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Measurement of the Size and Orientation of Human Masseter and Medial Pterygoid Muscles

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ABSTRACT

To gain a better understanding of biting and chewing performance, the size and orientation of the masseter and medial pterygoid muscles in living humans were studied. Twenty-seven young males having complete dentition, class I dental occlusion and normal muscle and jaw function were examined using magnetic resonance images of the head between the zygomatic arch and hyoid bone. The sections were parallel to the palatal plane, and the thickness was 3 mm without a gap. A computer software program (Medical Dental Image, MDI) was developed to identify and calculate the area of each cross section of the muscle, and the volume of the muscle was then estimated. The axis of the muscle was determined by connecting the centroids of the sections in the lower and upper 1/3 of the whole muscle. The effective muscle cross section area was then calculated by resectioning the muscle perpendicularly to the muscle axis. It was found that the mean masseter muscle volume was around 31 cm^3, and that the mean medial pterygoid muscle volume was 11 cm^3. Their mean effective cross section areas were around 6.2 cm^2 and 3.5 cm^2, respectively. The axis of the masseter muscle was more perpendicular to the palatal plane and parallel to the sagittal plane than was the medial pterygoid muscle. The results suggest that the use of magnetic resonance images (MRI) is an effective noninvasive measurement technique for determining the size and orientation of masseter and medial pterygoid muscles. This technique can be employed in future studies on human bite force evaluation and masticatory function.

Key Words: MRI, masseter and medial pterygoid muscles, muscle volume, muscle orientation

I. Introduction

The size and orientation of the masseter and medial pterygoid muscles have recently received much attention when the control mechanism of craniofacial growth and the performance of the masticatory system have been studied. Weijs and Hillen (1984) indicated that the mid-belly cross-section area of the jaw muscles obtained through computerized tomography (CT) was closely related to the anatomical cross-section, which represents the maximal isometric strength of that muscle (Maughan *et al.*, 1983; van Spronsen *et al.*, 1989, 1991, 1992). Hannam and Wood (1989) and Sasaki *et al.* (1989) in later studies utilized magnetic resonance images (MRI) as a substitute for CT to obtain images of jaw muscles and to study the relationship between the cross-section area of jaw muscles and craniofacial morphology as well as bite force performance. In their studies, the border of the muscle cross-section in CT and MR images was traced onto acetate paper and digitized manually so that the area could be calculated. This method was time-consuming and somewhat lacking in terms of reproducibility and accuracy. In addition, the volume of the muscles was not reported. The measurement of muscle volume was first reported by Gionhaku and Lowe (1989), who used CT images. However, in view of the radiation hazard encountered when CT examination is employed, MRI is a better choice for muscle volume estimation.

Muscle orientation has also been related to muscle performance. Calculation of two or three dimension vectors on the skull and mandible was employed in a mathematical approach to obtain the muscle position and the direction of force exertion (Sasaki *et al.*, 1989). However, direct determination of muscle orientation from images of muscles would

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be more accurate and practical.

The purpose of this study, therefore, was to apply a newly developed computer program to measure the size and to determine the orientation of human masseter and medial pterygoid muscles from MR images. The results may provide a basis for future studies on muscle power, craniofacial morphology and bite force performance.

