

Magnetic Resonance Imaging of Lateral Pterygoid Muscle after Performing Mouth-Opening and Jaw-Protruding Resistance Exercises

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Objective: To investigate the functions of the two heads of lateral pterygoid muscle in mouth-opening and jaw-protruding resistance exercises with magnetic resonance imaging (MRI).

Methods: Seven normal male subjects participated in the study. Four of the seven subjects did mouth-opening resistance exercises, while two did jaw-protruding resistance exercises and one did both mouth-opening and jaw-protruding resistance exercises over a period of two weeks. The oblique sagittal T₂-weighted MR images of lateral pterygoid muscle were obtained before and immediately after exercise and at 2, 4, 6, 8, 10, 15, 20 minutes after exercise. Signal intensity of the superior and inferior heads of lateral pterygoid muscle, cerebral grey matter, and masseter was also measured at these time points.

Results: The signal intensity (SI) of the two heads of lateral pterygoid muscle in all the subjects was increased significantly and homogeneously after mouth-opening or jaw-protruding resistance exercise. The increased SI declined approximately to pre-exercise level in 20 minutes. No changes of SI were found in masseter and cerebral gray matter after exercises.

Conclusion: The results of the present study strongly suggest that the two heads of the lateral pterygoid act synergistically and homogeneously during mouth-opening and jaw-protruding resistance exercise. The results do not support the concept that the two heads act antagonistically during jaw movements.

Key words: lateral pterygoid muscle, masticatory muscle, MRI, muscle recruitment, signal intensity

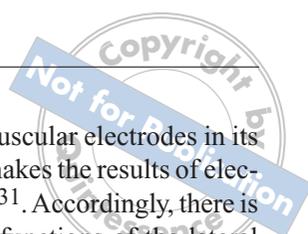
The lateral pterygoid muscle is located deep within the infratemporal fossa, behind many structures such as the zygomatic arch, masseter, superior half of ramus, coronoid process and temporalis¹. It consists of two heads, a smaller superior head and a larger inferior head. The superior head originates on the infratemporal

surface and infratemporal crest of the greater wing of sphenoid bone, while the inferior head originates on the lateral surface of the lateral pterygoid plate. The fibres of the superior head run downward, backward and outward and the fibres of the inferior head converge upward and outward. Both heads blend their fibres horizontally near their insertion to the condyle^{1,2}. These anatomical factors make the lateral pterygoid probably the most controversial muscle in the orofacial region and in temporomandibular disorders (TMD).

Since the 1950s, many studies on the muscle have attempted to explain its role in the physiology and pathophysiology of jaw movements. The functions of the two heads of the lateral pterygoid were not distinguished

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based on electromyography (EMG) investigations until 1973³⁻⁸. However, in 1973 Grant suggested that each head may serve opposite functions during jaw-opening and jaw-closing movements, by biomechanical and electromyographic analysis⁹. In the same year, McNamara provided data collected from 33 monkeys that the two heads of the lateral pterygoid act antagonistically during jaw movements based on the patterns of their EMG activities. He tried to verify the electrode placement in the superior or inferior head by injecting a drip of dye into the muscle and dissecting 12 monkeys. He suggested that the two heads of the lateral pterygoid muscle could be considered as two functionally distinct muscles¹⁰. Following this, EMG recordings similar to his results were widely reported¹¹⁻¹⁸.

The notion of the lateral pterygoid was gradually formed and it was written in textbooks that the superior head is active during the jaw-closing movement while the inferior head acts in the jaw-opening movement. However, some researchers questioned the functional independence of the two heads in their EMG or magnetic resonance imaging (MRI) observations¹⁹⁻²¹. Moreover, EMG recordings in five monkeys in which the electrodes were inserted visually into the two heads after the two heads were anatomically exposed by operation clearly demonstrated that the two heads acted synergistically during mouth opening and mouth closing²².

The key point of the controversy over lateral pterygoid muscle in the literature is the functional role of the superior head; namely, whether it acts with the inferior head synergistically or antagonistically. In most previous EMG studies of the lateral pterygoid, there was no effective method to confirm the electrode placement in the process of the EMG recordings of the superior head due to its small volume and deep location. Although computed tomography (CT) was used in verifying the electrode placement in the superior head, its functions still varied from similar to masseter and anterior temporalis²³, involved in both jaw opening and closing²⁴, to similar to the inferior head^{25,26}. Even under CT verification of fine-wire electrodes in the superior head, it is probably difficult for an EMG recording to avoid receiving signals interlacing between the superior head and the adjacent muscle fibres, such as the deep temporalis, as it frequently adjoins the lateral part of the superior head^{24,27}. Also, during EMG recordings, the wires may be displaced and enter the adjacent muscles; this may happen even though initially the wires were accurately placed within the target muscle²⁸⁻³⁰.

