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Maxillofacial morphology and masseter muscle thickness in adults

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SUMMARY The aim of this study was to investigate how the thickness of the masseter muscle relates to the maxillofacial morphology, including the thickness of alveolar process in the mandibular incisor region, and the thickness of the mandibular symphysis.

The subjects consisted of 80 adult male volunteers (mean age: 23 years 8 months).

The relationship between masseter muscle thickness and the maxillofacial skeleton was investigated by measuring the former by ultrasonography and the latter by roentgenographic cephalometry. The data were initially analysed using a multiple regression analysis. Thereafter, correlation coefficients were obtained by a simple regression analysis. The following results were found:

1. The thickness of the masseter muscle (mean ± SD) was 15.8 ± 3.0 mm in the relaxed state and 16.7 ± 2.7 mm at maximal clenching.
2. Masseter muscle thickness was negatively correlated with the mandibular plane angle.
3. Masseter muscle thickness was positively correlated with the mandibular ramus height (Cd–Go), and the thickness of the alveolar process and that of the mandibular symphysis.

It is therefore suggested that masticatory function influences the morphology of the mandible.

Introduction

Many researchers have suggested that bone shape and structure are closely related to the attached muscle activity. In recent experimental studies, significant correlations were found between changes in mechanical stresses and subsequent morphological alterations of bone tissue (Goldstein, 1992).

It is thought that a similar interaction occurs between bone shape and muscle activity in the maxillofacial complex. Inoue (1993) and Ito (1993) pointed out that there has been a decrease in the human masticatory system caused by the changes of eating style associated with the human dietary evolution. The poor functional stimulus through mastication is reported to have led to the underdevelopment of the mandible, including the condyle (Beecher and Corrucini, 1981; Kuroe and Ito, 1990). Furthermore, Kiliaridis (1989) showed that the density of trabecular alignment and/or the thickness of cortical bone of the jaw were poorly developed due to the low level of stimulation from the masticatory system.

Masticatory muscle activity has been investigated by electromyography (EMG) (Moyers, 1949; Ingervall and Thilander, 1974) and by muscle strength (Ingervall and Helkimo, 1978). Recently, muscle thickness has been considered as one indicator of jaw muscle function (Kiliaridis and Kälebo, 1991; Bakke *et al.*, 1992). These reports indicated that muscle thickness was significantly correlated with maxillofacial morphology. However, the alveolar bone thickness of the mandible was not considered. The aim of this study therefore was to investigate the effects of masseter muscle thickness on maxillofacial morphology, including the thickness of the alveolar process and that of the mandibular symphysis.

Subjects and methods

Subjects

The subjects consisted of 80 male volunteer dental students at Iwate Medical University, born between 1961 and 1972. Their mean age was 23 years 8 months (SD: ± 1 year 9 months). The nature and aims of this study were explained to all the subjects who gave their consent. The selection criteria for enrolment were as follows: no history of orthodontic treatment; no missing teeth in the incisor region; no more than two missing teeth in the molar region, apart from third molars; no asymmetry demonstrated on a postero-anterior roentgenographic cephalogram; and no pain in the temporomandibular joint.

Measurements of lateral roentgenographic cephalograms

The maxillofacial morphology was investigated by lateral roentgenographic cephalometry. Five angular and 10 linear measurements were analysed (Figures 1 and 2). The thickness of the alveolar process and that of the mandibular symphysis were defined and measured (Figure 2).

Measurement of masseter muscle thickness

Measurement of masseter muscle thickness was carried out using ultrasonographic scanning (Aloka Co., Ltd. SSD-500, Japan). The measurement error, using this equipment, was quantified by scanning a wet pig-head immediately following sacrifice. The scanning measurement and the actual measurement were compared giving a difference of 1.03 per cent.

For the subjects used in the study, the thickness of the masseter muscle was measured at a

