# Relationship Between the Morphologies of the Masseter Muscle and the Ramus and Occlusal Force in Patients With Mandibular Prognathism

**The relationship between the morphologies of the masseter muscle and the ramus and the occlusal force in patients with mandibular prognathism**

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**Abstract**

**Purpose:** The purpose of this study was to examine the relationship between the morphologies of the masseter muscle and the ramus and the occlusal force in patients with mandibular prognathism.

**Patients and Methods:** The study group consisted of 71 patients with mandibular prognathism. They were divided into two groups, consisting of prognathism with or without symmetry, determined by frontal cephalogram analysis. All patients underwent three-dimensional computed tomography and occlusal force was recorded with pressure-sensitive sheets.

**Results:** In the cross-sectional area of masseter muscle, there were no significant differences between the right and left sides in the symmetry and asymmetry groups.

In occlusal force, there was no significant difference between the symmetry and asymmetry groups. Occlusal force was not significantly correlated to the cross-sectional area of the ramus, but it was significantly positively correlated to the cross-sectional area of the masseter muscle ($P<0.05$).

**Conclusion:** Occlusal force was associated with the ipsilateral cross-sectional area of masseter muscle in patients with prognathism; however, it was not significantly associated with the degree of mandibular deviation.

The variation of jaw-muscle strength is associated with vertical craniofacial morphology. Measurements of bite force and electromyographic activity indicate that long -faced (dolichocephalic) individuals have weak jaw muscles as compared with normal and short-faced individuals (brachycephalic types).[1-5] Muscle cross-sectional sizes and muscle lever mechanics are important determinants of the magnitude of bite force. The cross-sectional size of a muscle bears a direct relationship to maximum tension-generating capacity,[6] and the length of its lever arm relative to the mandibular condyle determines the maximum torque that the muscle can exert.[7] Previous studies suggested that the cross-sectional area and thickness of masticatory muscles, as parameters of the functional ability of those muscles, are significantly correlated with biting force and the properties of facial morphology. Various methods have been described for measuring muscle morphology.[8,9] The direction and cross-sectional area of the masseter muscle have frequently been measured from cross-sectional images obtained by computed tomography and magnetic resonance imaging.[10-12].

Ariji et al. concluded that the morphology of the masseter muscle in patients with mandibular prognathism is significantly different from that in normal subjects.[13] Furthermore, functional activity and bite force have been shown to differ significantly in patients with mandibular prognathism from those in normal subjects. [8,9,14-19] However, no studies have investigated both masseter muscle morphology and occlusal force in the same patients with mandibular prognathism.

The purpose of this study was to examine the relationship between the morphologies of the masseter muscle and the ramus and the occlusal force in patients with mandibular prognathism.

**Patients and Methods**

The study group consisted of 71 patients (27 men and 44 women; mean age, 22.9 years and range, 15-36 years).

Although all cases were diagnosed as skeletal classⅢ on the basis of lateral cephalogram analysis, asymmetry needed to be taken into account for accurate frontal or axial cephalogram analysis. In the frontal cephalogram, the angle between the ANS-Menton line and the line perpendicular to the bilateral zygomatic frontal suture line was defined as the Mx-Md midline angle. A positive value of this Mx-Md midline angle represents mandibular deviation to the left and a negative value represents mandibular deviation to the right (Fig. 1). The Mx-Md midline angles of all cases were then given a positive value so that all consecutive measurements could be attributed to either the deviation or the non-deviation side.

The patients were first divided into male and female groups. Each group was then divided into two groups on the basis of the Mx-Md midline angulation. The asymmetry group consisted of those in whom the Mx-Md midline angle was greater than 3° and the symmetry group consisted of those in whom the Mx-Md midline angle measured less than 3°.

We studied the following four groups:

Male symmetry group (n=22; mean age 21.2±3.5 y)

Female symmetry group (n=28; mean age 24.1±6.9 y)

Male asymmetry group (n=5; mean age 18.0±1.0 y)

Female asymmetry group (n=16; mean age 24.4±5.2 y)

Mx-Md midline was mean 1.59 ±0.99 degrees and range 0.01-2.81 degrees in symmetry group, and mean 6.38±3.76 degrees and range 3.01-14.69 degrees in asymmetry group. Severe midface asymmetry such as orbital dystopia was not included in asymmetry group.

17 of 50 (34%) patients (27 of 100 (27%) joints) had symptomatic temporomandibular joint (TMJ) in symmetry group, and 13 of 22 (62%) patients (19 of 42 (45%) joints) had symptomatic TMJ in asymmetry group. However, these were very light symptoms such as clicking, there was neither severe pain nor trismus. Therefore, it was considered that TMJ problems might not affect the results of occlusal force.