In recent anatomical research of the lateral pterygoid from 179 fresh cadavers, it was suggested that the peniform structure and particular shape of this muscle

makes it useless to insert intramuscular electrodes in its only accessible portion, which makes the results of electromyographic studies debatable³¹. Accordingly, there is still no consensus on the basic functions of the lateral pterygoid, as to whether or not the two heads act synergistically or antagonistically during jaw closing or opening. To complement the EMG results, new methods should be tried to investigate the functions of the two heads of the human lateral pterygoid.

As a non-invasive method, MRI was introduced by Fleckenstein et al³² to detect whether the muscles were recruited in a specific exercise in vivo. Since then, a number of experiments have shown that the exercised muscles demonstrate higher signal intensity (SI) immediately after exercise than before exercise on MR imaging³³⁻⁴⁴. Our previous study also showed that performing a clenching exercise could increase the SI of mandible elevators, such as the masseter, medial pterygoid and temporalis on MR images⁴⁵. The purpose of the present study was to evaluate activities of the two heads of the lateral pterygoid by MRI during mouth-opening and jaw-protruding resistance exercises.

Materials and Methods

Subjects and exercise protocol

Seven healthy male subjects with no history or symptoms of disorders in the orofacial region, aged 25 to 36 years (mean 30.3 years), participated in the study. The subjects provided informed written consent in accordance with a protocol approved by the Institutional Human Investigations Committee. Four of the seven subjects did mouth-opening resistance exercises, while two did jaw-protruding resistance exercises, and one did both mouth-opening and jaw-protruding resistance exercises over a period of two weeks.

The device applied for the resistance exercise consisted of a headgear, two elastic bands and an aluminium chin cap. The force of the elastic bands onto the chin of the subjects through the chin cap was approximately 4 kg while their mouth was closed. The subject needed to generate more than 4 kg force to resist the force generated by the elastic bands while trying to move the mandible for mouth opening or jaw protrusion. The subject's head, wearing the headgear, was put inside the receive coil and placed in the MR gantry for obtaining pre-exercise imaging. The subject was then removed from the MR gantry and the chin cap was put on to perform the resistance exercise while lying supine on the table. The subject was requested to maintain maximum mouth opening or jaw protrusion under the force generated by

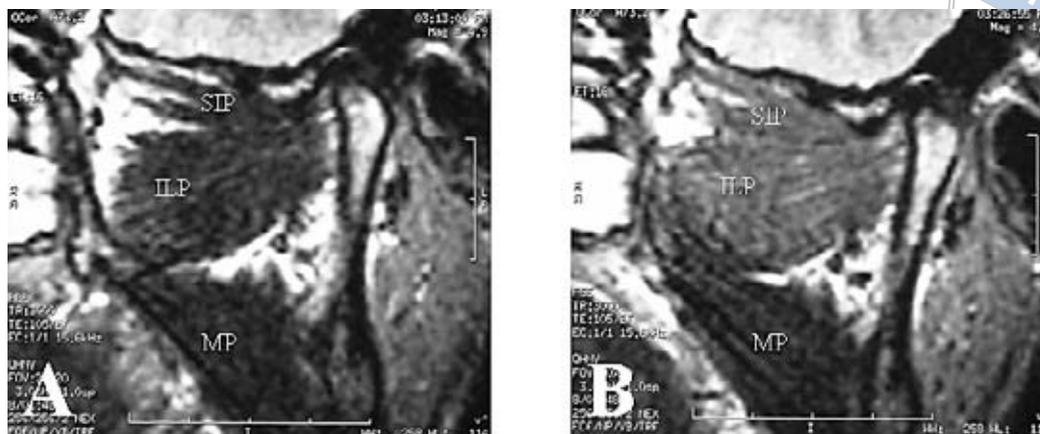


Fig 1 Representative T₂-weighted images (TR/TE = 3000/105 ms) of lateral pterygoid before (A) and immediately after (B) mouth-opening resistant exercise. Signal intensities (SI) of the superior head (SLP) and the inferior head (ILP) are significantly and homogeneously increased. Note: SI of the medial pterygoid muscle (MP) was not changed after exercise.

the elastic bands until they could no longer voluntarily maintain mouth opening or jaw protrusion owing to muscle fatigue or pain. The average time of each exercise was 5 minutes (3–10 min). After exercise, the chin cap was removed and the subject was immediately returned to the MR gantry for post-exercise images. For the whole imaging process, the subject was asked to keep the position of their head unchanged.