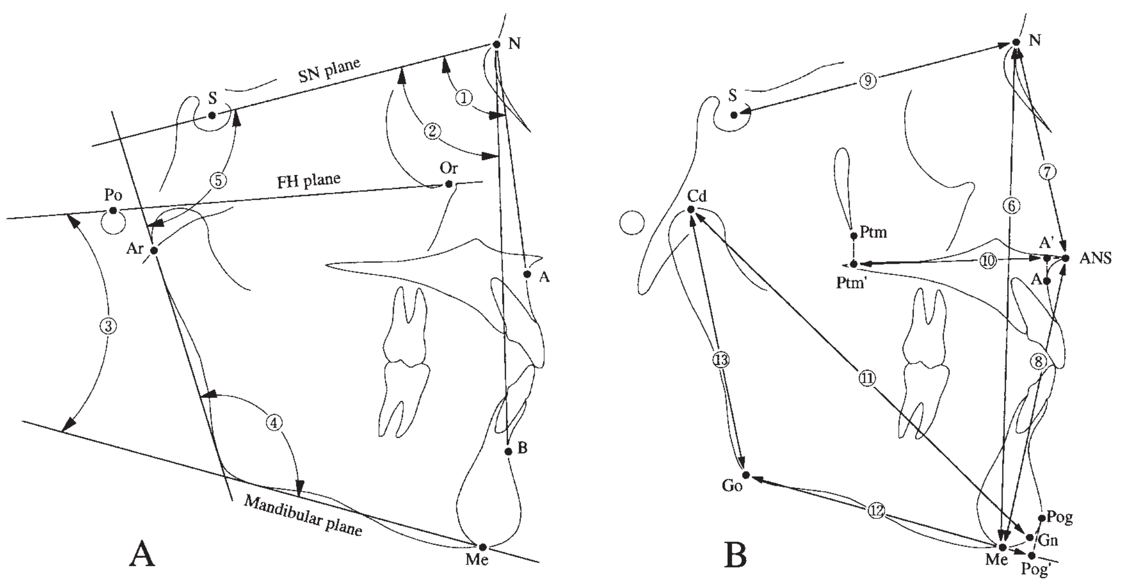

Figure 1 Analysis of roentgenographic cephalogram. (A) Angular measurements: 1, SNA; 2, SNB; 3, mandibular plane angle; 4, gonial angle; 5, ramus inclination to SN. (B) Linear measurements: 6, N–Me ; 7, N–ANS; 8, ANS–Me; 9, S–N; 10, A′–Ptm′ (maxillary length); 11, Gn–Cd (mandibular length); 12, Pog′–Go (mandibular body length); 13, Cd–Go (mandibular ramus height).

Abbreviations: S = sella turcica; N = nasion; A = subspinale; B = supramentale; Me = menton; Ptm = pterygomaxillary fissure; Gn = gnathion; Cd = condylion; Go = gonion; A′ = the point reflected from subspinale on the palatal plane; Ptm′ = the point reflected from pterygomaxillary fissure on the platal plane; Pog′ = the point reflected from pogonion on the mandibular plane.

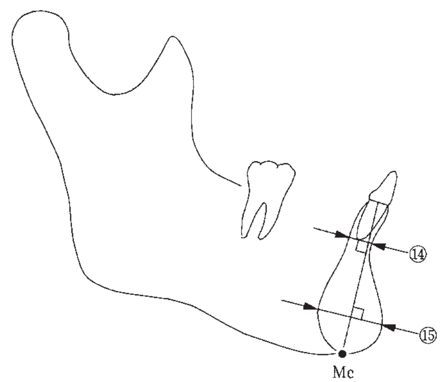

Figure 2 Landmarks and reference lines used for measurement (14). Thickness of the alveolar process. (A line passing the Me point and the anteroposterior mid-point of the cervical thickness of the mandibular central incisor was established. The thickness of the alveolar process was defined as that obtained on a line crossing this line perpendicularly and passing the root apex of the mandibular central incisor.) (15) Thickness of the mandibular symphysis. (A line passing the Me point and the anteroposterior mid-point of the cervical thickness of the mandibular central incisor was established. The thickness of the mandibular symphysis was defined as the maximum thickness of the mandibular symphysis obtained on a line crossing this line perpendicularly.)

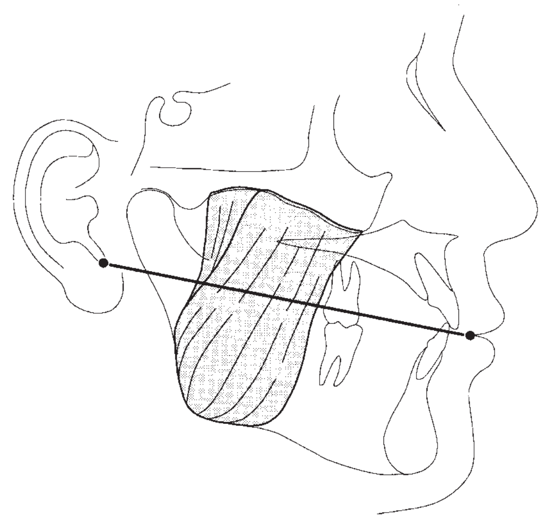

Figure 3 The thickness of the masseter muscle was measured at a site on the buccal surface of the habitual chewing side where the arrangement of the masseter muscle crosses a line connecting the labial corner to the intertragic notch of the ear.