**Measurements with three-dimensional computed tomography**

Tomographs were obtained in the resting position of the mandible using a high-speed advantage-type computed tomography (CT) generator (GE Medical Systems, Milwaukee, WI, USA), with each sequence taken 1.5 mm apart in the horizontal plane parallel to the Frankfurt horizontal (FH) plane (120 kV, average 170 mA, scanning time 40 sec). The resulting images were stored in the attached workstation computer and three-dimensional (3-D) reconstruction was performed. A lateral view of the 3-D image was reconstructed by superimposition. The horizontal plane 5 mm above the mandibular foramen parallel to FH plane was identified, and the masseter muscle area and ramus area were measured. Furthermore, the masseter muscle length (the distance between the most inferior point of zygomatic arch and the gonion point) was measured using the attached computer (Figs. 1-3).

**Measurements**

A pressure-sensitive system was used in this study. This system consists of a pressure-sensitive sheet (Dental Prescale; Fuji Photo Film Co., Tokyo, Japan) and its analyzing apparatus (Dental Occlusion Pressuregraph FPD-705; Fuji Photo Film Co.) connected with a personal computer (LaVieC, LC50H/3, NEC, Tokyo, Japan). Each patient was seated with his or her head in an unsupported natural position, looking forward. The pressure-sensitive sheet was placed between the maxillary and mandibular teeth and the patient was instructed to bite as forcefully as possible for about 3 seconds. The sheet was read and analyzed by the Dental Occlusion Pressure graph and the results were put into the computer and visualized on the display screen.

We recruited 35 volunteers (18 men and 17 women; mean age 24.2 years; range, 22-34 years) as controls; their bite forces were recorded to compare with those of patients with prognathism, but no tomographs were taken. All of the volunteers had skeletal and dental Class I relationships with no signs of temporomandibular joint involvement.

**Statistical analysis**

Data of masseter muscle area, ramus area, and bite force were statistically analyzed with StatView™ version 4.5 software (ABACUS Concepts, Inc., Berkeley, CA, USA). The statistical significance of a difference within the same group was analyzed by paired comparison using the Wilcoxon signed-rank test. Differences between groups were analyzed by non-paired comparison using the Mann-Whitney U test. The relationships among the bite force, the area of masseter muscle, the area of ramus, and the length of masseter muscle were evaluated using simple regression analysis.

**Results**

Significant differences were found in the bilateral masseter muscle area and the ramus area between the male symmetry group and the female symmetry group ($P<0.05$); however there was no difference in bite force between these groups. Significant differences were also found in the bilateral masseter muscle area and the bite force between the male asymmetry group and the female asymmetry group ($P<0.05$).

No significant difference in masseter muscle area was found between the deviation and non-deviation sides in all groups. However, the ramus area on the right side was significantly greater than that on the left side in the female symmetry group ($P<0.05$).

No significant difference in masseter muscle length (distance between the most inferior point of zygomatic arch and gonion point) was found between the right and left sides in both symmetry groups or between the deviation and non-deviation sides in both asymmetry groups. However, a significant difference in ipsilateral distance was found between male and female symmetry groups and between male and female asymmetry groups ($P<0.05$).

No significant differences in masseter muscle area, ramus area, and bite force were found between the symmetry and asymmetry groups, although the values of the symmetry group were greater than those of the asymmetry group (Table1).

Bite force could not be divided into right and left sides, so the values of the right and left masseter muscle areas and the ramus areas were summed up for analysis with simple regression.

As a result, the bite force was significantly positively correlated to the masseter muscle area (n=71, R=0.371, adjusted $R^2$=0.137, RMS Residual=167.287; P=0.0015). However, no significant difference was found in the relationship between bite force and ramus area. The masseter area was also correlated to ramus area (n=71, R=0.458, adjusted $R^2$ =0.198, RMS Residual=160.143; P<0.0001) (Fig. 4).

Significant positive correlations were found between the masseter muscle area and the ipsilateral ramus area (n=142, R=0.415, adjusted $R^2$ =0.166, RMS Residual=83.432; P<0.0001), the ramus area and the ipsilateral masseter muscle length (n=142, R=0.210, adjusted $R^2$=0.037, RMS Residual=49.025; P=0.0123), and the masseter muscle area and the masseter muscle length (n=142, R=0.279, adjusted $R^2$=0.071, RMS Residual=88.029; P=0.0008) (Fig. 5).

**Discussion**

With the use of computer tomography (CT), measuring the cross-sectional areas of the upper arm muscles and the jaw muscles in living subjects became possible.[10,20] Furthermore, the cross-sectional area has been used frequently as a parameter of muscle size because it has a high correlation with muscle volume.[8,9] In this study, a significant correlation between the cross-sectional area and the length of the masseter muscle was also found. Different sites have been proposed as appropriate for determining the cross-sectional area of the masseter muscle: 8 mm above the mandibular foramen,[12] 20 mm below the FH plane,[21] or 30 mm ventrocranially to the angle of the mandible.[11] The plane 5 mm above the mandibular foramen was identified from horizontal planes in this study.