MRI technique

MRI was performed with a 1.5 T superconducting magnet operation system (Signal Horizon, GE, USA). A Quad Head and Neck Coil was used and the images were obtained with fast spin-echo sequences (TR = 3000 ms, TE = 105/Ef, Fov = 20 × 20 cm², Nex = 2, matrix = 256 × 256, thickness = 3 mm, and gap = 1 mm). A transaxial locator sequence was used for orientation so that the direction of oblique sagittal imaging was parallel to the muscle fibre of the lateral pterygoid⁴⁶. The oblique sagittal images were obtained before and immediately after exercise and at 2, 4, 6, 8, 10, 15 and 20 minutes post-exercise. The total scan time was about 20 minutes in each case.

Five regions of interest (ROIs) were determined in the superior or inferior head of the lateral pterygoid on the image before exercise and duplicated on the images after exercise by the operation system's software. SI for superior or inferior head of the lateral pterygoid was measured as mean value ± standard deviation (SD). As a con-

trol, five ROIs were also determined and duplicated in the masseter and cerebral grey matter on the images before and after exercise. This was used to compare the SI of a specific muscle before and after exercise, as all the ROIs were duplicated in the same location on the images before and after exercise^{32,34,39,47}.

Statistical analyses

A two-tailed, paired Student *t* test was used to compare the mean values of each muscle before and immediately after exercise, while an independent Student *t* test was used to compare the mean values of the two heads before and immediately after exercise. The null hypothesis was rejected at the level $p < 0.05$.

Results

The lateral pterygoid muscle was clearly depicted by oblique sagittal T₂-weighted MR imaging. Three successive images showed the lateral, middle and medial part of the two heads. The two heads were distinguished by the fatty tissue in the frontal part. The volume of superior head was much smaller than the inferior head, less than one-third of the inferior head (Fig 1A). The two heads were seen to blend their fibres near the insertion to the condyle.

SI of both heads significantly increased ($p < 0.001$, Table 1) immediately after mouth-opening and jaw-pro-

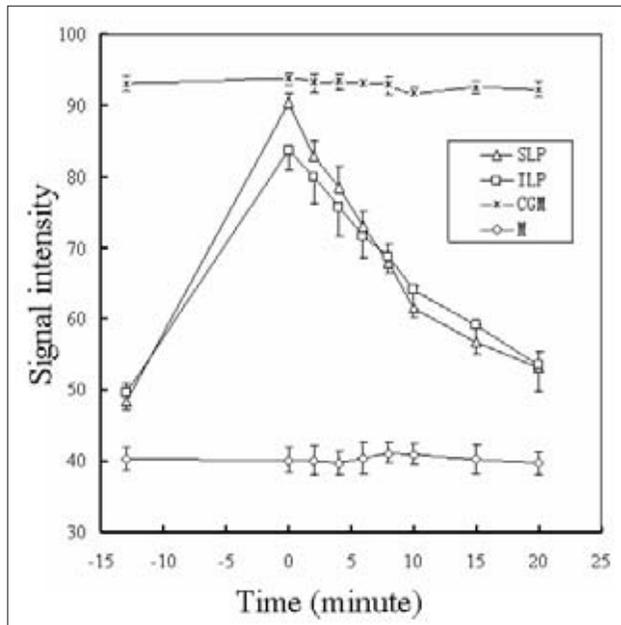


Fig 2 SI typical post-exercise recovery time course. SI of the superior head (SLP) and inferior head (ILP) of lateral pterygoid declined exponentially with time after exercise. SI of the cerebral grey matter (CGM) and masseter (M) were not changed ($p > 0.05$) after exercise.

TABLE 1 Signal intensity before and immediately after resistance exercises

Tissue	Pre-exercise Mean \pm SD	Post-exercise Mean \pm SD	P
SLP	47.39 \pm 4.54	75.99 \pm 12.22	< 0.001
ILP	45.26 \pm 3.59	73.77 \pm 7.74	< 0.001
CGM	88.77 \pm 6.46	88.78 \pm 7.36	> 0.05
M	38.15 \pm 5.22	37.87 \pm 5.05	> 0.05

Values are mean SI \pm standard deviation (SD) of seven subjects (five mouth-opening trials and three jaw protruding trials, $n = 8$). SI was measured from the images obtained before and immediately after the exercises. SLP, superior head of lateral pterygoid; ILP, inferior head of lateral pterygoid; CGM, cerebral grey matter; M, masseter.

truding resistance exercises than before exercise, as shown in Fig 1. The enhanced SI of the two heads declined exponentially with time (minutes) after exercise and recovered approximately to the pre-exercise level in 20 minutes (Fig 2). The SI of the two heads was homogeneously increased on the successive images from the lateral to the medial side. There was no difference between the two heads before and after exercises ($p > 0.05$). All the subjects who did mouth-opening or jaw-protruding resistance exercises or both exercises

showed similar results. No changes of SI were found in the masseter and cerebral grey matter of the subjects before and after mouth-opening or jaw-protruding resistance exercises ($p > 0.05$).