site on the buccal surface of the habitual chewing side where a line joining the lateral commissure of the mouth to the intertragic notch of the ear crossed the masseter muscle (Figure 3). The 7.5 MHz scanning probe (Aloka Co., Ltd. UST-5512U-7.5, linear type, Japan) was attached to the buccal surface perpendicular to the ramus with a feather-like pressure, and its position was confirmed on the visual display. The images of the muscle during relaxation and maximal clenching were recorded and printed out on high density printing paper (Aloka Co., Ltd. ECP-303HD, Japan). All recordings were performed by the same observer to eliminate the inter-observer difference.

Muscle thickness measurements were made on the scanned images. Ten points at intervals of 2 mm were measured on both the inner and outer borders of the muscle which corresponded with the central area of the muscle. The thickness was measured by computerized analysis (computer: NEC, PC9801, Japan; digitizer: Graphtec, KD4030, Japan). The mean value of the 10 points was regarded as the thickness of the masseter muscle for each subject (Figure 4).

The intra-observer error was investigated on 21 imaging photographs of muscle selected at random, both during relaxation and maximal clenching. These were measured twice, respectively, and the data were calculated according to Dahlberg's double determination method (Dahlberg, 1940) as follows;

$$\sigma i = \sqrt{\frac{\sum d^2}{2n}}$$

where σi is the intra-observer measurement error, n is the number of subjects, and d is difference between the first and second measurement.

The results of this measurement error were 0.51 mm in the relaxed state and 0.60 mm at maximal clenching.

Statistical methods

The cephalometric data and masseter muscle thickness were checked and shown to be

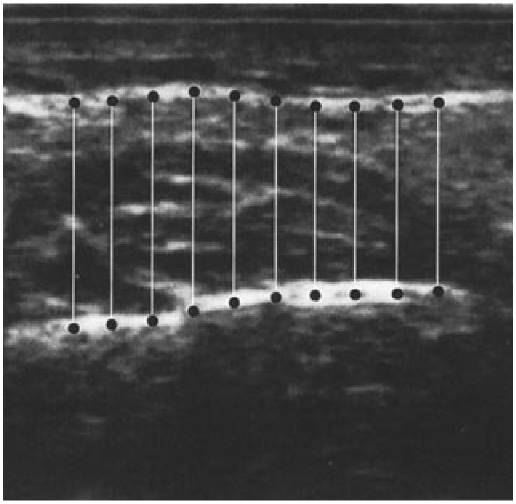

Figure 4 Transverse ultrasound image of the masseter muscle and measuring points. White wide shadows depict the fasciae of the masseter muscle. The shadow on the upper side is the outer fascia, and on lower side the inner fascia. The image of the masseter muscle lies between both the fasciae. The narrow white shadow above the outer fascia is skin echo. The dark area beneath the inner fascia is the lateral part of the ramus. Ten measuring points were set on both the inner and outer fasciae corresponding to the central area of the masseter muscle. The mean value at 10 point at intervals of 2 mm was regarded as the thickness of the masseter muscle.

normally distributed. To examine the relationship between the thickness of the masseter muscle and the maxillofacial morphology, a multiple regression analysis was first performed, followed by determination of correlation coefficients by means of a simple regression analysis. Using multiple regression analysis, the thickness of the masseter muscle was treated as a dependent variable and the cephalometric data as independent variables.

Results

The masseter muscle thickness was 15.8 ± 3.0 mm in the relaxed state, and 16.7 ± 2.7 mm whilst clenching (Table 1). The results of the multiple regression analysis showed that masseter muscle thickness was significantly correlated with the mandibular plane angle, the thickness of the alveolar process, the thickness of the mandibular symphysis ($P < 0.01$), and the mandibular ramus height (Cd–Go) ($P < 0.05$). Ramus inclination to SN was only correlated with muscle thickness in the relaxed state ($P < 0.05$; Table 2). Table 3 shows the results of a simple regression analysis which revealed a significant correlation for muscle thickness with the mandibular plane angle, Cd–Go, the thickness of the alveolar process, and the thickness of the mandibular symphysis ($P < 0.01$). The results of the simple regression analysis corresponded well with those of the multiple regression analysis.