II. Materials and Methods

Twenty-seven young Taiwanese males (18 ~ 24.5 years of age) having complete dentition, class I dental occlusion and normal function of the perioral muscles and temporomandibular joints were selected. For each subject, a series of MRI scans were obtained using a 0.15 T Superconducting Scanner (General Electric, Signa, Milwaukee, WI, U.S.A.). T1-weighted images were used with a repetition time of 500 – 550 msec and an echo time of 30 msec. Continuous 3 mm-thick axial plane sections without a gap were sampled with the subjects in a supine position and the teeth lightly in contact. The sections were parallel to the palatal plane between the hyoid bone and the zygomatic arch of the head (Fig. 1). All the MR images were converted and loaded onto a personal computer equipped with a custom-made software program (Medical Dental Image, MDI). The MR images of the masseter and medial pterygoid muscle cross sections were identified by one observer (C.W.H.) at two times. According to the "Region growing principle" employed in the MDI software, the area within a gray level threshold was automatically shown and calculated when the center of that area was clicked. Manual determination of the muscle border was often necessary in the sections near the points of origin and insertion in the muscle where the border of the muscle was not as clear, and also where the muscle tissue was not homogenous and, therefore, was difficult to identify based on the region growing principle. The average measurement error in a muscle cross section area between the two measurements was 4.02% in masseter muscle and 5.01% in medial pterygoid muscle. The muscle volume was then obtained by multiplying the cumulated cross section area by 3 mm (the thickness of each slice), ie.:

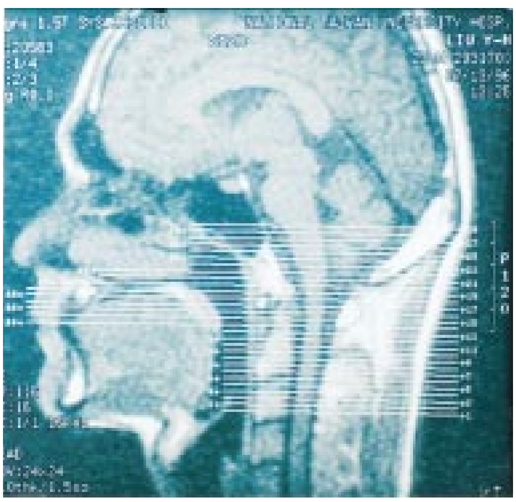

Fig. 1. Continuous 3 mm-thick MR axial plane sections of the head.

$$\text{Volume (mm}^3) = (A_1 + A_2 + \ldots\ldots + A_n) \times 3 \text{ mm},$$

in which A_1 to A_n are the cross-section areas of the muscle measured on MR images.

The muscle orientation was defined by an axis line drawn through the centroids of slices at one-third and two-thirds of the muscle. The angles formed by the axis line and the palatal and mid-sagittal planes were used to describe the orientation of that muscle.

The muscles were then resectioned perpendicular to the estimated muscle axis. The area of the perpendicularly sectioned muscle was then referred to as the effective cross section area (ECA) of that muscle.

III. Results

The treated MRI sections along with areas of the masseter and medial pterygoid muscles are shown in Fig. 2. The mean ECAs of the right and left masseter and medial pterygoid muscles are given in Table 1. The ECAs of the masseter and medial pterygoid muscles are shown in Fig. 3. It can be seen in Fig. 3 that neither the masseter nor the medial pterygoid muscle was spindle shaped. However, the right and left sides were often symmetrical in thickness. The masseter muscle was on average 3 times larger in volume and 2 times larger in cross-section area than the medial pterygoid muscle. There was a strong correlation between the volume and the ECA of the muscles (masseter, $r = 0.75$, $p < 0.0001$; medial pterygoid, $r = 0.64$, $p < 0.001$). The angle formed between the axis of the masseter muscle and the palatal plane was $74.6 \pm 4.9°$ and that between the medial pterygoid muscle and the palatal plane was $66.6 \pm 4.3°$. The angle formed between the axis of the masseter muscle and the sagittal plane was $2.9 \pm 2.0°$, and that between the medial pterygoid muscle and the sagittal plane was $21.4 \pm 4.6°$ (Table 2). The masseter muscle was more vertically oriented than the medial pterygoid muscle on the sagittal and palatal planes (Fig. 4).

IV. Discussion

This is the first time that the volume of masseter and medial pterygoid muscles of living human beings has been measured using MRI. The most difficult task in measuring the muscle size was determining the presence of a muscle image at the levels of insertion and origin. Therefore, repeated identification and comparison of a series of sections was necessary before the sections of interest could be determined.