There have been many reports on the cross-sectional area of the masseter muscle using CT or magnetic resonance imaging in subjects with normal craniofacial morphology. Xu et al. reported that in Japanese subjects, the masseter muscle area was 570 $mm^2$ in males and 487 $mm^2$ in females.[12] However, Ando stated that in Japanese subjects, the masseter muscle area was 381 to 399 $mm^2$ in males and 288 to 293 $mm^2$ in females.[21] Ariji has reported that the cross-sectional area of the masseter muscle in patients with mandibular prognathism was an average of 318.3 $mm^2$, significantly smaller than that in normal subjects (an average of 368.3 $mm^2$).[13] In this study, the area was 394.2 $mm^2$ on the right side and 399.4 $mm^2$ on the left side in cases of prognathism with symmetry, and 389.7 $mm^2$ on the right side and 391.7 $mm^2$ on the left side in cases of prognathism with asymmetry. These values were larger than previously reported values because of differences in measurement methods. In this study, no significant difference in the area of the masseter muscle was found between the symmetry and asymmetry groups. Furthermore, no statistically significant difference in the area of the masseter muscle was found between the deviation side and the non-deviation side.

In this study, the significant difference between right and left side was not found in the masseter muscle area in all group, as previously reported. However, ramus area of right side was significantly greater than that of left side in ramus area in symmetry female group. The patients with excessive vertical facial growth on one side was not found, so that we could not explain the cause.

Other studies have used sensitive-sheet systems similar to the one in our study to examine bite force for normal controls and patients with mandibular prognathism. Harada et al. has reported that mean bite force in control subjects was 721.0 N in men and 530.7 N in women, and that mean bite force in preoperative prognathism patients was 293.2 N in men and 208.5 N in women.[22] Nagai et al. reported that mean bite force in control subjects was 677.5 N in men and 625.2 N in women, and that mean bite force in preoperative prognathism patients was 183.7 N in men and 120.3 N in women.[23] In this study, the average bite force of patients with prognathism with symmetry was 441.6 N in men and 403.6 N in women, and that of patients with prognathism with asymmetry was 515.8 N in men and 322.1 N in women. Measurements in our study were taken before orthodontic treatment so that our study results could show higher values than other studies. It was obvious that the bite force of patients with mandibular prognathism showed lower values than that of control subjects.

Using simple equations for static mechanical equilibrium, van Spronsen et al.[24] and Weijs and van Spronsen[25] showed that the significantly smaller jaw muscles of long-face subjects could not fully explain their smaller maximum molar bite forces. These authors pointed out that maximum bite-force magnitude is determined by muscle cross-sectional area, muscle orientation and moment arms, and force per unit of cross-sectional area of muscle. Furthermore, van Eijden et al.[26] showed that bite-force magnitude also depends on bite-force direction. This may be due to anatomical factors such as variation of muscle fiber composition, capillary density, and adipose and connective tissue content.

Most studies of muscle fiber types are hampered by the almost inevitable use of a single-region biopsy, which is not appropriate for describing the fiber-type distribution of the heterogeneous human jaw muscle.[27] The distribution of fiber type and the size of the jaw muscles of long–face subjects reportedly differs significantly from those of control subjects,[28,29] although Shaughnessy et al.[27] found no differences. Some studies suggested that as the result of impaired oral function, long-face subjects show arrested development of their jaw muscles, reflected not only by a reduction of cross-sectional area but also by a reduction of intrinsic muscle strength.[4] If the suggestion was supported, it could be hypothesized that reduction of cross-sectional area or intrinsic muscle strength should exist on only one side of the mandible in patients with prognathism with asymmetry. However, no significant difference in bite force was found between symmetry and asymmetry groups. Furthermore, no significant differences were found in masseter muscle area and the distance from the most inferior point of the zygomatic arch to the gonion point between the deviation and non-deviation sides.

Although these results are supported by the validity of the group division using the Me position on the frontal cephalogram and the measurement method of the cross-sectional area of the masseter muscle, it seemed that in patients with prognathism, asymmetry did not reduce the masticatory function appreciably. Paradoxically, the function in patients with prognathism with asymmetry may adapt to the patient's own maxillofacial morphology as well as in patients with prognathism with symmetry. The increased bite force in the male asymmetric may be explained by these reasons.