Table 1 Means and standard deviations of the variables of lateral roentgenographic cephalogram and the thickness of masseter muscle.

	Mean	SD
Angular measurements (degrees)		
SNA	82.9	3.7
SNB	80.4	4.0
Mandibular plane angle	29.0	6.9
Gonial angle	121.6	6.8
Ramus inclination to SN	92.0	5.3
Linear measurements (mm)		
N–Me	137.7	5.8
N–ANS	61.3	3.3
ANS–Me	78.2	5.3
S–N	73.6	3.4
A′–Ptm′	54.1	3.5
Gn–Cd	130.4	5.8
Pog′–Go	84.6	5.2
Cd–Go	67.6	5.2
Thickness of the alveolar process	8.4	1.9
Thickness of the mandibular symphysis	15.6	1.9
Relaxed thickness of masseter muscle (mm)	15.8	3.0
Contracted thickness of masseter muscle (mm)	16.7	2.7

Discussion

The measuring method of the muscle thickness by ultrasonography

Fukunaga and Matsuo (1986), using ultrasonography connected to automatic circular compound scanning, measured subcutaneous fat, muscle, and bone in an adult male using a 5 MHz scanning probe, and reported that the difference between the scanning measurement and the actual measurement was under 5 per cent. Fukunaga *et al.* (1989) reported that the difference was 0.3–3.7 per cent for ultrasonography

Table 2 Multiple regression analysis of the thickness of masseter muscle and the lateral roentgenographic cephalogram variables.

Independent variables	Dependent variables	
	Muscle relaxing	Muscle clenching
SNA	0.07	0.05
SNB	0.06	0.01
Mandibular plane angle	–0.38**	–0.34**
Gonial angle	–0.12	–0.08
Ramus inclination to SN	–0.24*	–0.22
N–Me	–0.11	–0.13
N–ANS	–0.02	–0.06
ANS–Me	–0.12	–0.11
S–N	0.11	0.10
A′–Ptm′	–0.02	–0.01
Gn–Cd	0.06	0.02
Pog′–Go	–0.04	–0.12
Cd–Go	0.27*	0.28*
Thickness of alveolar process	0.39**	0.34**
Thickness of mandibular symphysis	0.42**	0.39**
Multiple correlation coefficients (*r*)	0.65	0.62
r^2	0.42	0.39

Significance of the correlation coefficients $*P < 0.05$; $**P < 0.01$.

Table 3 Correlation coefficients between the thickness of masseter muscle and the roentgenographic cephalogram data.

	Muscle relaxing	Muscle clenching
SNA	0.13	0.12
SNB	0.05	0.03
Mandibular plane angle	–0.41**	–0.37**
Gonial angle	–0.20	–0.16
Ramus inclination to SN	–0.18	–0.18
N–Me	–0.07	–0.09
N–ANS	–0.07	–0.03
ANS–Me	–0.14	–0.11
S–N	0.14	0.16
A′–Ptm′	–0.11	–0.11
Gn–Cd	0.04	0.04
Pog′–Go	–0.01	–0.06
Cd–Go	0.32**	0.32**
Thickness of alveolar process	0.39**	0.34**
Thickness of mandibular symphysis	0.42**	0.39**

Significance of the correlation coefficients $**P < 0.01$.

using a 5 MHz scanning probe for investigation of the thickness of subcutaneous fat and muscles at the forearm, upper arm, and subscapla. The results of our preliminary study showed that the difference was 1.03 per cent using a 7.5 MHz scanning probe, which indicates a higher accuracy compared with Fukanaga's reports. The high ultrasonic frequency of the probe produced clearer images of the superficial structures.

Kiliaridis and Kälebo (1991) measured masseter thickness using a 7 MHz scanning probe, and reported an intra-observer error of 4.0–7.1

per cent. Bakke *et al*. (1992) used a 7.5 MHz scanning probe, and reported the error as 3–7 per cent. They measured muscle thickness twice directly from the image at the time of scanning, and the error was calculated by the method of double recordings of imaging. In this study, the measurements were performed twice on the same recording, giving an intra-observer error of 3.2–3.6 per cent.

From these data, it was concluded that these methods are accurate and reproducible for practical use.

Relationship between maxillofacial morphology and the thickness of the masseter muscle

Wolff (1870) pointed out that the shape and internal structure of the femur head is closely related to the lower extremity function for the following reasons; the trabecular alignment of the head reflects the stress trajectory formed in resistance to manifold functional stresses, and the stimulating influence of muscle or the extra-functional force seem to produce demonstrable changes of the bone. This theory concerning the relationship of bone shape and muscle function is recognized in the field of biodynamics as Wolff's law (Dibbets, 1992).

