis

Reproducibility was assessed using the coefficient of reproducibility for random error and a repeated measures analysis of variance for systematic error. The associations between the cephalometric and muscular data were assessed using the Spearman rank order correlation coefficient using YStat 2000 software. The level of significance was chosen as $P<0.05$ for all tests.

Results

Reproducibility

No significant differences were found for the three repeated measurements indicating that there was no systematic error (Table 1). The coefficient of reproducibility (intra class correlation coefficient) results for the three repeated measurements were acceptable (0.72–0.99).

Morphology of medial pterygoid muscle

Figure 3 shows images of the medial pterygoid muscle superimposed on the cephalograms of 16 patients. The medial pterygoid muscle depicted on the cephalograms connects the external plate of the sphenoid and the mandibular angle, and the outline of the medial pterygoid muscle is shown in the form of a parallelogram or pentagon. Based on the locations of the origins and insertion of this muscle, the outline of the muscle was observed to have a linear or slightly curved shape.

Muscle inclination axis and volume

The straight lines on the images of the medial pterygoid muscle reflect the muscle inclination (Figure 3). The mean angle formed between the inclination axis of the medial pterygoid muscle and the Frankfort horizontal (FH) plane was 80.9° (SD 7.8°). The mean volume of the medial pterygoid muscle was 8.8 cm^3 (SD 1.5 cm^3).

Table 1 Reproducibility of cephalometric measurements including coefficient of reproducibility (ICC) and *P* value of repeated measures ANOVA

Angular measurements (degree)	ICC	*P*
SNA	0.77	0.428
SNB	0.83	0.398
ANB	0.99	0.510
Mandibular plane angle	0.99	0.089
Gonial angle	0.95	0.179
Ramus inclination	0.99	0.516
Y-axis	0.88	0.558
Facial angle	0.79	0.289
Linear measurements		
(Depth)		
Ba-Nmm	0.78	0.066
Ba-Po%	0.95	0.558
Ar-Po%	0.96	0.092
Ar-Go%	0.99	0.161
Go-Po%	0.95	0.071
Ar-Go(AL)%	0.87	0.499
Go-Po(AL)%	0.86	0.771
(Height)		
N-Mmm	0.93	0.066
N-Ans%	0.72	0.431
Ans-M%	0.74	0.756
S-G%	0.94	0.332
Ar-Go%	0.93	0.570
N-M%	0.96	0.152