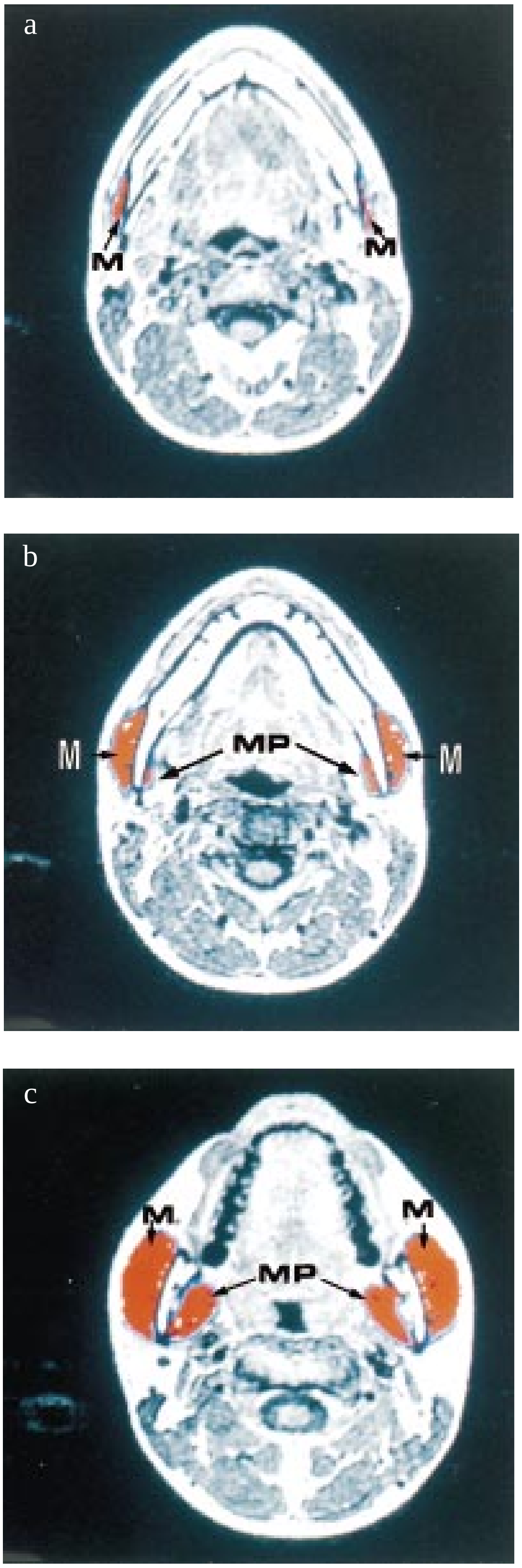

Fig. 2. Series of MR axial sections (a, b and c) showing the presence of masseter muscle (M) and medial pterygoid (MP) muscle. (a) section 3, (b) section 5 and (c) section 9.

Table 1. Measurement Values of the Volume and Effective Cross Section Area of the Masseter and Medial Pterygoid Muscles

	Volume (cm^3)		ECA (cm^2)	
	$\bar{X}$	SD	$\bar{X}$	SD
RM	30.9 ±	6.2	6.2 ±	0.8
LM	31.8 ±	6.9	6.3 ±	0.9
RMP	10.7 ±	2.1	3.2 ±	0.5
LMP	11.2 ±	2.2	3.6 ±	0.6

Abbreviations used: **ECA**, effective cross section area; **RM**, right masseter muscle; **RMP**, right medial pterygoid muscle; **LM**, left masseter muscle; **LMP**, left medial pterygoid muscle.

This difficulty was more evident in the measurement of the medial pterygoid muscle because of its relatively smaller size and more complicated surroundings. Nevertheless, the resulting minor measurement error did not substantially affect the estimation of the muscle size.