In the field of orthopaedics, the cortical thickness of the humeri of a group of professional tennis players, on the playing side, was greater compared with the control side (Jones *et al*., 1977). This finding supports the results of an animal experiment which investigated the effects of training on the lower extremities (Saville and Whyte, 1969).

Embryologically, the bones that make up the maxillofacial region are essentially membranous bones, and as such are more susceptible to environmental factors, such as the stimulating influence of muscles and extra-functional force, in comparison with the long bones of the extremities which are formed by cartilaginous ossification (Dulkin, 1972). It is suggested that the influence of the activity of the attached muscles is more apparent in the maxillofacial bones as compared with the long bones of the extremities.

Different approaches to clarify muscle activity and bony shape/structure have been performed by CT, MRI and ultrasonography at the cross-sectional muscle band. Weijs and Hillen (1984, 1986) reported that the cross-sectional area of the masseter muscle obtained from CT was negatively correlated with both the anterior facial height and gonial angle, and positively correlated with head width and mandibular length. Gionhaku and Lowe (1989) also pointed out that the cross-sectional image of this muscle showed negative correlation with the mandibular plane angle and gonial angle, and recognized positive correlation with the mandibular ramus height. Bakke *et al.* (1992) described similar findings, in that the masseter muscle thickness obtained from ultrasonographic image during maximal clenching correlated negatively with both anterior facial dimension and the mandibular plane angle. There is considerable evidence that masseter muscle thickness, as obtained by cross-sectional imaging, is intimately related to the gonial angle and the mandibular plane angle.

As shown in Table 3, a negative correlation was found between masseter muscle thickness and the mandibular plane angle, and a positive correlation was noted in the mandibular ramus height. This is in agreement with Weijs and Hillen (1984, 1986), Gionhaku and Lowe (1989), and Bakke *et al.* (1992).

Moss (1962) suggested that maxillofacial morphology is controlled by the development of function including the nasal cavity or maxillary sinus, and the mandible is particularly influenced by the masticatory muscle function (masseter, medial pterygoid, and temporal muscles), with the final morphology being dependent on the muscle activity.

Measurable differences on the lateral roentgenographic cephalogram in the external bone shape were observed at the gonial region in association with masseter muscle thickness (Table 3). These results seem to suggest that the shape of the gonial region is influenced by the functional activity of the masseter muscle.

Weijs and Hillen (1986) noted the effects of a soft diet on the size of the masticatory muscles. Some reports indicate a significant relationship between maxillofacial morphology and dietary consistency during growth (Corruccini and Lee, 1984; Corruccini *et al*., 1985). In addition, experimental studies carried out by Watt and Williams (1951), Barber *et al.* (1963), Moore (1965), Ito *et al.* (1988), and Kiliaridis (1989) in which animals during the growth stage were bred under different physical conditions, showed for animals given soft or liquid foods the following characteristics:

(1) decreased cranial capacity, length, and width;
(2) decreased weight of the masseter and temporal muscles;
(3) decreased maxillary arch width;
(4) decreased mandibular ramus height;
(5) decreased antero-posterior diameter and width of the condyle.

It was concluded that a soft or liquid diet brought about a decrease in masticatory activity, leading to an underdeveloped maxillofacial skeleton, following the reduced development of masticatory muscle function.

Relationship between the shape of the mandibular symphysis and muscle thickness

Buschang *et al*. (1992) stated that the stress resulting from occlusion of the anterior teeth is compensated by bony deposition on the lingual symphyseal surface. This finding suggests that the thickness of the mandibular symphysis is closely related to masticatory pressure. A reduced masticatory pressure may be caused when the bite force is weak, which may lead to the under-development of the masticatory muscles or when normal bite at the incisor region is impossible, such as in subjects with an anterior open bite.

Several studies have revealed that the thickness and/or the cross-sectional area of the masseter muscle shows significant correlation with incisor and molar bite force (Sasaki *et al*., 1989; van Spronsen *et al*., 1989; Bakke *et al*., 1992). Shozushima *et al*. (1996) found a significant correlation between bone mineral content of the human mandible and bite force.

Given the positive correlation observed with the thickness of the masseter muscle and the thickness of the alveolar process, and mandibular symphysis, it is suggested that the stimulating influence of masticatory pressure applied to bone tissue is important in the development of bone thickness at the alveolar process and the mandibular symphysis.

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