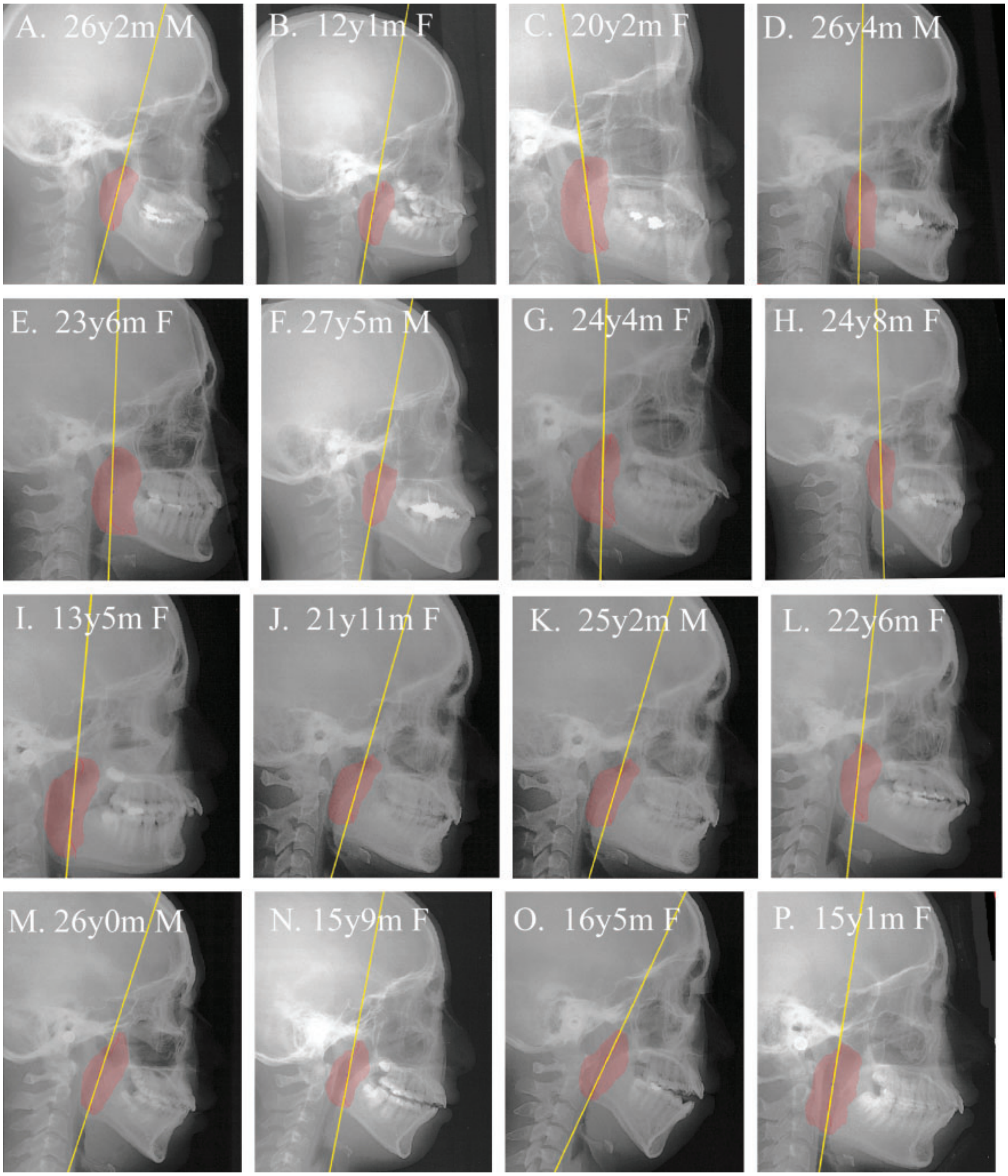


Figure 3 Superimposition of MRI and cephalogram images of 16 subjects

Correlations between cephalometric variables and muscle inclination axis

Table 2 shows the correlations between the cephalometric variables and the inclination axis of the medial pterygoid muscle. Significant relationships were found between the muscle inclination axis and SNB (r=0.658), facial angle (r=0.601), ANB (r=−0.597), ramus inclination (r=0.676), Ba-Po% (r=0.585), and N-Mmm (anterior facial height) (r=−0.597). Moderate relationships were found between the muscle inclination axis and Y-axis (r=−0.515), Ar-Po% (r=0.432), Ar-Go%(depth) (r=0.491), Ar-Go(height)% (r=0.438), S-G% (r=0.432), and N-M% (r=−0.447).

Correlations between cephalometric variables and muscle volume

Table 3 shows the correlations between the cephalometric variables and medial pterygoid muscle volume. A significant relationship was found between the muscle volume and Ba-N mm (r=0.676). Moderate relationships were found between the muscle volume and ramus inclination (r=0.453), Ba-Po% (r=0.447), Ar-Go% (r=0.444) and Ar-Go (AL)% (r=0.532).

Discussion

Morphology of medial pterygoid muscle

In this study, we observed the morphological relationship between the medial pterygoid muscle and craniofacial morphology by superimposing the contour of the medial pterygoid muscle on the corresponding cephalogram. The location and shape of the origin and insertion of the medial pterygoid muscle varied between samples, and variation was also observed with regard to the longitudinal diameter and length of this muscle.

Higashino[13] observed the morphology of the masseter muscle using a similar method, and revealed that the outline of the masseter muscle was primarily rectangular, but in some cases appeared as a parallelogram or trapezoid. He suggested that the different outlines of the masseter muscle appeared to depend on the location and shape of the muscle origin and insertion.

The basic outline of the medial pterygoid muscle depicted on most of superimposed images was in the form of a parallelogram that connected the external plate of the lamina lateralis with the mandibular angular process; however, in some samples it appeared as a rectangle or pentagon. In some of the superimposed images the medial pterygoid muscle originated from the posterior border of the pterygopalatine fossa. In others it originated from below and posterior to the pterygopalatine fossa.