The mean cross-sectional area of masseter muscle calculated in this study was larger than the results reported by Hannam and Wood (1989) (5.76 ± 1.11 cm^2), Weijs and Hillen (1985) (5.33 ± 1.43 cm^2) and Spronsen *et al*. (1991) (4.47 cm^2) The differences may be due to the difference in the age of the samples used in our study and more importantly, the method of muscle scanning used. Weijs and Hillen (1984, 1985) and Spronsen *et al.* (1989) scanned the head at a 30° angle with the Frankfort horizontal (FH) plane for observation of the masseter muscle while Hannam and Wood (1989) and Sasaki *et al.* (1989) scanned the masseter and the medial pterygoid muscles parallel to the FH plane. The scanning direction with respect to the FH plane with or without the 30° angle adjustment was not necessarily perpendicular to the long axis of the muscle. The force exertion of a muscle is theoretically related to the direction of the whole muscle and to the obtained cross section area perpendicular to that direction. ECA in this study, should be more important if the size be related to the force of the muscle. Furthermore, the FH plane can not be easily defined on either CT or MRI axial sections. It is, rather, a two-dimensional image in a lateral cephalometric x-ray picture. On the other hand, the palatal plane in both CT and MRI is much easier to identify, and is more useful as a reference plane than is the FH plane. In future studies, the effective muscle cross section area as obtained in this study will be related to the craniofacial morphology and to the bite force during clenching and chewing.

The masseter muscle orientation in this study was more vertical than that of the medial pterygoid muscle. This finding is similar to that of Koolstra *et al.* (1990) while slightly different from that of van Spronsen *et al.* (1996) who reported a more vertically (1 ~ 2°) oriented medial pterygoid muscle. The present results may indicate a stronger jaw closing force of the masseter. There is no big difference in muscle volume between this study and that of Gionhaku and Lowe (1989), who used CT to perform muscle volume measurement. The minor difference may also be related to the selection of a ref-