In this study of patients with prognathism, bite force was significantly positively correlated to masseter muscle area, as reported in previous studies. The masseter area was also correlated to ramus area. Xu et al.[12] reported positive correlations between the masseter and medial pterygoid muscles for both volume and maximum cross-sectional area. These findings suggest that the development of both masseter muscles and medial pterygoid muscles is related to ramus morphology.

Finally, bite force was also associated with the ipsilateral cross-sectional area of the masseter muscle in patients with prognathism; however, no statistically significant differences in bite force and masseter muscle area were found between symmetry and asymmetry groups.

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Figure Legends

Figure 1. An algorithm of measurements on the masseter muscle and ramus using computed tomography image analysis.

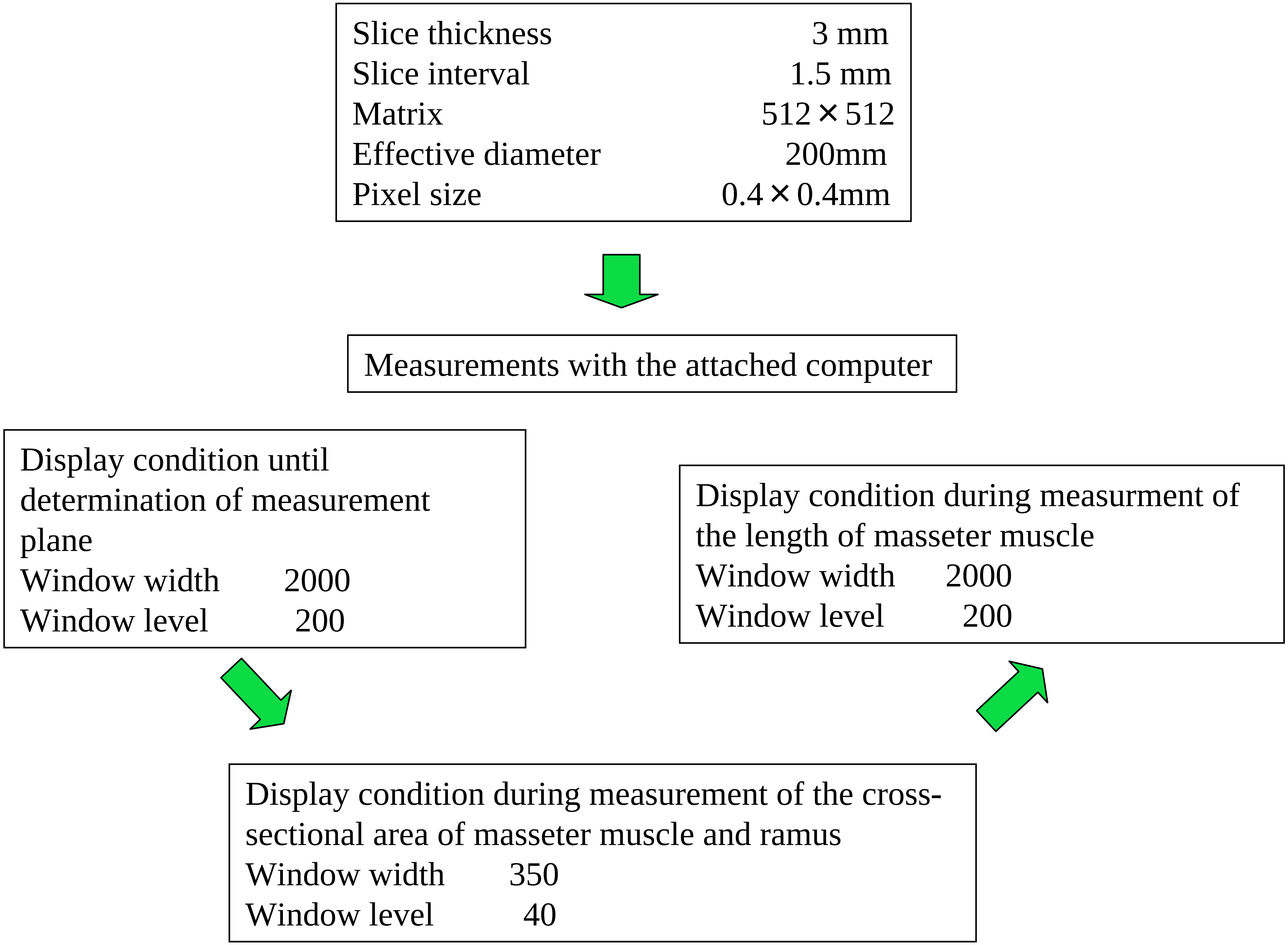
Figure 2. The determination of the measurement plane on a computed tomography image. A) The upper line shows the Frankfurt horizontal (FH) plane and the lower line shows a plane that passes through the mandibular foramen parallel to the FH plane. B) Image at the level of the mandibular foramen parallel to the FH plane. Arrow shows mandibular foramen. C) The upper line shows the plane 5 mm above the mandibular plane parallel to the FH plane. D) Image at the level 5 mm above the mandibular foramen.