Variation was also observed in the insertion of the medial pterygoid muscle. In some cases, the insertion of the muscle covered the lower two-thirds of the posterior border of the mandibular ramus, while in others it covered the area from the mandibular angle to the lower half of the posterior border of the mandibular ramus. Based on the location and extent of the attached muscle area, the outline of the muscle had either a linear or slightly curved shape. These morphological differences in muscle origin and insertion are thought to be responsible for the differences in muscle shape.

Table 2 Correlations between cephalometric variables and muscle inclination axis

			95% confidence intervals					
	Mean	SD	Lower	Upper	Max.	Min.	Correlation	*P*
Angular measurements (degree)								
SNA	81.3	4.2	73.1	89.5	87.0	75.0	0.244	0.181
SNB	79.3	4.9	69.7	88.9	86.9	73.0	0.658	0.003
ANB	2.0	4.4	−6.6	10.6	8.1	−5.9	−0.597	0.007
Mandibular plane angle	21.3	9.5	2.7	39.9	41.0	5.5	−0.162	0.275
Gonial angle	114.8	10.6	94.0	135.6	129.7	98.2	0.074	0.393
Ramus inclination	3.5	4.7	−5.7	12.7	11.8	−4.4	0.676	0.002
Y-axis	61.9	5.0	52.1	71.7	74.2	56.1	−0.515	0.021
Facial angle	86.8	4.2	78.6	95.0	93.5	76.8	+0.601	0.007
Linear measurements								
(Depth)								
Ba-Nmm	98.4	5.0	88.6	108.2	106.7	85.9	−0.038	0.444
Ba-Po%	90.9	10.7	69.9	111.9	107.3	62.5	0.585	0.009
Ar-Po%	81.7	11.1	59.9	103.5	97.4	52.1	0.432	0.047
Ar-Go%	4.9	4.1	−3.1	12.9	14.7	0.5	0.491	0.027
Go-Po%	78.0	9.2	60.0	96.0	91.1	58.1	0.174	0.260
Ar-Go(AL)%	53.7	4.5	44.9	62.5	58.8	43.6	0.326	0.109
Go-Po(AL)%	85.0	5.6	74.0	96.0	94.4	75.6	0.138	0.305
(Height)								
N-Mmm	127.8	9.9	108.4	147.2	142.8	107.6	−0.597	0.007
N-Ans%	45.8	2.9	40.1	51.5	49.8	41.2	−0.062	0.410
Ans-M%	53.0	2.8	47.5	58.5	58.2	49.4	0.423	0.229
S-G%	67.3	7.8	52.0	82.6	85.7	51.8	0.432	0.047
Ar-Go%	41.3	5.8	29.9	52.7	51.3	28.8	0.438	0.045
N-M%	129.9	13.8	102.9	156.9	158.9	100.8	−0.447	0.041

Skeletal morphology and muscle inclination in cephalograms

A definite trend was observed between the morphology of mandibular bone and the inclination axis of the medial pterygoid muscle. In most cases, the upper part of the inclination axis of the medial pterygoid muscle passed through the vicinity of the deepest point of the mandibular notch. Meanwhile, the lower part of the inclination axis passed through the domain between the gonion and antegonion. From our observation, we conclude that the inclination lines of the medial pterygoid muscle might strongly influence the morphology of the articular process, coronoid process and the mandibular angle. Our findings also suggest that the inclination of the medial pterygoid muscle is correlated to the morphology of the mandibular ramus.

Inclination axis and volume of medial pterygoid muscle

Several reports have described the inclination of the medial pterygoid muscle;[5,6,8,14–18] however, these reports have used different reference lines. The results of a study conducted by Ota[5] in which the muscle inclination axis was measured using the FH plane as a reference, as in the current study, yielded an average inclination axis of 73.4° (SD 4.1°); however, they observed a more posterior inclination than that observed in the current study. The samples used by Ota[5] were taken only from subjects with an Angle class I malocclusion and an average overjet and overbite, whereas the samples used in the current study, with an average ANB of 2.7° are considered to exhibited a tendency towards mandibular protrusion in a Japanese population. This may explain why our data revealed muscle inclination values closer to vertical compared to the results of Ota.[5]