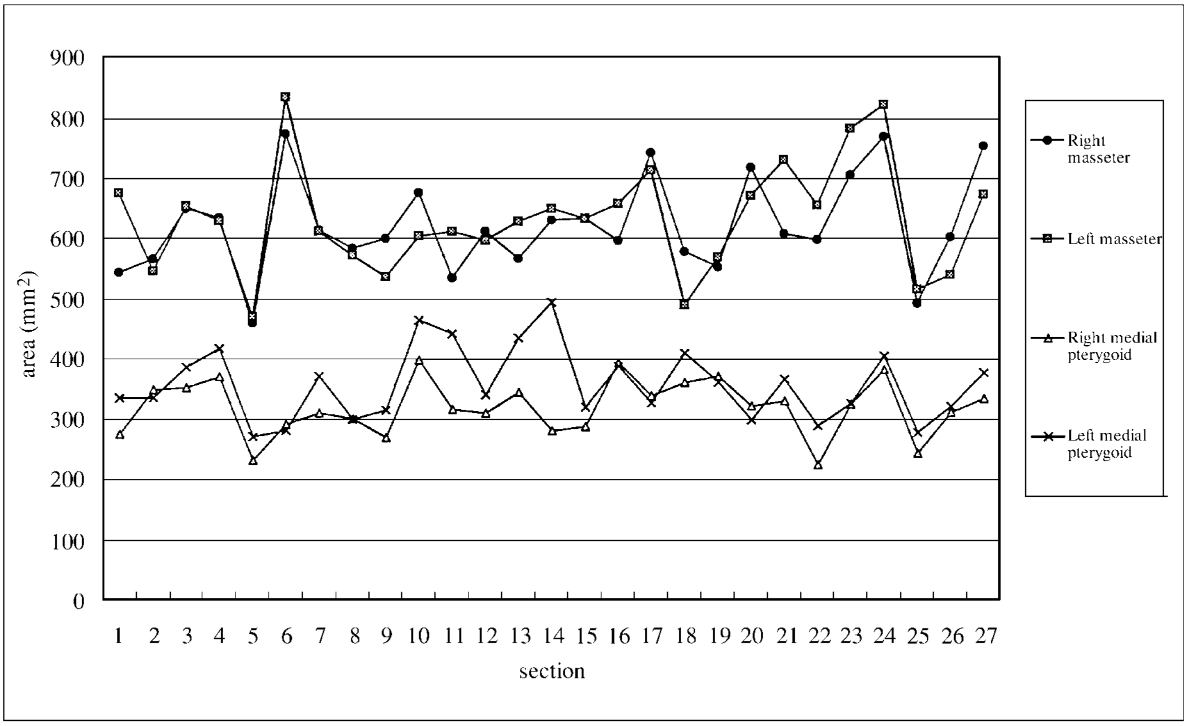

Fig. 3. Line graph of the effective cross section areas of the right and left masseter and medial pterygoid muscles.

Table 2. Orientation of the Masseter and Medial Pterygoid Muscles Represented by Angles Formed between the Muscle Axis and the Sagittal and Palatal Planes (in Degrees)

	Palatal plane	Sagittal plane
	$\bar{X}$ SD	$\bar{X}$ SD
RM	74.4 ± 5.2	3.2 ± 2.5
LM	74.4 ± 4.9	2.0 ± 1.6
RMP	67.1 ± 5.3	21.4 ± 5.0
LMP	66.2 ± 4.6	21.6 ± 5.2

Abbreviations used: **RM**, right masseter muscle; **RMP**, right medial pterygoid muscle; **LM**, left masseter muscle; **LMP**, left medial pterygoid muscle.

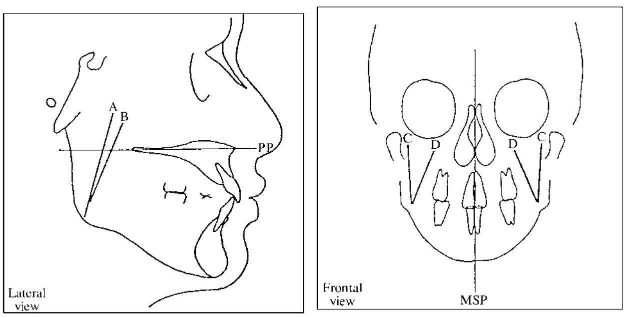

Fig. 4. The relative positions of the masseter and the medial pterygoid muscles on the palatal and sagittal planes of the head.

Note: A: masseter muscle axis with respect to the palatal plane; B: medial pterygoid muscle axis with respect to the palatal plane; PP: palatal plane; C: masseter muscle axis with respect to the sagittal plane; D: medial pterygoid muscle with respect to the sagittal plane; MSP: mid sagittal plane

erence plane during sectioning. We believe that both CT and MRI are good methods for describing masseter and medial pterygoid muscles. However, since MRI is safer with regard to radiation, the use of MRI for this purpose is recommended. Further studies, such as on how bite force exertion may be related to the masticatory muscle size and orientation, will be conducted using the MRI technique.

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人體咬肌與內翼肌大小及方向之測量

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摘　　要

為瞭解人類的咬力施出，需先研究閉口肌如咬肌及內翼肌之大小及方向。本研究對 27名年青男性進行閉口肌大小的觀察，彼等皆具完整齒列及正常顎肌功能，咬合狀態為第一類咬合。以磁共振方法(MRI)切取頭部自顴骨至舌骨之間的　板平行面影像，切距為 3 mm。經以自製電腦程式計算每一切面之咬肌及內翼肌面積，從而換算為肌體積。肌之軸線，以穿越該肌上下1/3部位之切面中心形成之連線為代表。有效肌切面積則為以垂直肌軸線之切法測得之 MRI 肌切面積。結果發現咬肌之平均體積約為31 cm^3，內翼肌體積為11 cm^3。有效切面面積為咬肌6.2 cm^2，內翼肌3.5 cm^2。咬肌之肌軸較內翼肌垂直於　面及矢狀面。此結果顯示 MRI 為有效而非侵入性之肌體積測量法，且此方法可為爾後有關人體咀嚼肌咬力及咀嚼功能之研究基礎。