Figure 3. A tomograph image that demonstrates a) the ramus area, b) masseter muscle area, and c)masseter muscle length.

Figure 4. Simple regression analysis between masseter muscle area, ramus area, and bite force by group.

Figure 5. Simple regression analysis between the masseter muscle area and the ipsilateral ramus area, the ramus area and the ipsilateral masseter muscle length, and the masseter muscle area and the masseter muscle length by group.

Table 1. Measurements of masseter muscle area, ramus area, and bite force by group.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Display condition during measurment of the length of masseter muscle
Window width 2000
Window level 200
Display condition during measurement of the cross-sectional area of masseter muscle and ramus
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Window level 40

Fig. 1

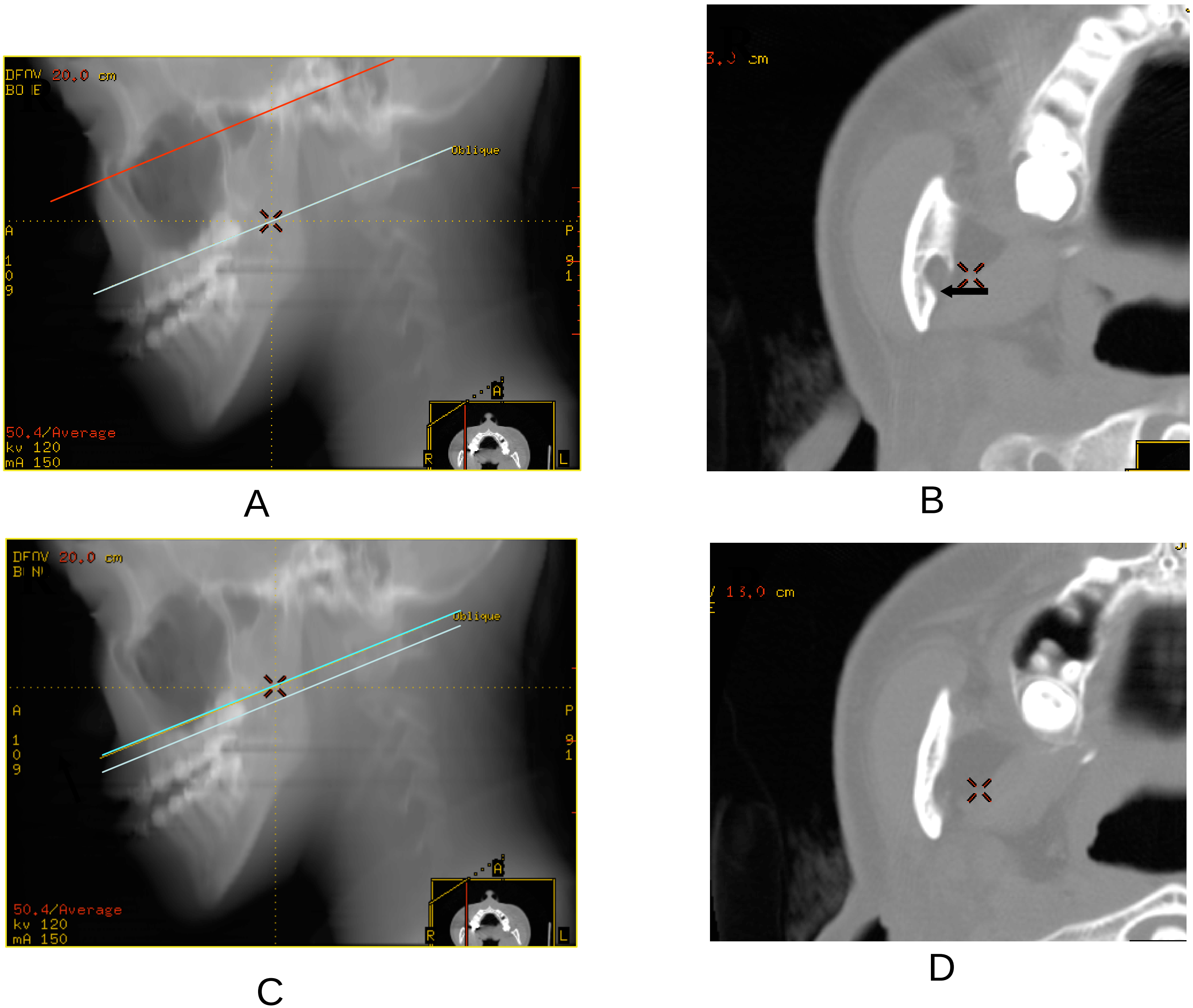


Fig. 2

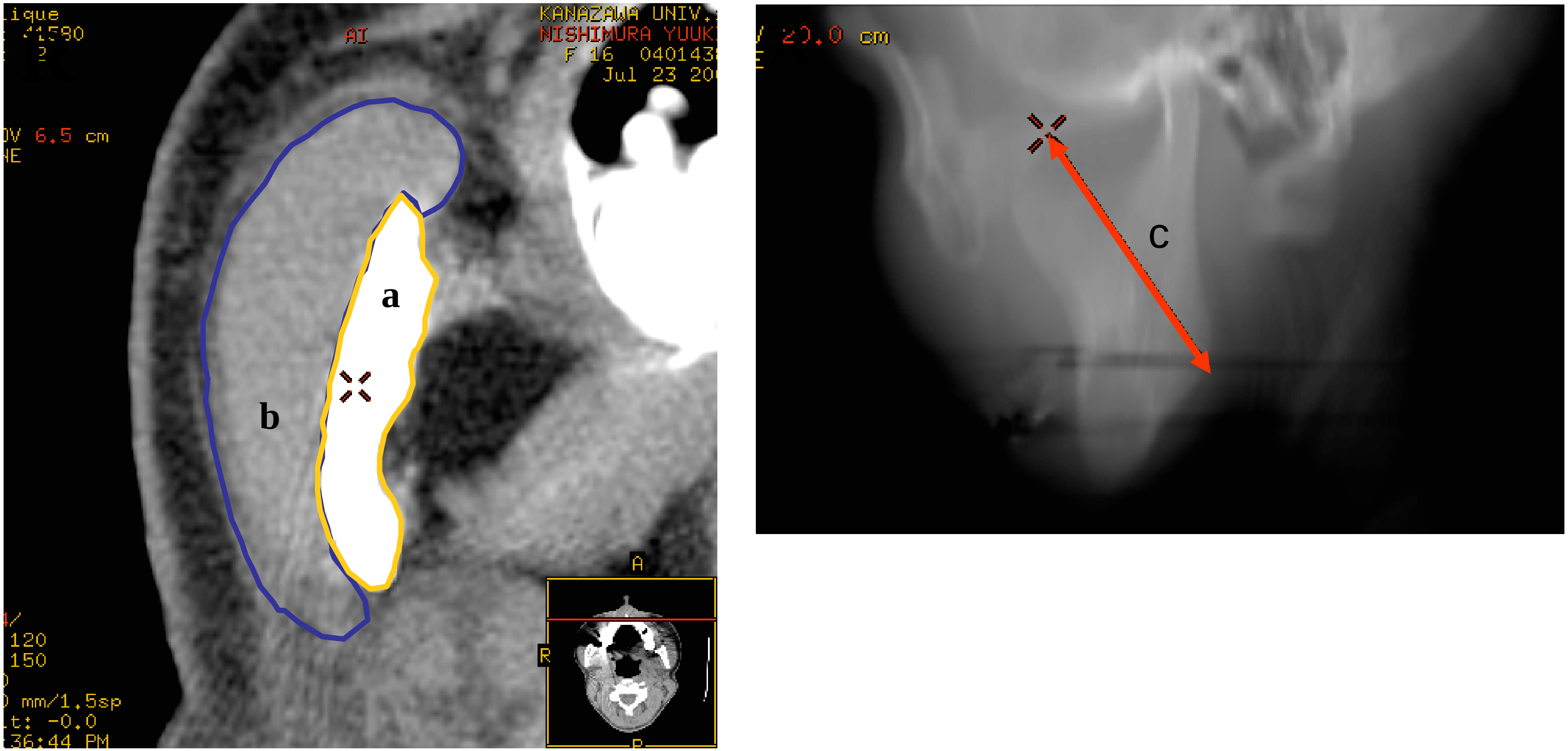
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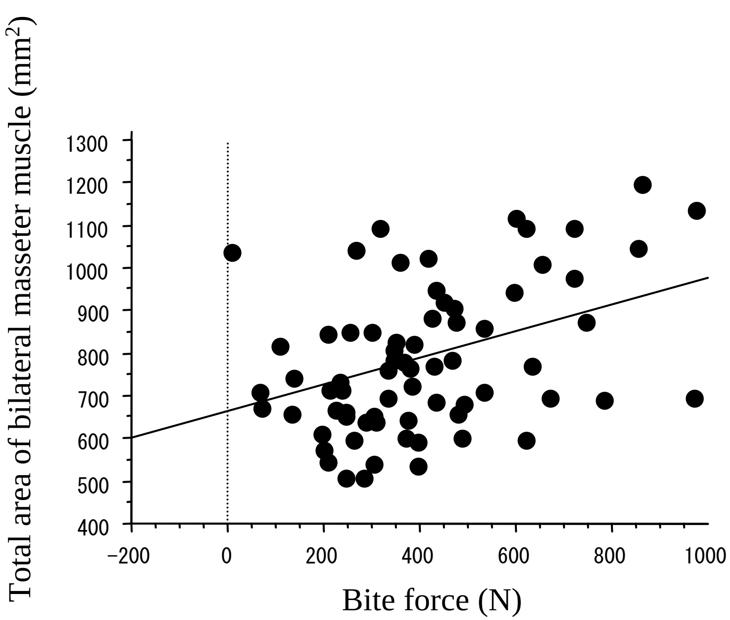
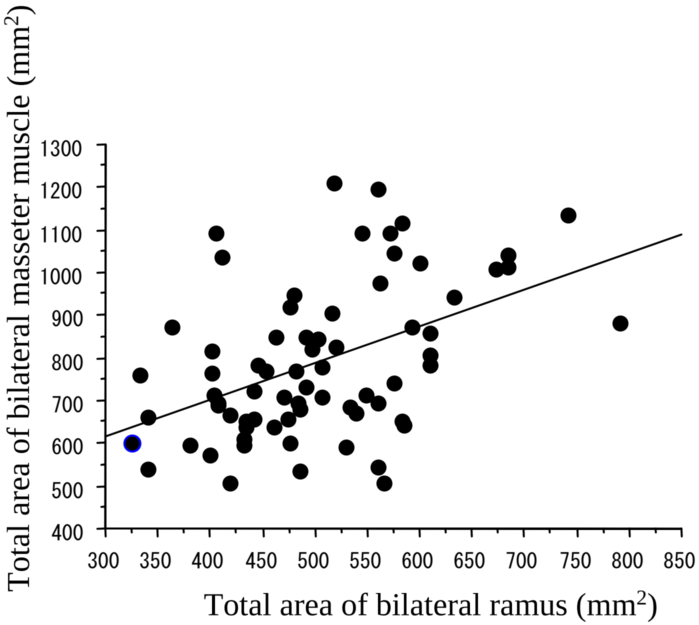
Fig. 3