Previous studies have examined medial pterygoid muscle volume.[19–27] The volume of the medial pterygoid muscle measured in this study was smaller than that obtained by Giohanku,[3] who only measured samples from men. Lo[19] reported that the volume of the medial pterygoid muscle in women is 66 to 73% smaller than that in men, based on MRI measurements of the volume of the medial pterygoid muscle in square and normal male and female faces. In addition, Lamey[20] calculated a value between 5 and 8 cm^3 by measuring the volume of

Table 3 Correlations between cephalometric variables and muscle volume

			95% confidence intervals					
	Mean	SD	Lower	Upper	Max.	Min.	Correlation	*P*
Angular measurements (degree)								
SNA	81.3	4.2	73.1	89.5	87.0	75.0	0.206	0.222
SNB	79.3	4.9	69.7	88.9	86.9	73.0	0.297	0.132
ANB	2.0	4.4	−6.6	10.6	8.1	−5.9	−0.191	0.239
Mandibular plane angle	21.3	9.5	2.7	39.9	41.0	5.5	−0.282	0.145
Gonial angle	114.8	10.6	94.0	135.6	129.7	98.2	−0.079	0.385
Ramus inclination	3.5	4.7	−5.7	12.7	11.8	−4.4	0.453	0.039
Y-axis	61.9	5.0	52.1	71.7	74.2	56.1	−0.268	0.158
Facial angle	86.8	4.2	78.6	95.0	93.5	76.8	0.424	0.051
Linear measurements								
(Depth)								
Ba-Nmm	98.4	5.0	88.6	108.2	106.7	85.9	0.676	0.002
Ba-Po%	90.9	10.7	69.9	111.9	107.3	62.5	0.447	0.041
Ar-Po%	81.7	11.1	59.9	103.5	97.4	52.1	0.394	0.065
Ar-Go%	4.9	4.1	−3.1	12.9	14.7	0.5	0.444	0.042
Go-Po%	78.0	9.2	60.0	96.0	91.1	58.1	0.076	0.389
Ar-Go(AL)%	53.7	4.5	44.9	62.5	58.8	43.6	0.532	0.017
Go-Po(AL)%	85.0	5.6	74.0	96.0	94.4	75.6	−0.088	0.373
(Height)								
N-Mmm	127.8	9.9	108.4	147.2	142.8	107.6	0.003	0.496
N-Ans%	45.8	2.9	40.1	51.5	49.8	41.2	0.162	0.275
Ans-M%	53.0	2.8	47.5	58.5	58.2	49.4	−0.006	0.491
S-G%	67.3	7.8	52.0	82.6	85.7	51.8	0.300	0.130
Ar-Go%	41.3	5.8	29.9	52.7	51.3	28.8	0.365	0.082
N-M%	129.9	13.8	102.9	156.9	158.9	100.8	−0.203	0.225

the medial pterygoid muscle in nine women and one man. Since women also comprised a large proportion of the subjects in this study (11 women, 5 men), the values for the volume of the medial pterygoid muscle are probably somewhat lower than if the measurements were only taken from men.

Correlations with cephalometric variables

A positive correlation was clearly observed between the muscle inclination axis and ramus inclination based on measurements in this study. This indicates that the inclination axis of the medial pterygoid muscle was closely correlated to the anteroposterior position of the mandibular angle where the medial pterygoid muscle was attached. Specifically, the inclination axis of the medial pterygoid muscle approaches the vertical as the mandibular ramus rotates in a counterclockwise direction and the mandibular angle is positioned anteriorly. Since a counterclockwise or forward rotation of the mandibular ramus pushes the mandibular body out in the anterior direction, both the SNB and facial angle increase while the Y-axis decreases. As shown in the results, a positive correlation was observed between the muscle inclination axis and both the SNB and facial angle, while a negative correlation was observed with the Y-axis, indicating that the inclination axis of the medial pterygoid muscle is closely associated with the anteroposterior location of the mandible. This relationship may be explained by the fact that the muscle connects the inside angle of the mandible to the external plate of the pterygoid process of the sphenoid bone.