| | (years) | Area of masseter muscle ($mm^2$) | | Area of ramus ($mm^2$) | | Length of masster muscle (mm) | | Bite force (N) |
|---|---|---|---|---|---|---|---|---|
| | Age | Right | Left | Right | Left | Right | Left | Total |
| Total | 22.9 | 393.8 | 396.2 | 253.1 | 249.0 | 59.0 | 59.1 | 404.9 |
| s.d. | 5.8 | 95.2 | 88.1 | 47.4 | 52.7 | 5.3 | 4.8 | 211.4 |
| | Age | Right | Left | Right | Left | Right | Left | Total |
| Symmetry male | 21.2 | 431.1 | 434.0 | 262.3 | 272.4 | 63.7 | 62.6 | 441.7 |
| s.d. | 3.4 | 79.6 | 85.2 | 53.6 | 57.3 | 4.7 | 4.9 | 204.9 |
| Symmetry female | 24.1 | 365.2 | 372.2 | 247.3 | 237.6 | 56.5 | 57.5 | 403.6 |
| s.d. | 6.9 | 89.4 | 79.7 | 44.0 | 46.4 | 3.8 | 3.7 | 241.7 |
| Symmetry total | 22.8 | 394.2 | 399.4 | 253.9 | 252.9 | 59.6 | 59.8 | 420.3 |
| s.d. | 5.8 | 90.6 | 87.0 | 48.5 | 53.8 | 5.5 | 4.9 | 224.8 |
| | Age | Deviation | Non-deviation | Deviation | Non-deviation | Deviation | Non-deviation | Total |
| Asymmetry male | 18.0 | 477.0 | 474.4 | 266.3 | 265.2 | 62.2 | 61.1 | 515.8 |
| s.d. | 1.0 | 84.7 | 70.7 | 7.7 | 35.7 | 3.3 | 3.7 | 192.1 |
| Asymmetry female | 24.4 | 365.0 | 363.2 | 239.3 | 238.8 | 55.5 | 56.7 | 322.1 |
| s.d. | 5.2 | 103.9 | 80.1 | 52.9 | 51.5 | 2.9 | 3.6 | 146.4 |
| Asymmetry total | 22.8 | 391.7 | 389.7 | 245.7 | 245.1 | 57.1 | 57.7 | 368.2 |
| s.d. | 5.3 | 109.2 | 90.4 | 47.4 | 48.8 | 4.1 | 4.0 | 175.0 |
| | Age | | | | | | | Total |
| control male | 24.3 | | | | | | | 978.3 |
| s.d. | 2.7 | | | | | | | 463.0 |
| control female | 24.1 | | | | | | | 934.2 |
| s.d. | 2.8 | | | | | | | 419.9 |

Table. 1




Y = 662.985 + .314 * X; R^2 = .137




Y = 360.907 + .855 * X; R^2 = .21

Fig. 4

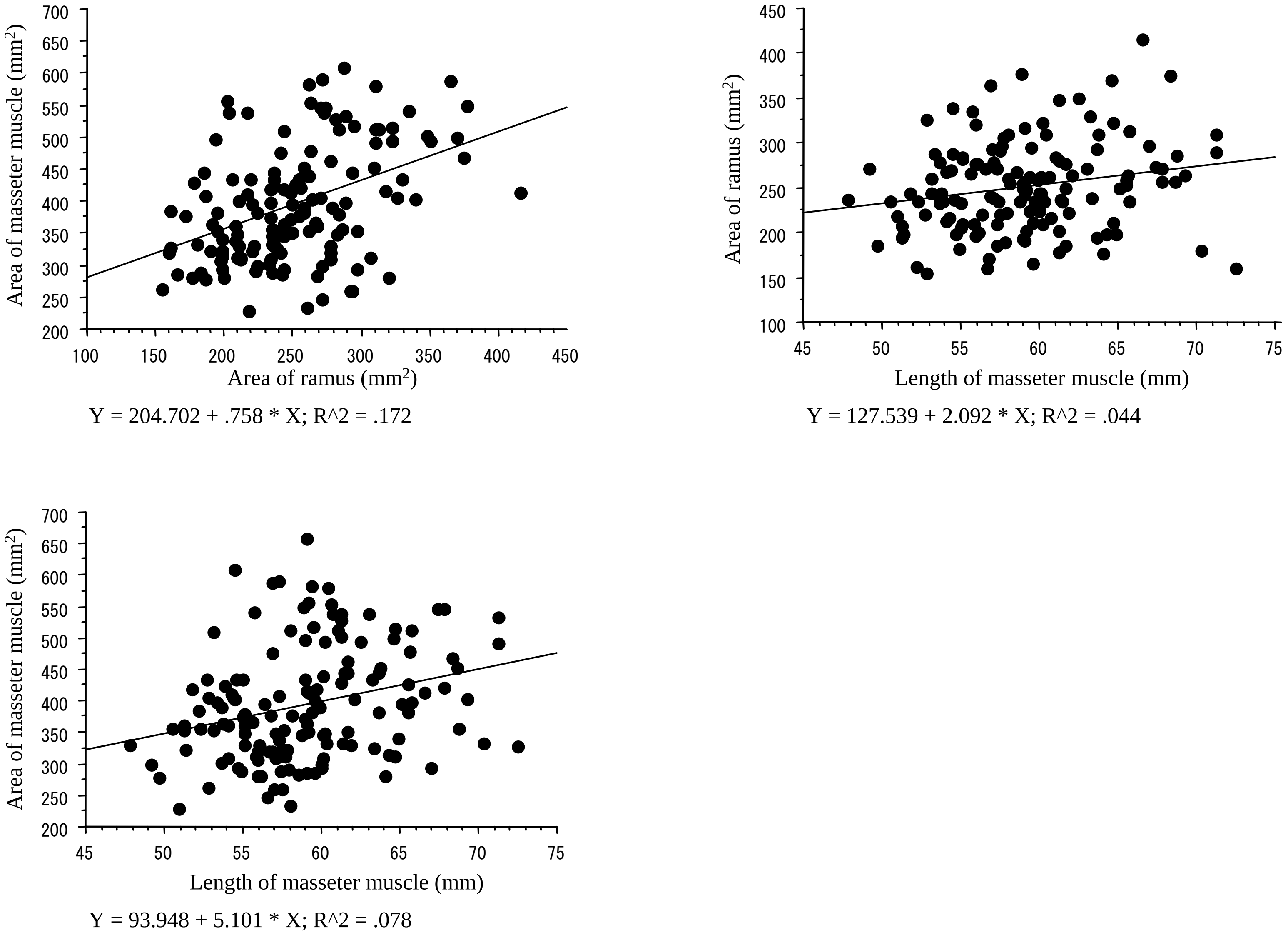

Area of masseter muscle (mm2)
Area of ramus (mm2)
Y = 204.702 + .758 * X; R^2 = .172
Area of ramus (mm2)
Length of masseter muscle (mm)
Y = 127.539 + 2.092 * X; R^2 = .044
Area of masseter muscle (mm2)
Length of masseter muscle (mm)
Y = 93.948 + 5.101 * X; R^2 = .078

Fig. 5