Spronsen[6] observed a correlation between the inclination axis of the medial pterygoid muscle and the gonial angle, but we did not observe a similar relation in the current study. We did observe a positive correlation between the muscle inclination axis and both mandibular length and posterior lower facial height. In contrast, we observed a negative correlation between the muscle inclination axis and anterior facial height. This suggests the possibility that patients with a long face tend to have a more inclined medial pterygoid muscle and, as a result, lack the ability to suppress vertical growth of the maxillofacial skeleton. These results are consistent with those of Chan.[24]

An analysis of the relationship between muscle volume and the maxillofacial skeleton revealed a positive correlation between muscle volume and the inclination of the mandibular ramus and also between muscle volume and the length of the mandibular ramus. If we consider that the volume of the medial pterygoid muscle represents the strength of the medial pterygoid muscle, the mandibular ramus tends to be rotated counterclockwise or forward in individuals with high muscle strength. Although both Gionhaku[3] and Ota[5] observed a correlation between muscle volume and gonial angle, and Ota[5] further observed a negative correlation with the mandibular plane angle, similar results were not found in the current study.

Higashino[13] analyzed the relationship between the masseter muscle and maxillofacial skeleton using a technique similar to that used in this study, and clearly demonstrated that the masseter muscle volume was negatively correlated with the mandibular plane angle, the gonial angle, and the Y-axis. These results suggest that the medial pterygoid muscle strongly influences the morphology of the mandibular ramus, while the masseter muscle affects the morphology of the mandibular body. Although some correlations were found between the muscle volume and cephalometric variables, further investigations are needed to determine the direct developmental relationship between facial skeletal and muscular morphology.

Methodology

In this study, we developed a new method for superimposing MRI images on cephalograms. The ingenuity of this method lies in displaying the morphology of the medial pterygoid muscle obtained from an MRI and projecting it onto a cephalogram. By superimposing cephalograms and MRI images using the method described here, we might be able to analyze both the morphological relationship of the maxillofacial skeleton and the soft tissues on the superimposed images. Although a CT makes it possible to obtain image data on both hard tissue and soft tissue simultaneously, difficulties are encountered when CT is used to depict soft tissue morphology in detail, and CT also has the disadvantage of exposing the patient to extremely high doses of radiation. On the other hand, MRI can be used to depict the morphology of soft tissue while also eliminating exposure to radiation; hence we decided to use MRI to obtain muscle images in this study; however MRI has the disadvantage of requiring the patient to remain confined for a long period of time during imaging.

Although the number of subjects used in this research was low, the present findings suggest a correlation between the morphology of the maxillofacial skeleton and that of the medial pterygoid muscle. This information may help us to better understand the orientation and morphology of muscle in the maxillofacial region as well as the mechanism of skeletal morphogenesis.

Clinically, this study may provide a basis for future studies on post-operative stability following surgical correction of mandibular prognathism. Fukui[28] described the importance of appropriate positioning of the proximal segment and countermeasures to reduce stress on the medial pterygoid muscle during orthognathic surgery to reduce postoperative relapse. Based on investigations of the morphology and orientation of the medial pterygoid muscle and post-operative stability, we may be able to gain a better understanding of the relationship between these two factors. It may also be worth investigating the relationship between medial pterygoid muscle morphology and bite force, for which there is little information available compared to the masseter muscle, and comparing the effects of these two muscles on bite force.

Conclusions

- Morphometric analysis, using a combination of a cephalogram and MRI of the medial pterygoid muscle, is useful for investigating the relationship between skeletal morphogenesis and muscle function in the maxillofacial region.
- Medial pterygoid muscle volume may influence the shape of mandibular bone, particularly the mandibular ramus.

Contributors

Shinta Wirahadi Kusumah was responsible for study design, recruitment of participants and data collection, analysis and drafting. Shoichi Suzuki was responsible for obtaining funding, administrative support and data interpretation, critical revision and final approval of the article. Kouichi Itoh was responsible for study design, technical support and critical revision. Ryoji Higashino was responsible for recruitment of participants and technical support. Naoto Ohbayashi was responsible for study design, technical support and data interpretation. Tohru Ohbayashi was responsible for administrative support. Keiji Moriyama is the guarantor.

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