Discussion

In the present study, MRI data from humans was used to demonstrate that the two heads of the lateral pterygoid acted synergistically, not antagonistically or independently, during mouth-opening and jaw-protruding movements. The use of MRI to detect the imaging change of the two heads after exercise was described. On T_2 -weighted MR images, the SI of the two heads dramatically increased after performing mouth-opening or jaw-protruding resistance exercise in all subjects (Figs 1 and 2, Table 1). As an internal control, the SI of the masseter and cerebral grey matter were not altered (Figs 1 and 2, Table 1). It has been demonstrated previously *in vivo* that an increase of SI on MR image after voluntary exercise is strongly related to muscle activation³²⁻⁴⁴. This muscle phenomenon was based on the property that short-term intensive exercise can cause water content to increase in the exercised muscles⁴⁸⁻⁵⁰.

It is well known that T_2 -weighted MR imaging is highly sensitive to changes in water distribution. These changes in water distribution in muscle after exercise should be detectable by MR imaging. In 1988, Fleckenstein et al³² first demonstrated that, after exercise, the SI of activated muscle was significantly higher than that of inactivated muscle, and that activated muscle was easily and clearly distinguishable from inactivated muscle on T_2 -weighted MR images. This phenomenon of striated muscle was later intensively studied³³⁻⁴⁴. This phenomenon was also observed in masticatory muscles after performing clenching exercises, as previously reported⁴⁵. Therefore, an increase of SI after exercise is one of the characteristics of striated muscle.

The results of SI increase in both heads of the lateral pterygoid after mouth-opening and jaw-protruding resistance exercises would plainly indicate that the two heads were activated in the exercises, and that the two heads, therefore, had similar functions at least during mouth-opening and jaw-protruding movements. Given the direction of the fibres of the two heads, the lateral pterygoid would move the mandible downwards and forwards during mouth opening and would also be the major muscle to move the mandible forward. The results of the present study further support the previous observations¹⁹⁻²² and recent observations in humans^{25,26}, but are not in agreement with the observations from EMG studies by Grant⁹, McNamara¹⁰, and Juniper¹²,

that the superior and inferior heads of the lateral pterygoid muscle act reciprocally or antagonistically in mouth opening.

Due to its location deep within infratemporal fossa and its presumed roles in TMD, the lateral pterygoid is the masticatory muscle that has probably received the most attention from researchers and clinicians. Whether the superior head acts antagonistically or synergistically with the inferior head was the main subject of controversy. EMG has been the main method of investigating the lateral pterygoid. However, electrode placement in the superior head was not convincingly verified in most previous EMG studies of the lateral pterygoid. Several methods had been attempted to verify the electrode placement. McNamara tried to verify the electrode placement after the EMG recording by injection of a drip of ink into the muscle and anatomical dissection¹⁰. Sessle and Gurza¹⁴ described insertion of the electrode visually into the superior head by exposure of the lateral pterygoid of monkey by cutting the surface layer of masseter and then observing the EMG activities in the superior head synergistically with the temporalis and masseter. The present authors once followed their method to expose the lateral pterygoid in five monkeys by operation. However, only after the complete layers of the masseter and the process of coronoid and the deepest layer of the temporalis were cut and removed, could the whole lateral pterygoid be seen²². Therefore it would be unlikely that Sessle et al¹⁴ inserted the electrode into the two heads under direct vision. After the insertion of the electrodes under direct vision into the two heads, the present authors observed that the EMG activities of the two heads acted synergistically in mouth opening, but there was no activity in mouth closing in all the five monkeys. The placement of the electrodes was also confirmed, and there was no displacement after EMG recordings. However, it was not adequate to directly apply data obtained from monkeys to humans without reconfirmation in humans. It was also almost impossible to observe the monkey in protrusive movement, and thus the data from monkeys was not sufficient to understand the function of the two heads of lateral pterygoid in humans. To understand the functions of the two heads of human lateral pterygoid, it was still necessary to overcome the uncertainty of the placement of electrode. Orfanos et al²³ reported that in humans the placement of an electrode in the superior head of lateral pterygoid can be effectively verified by CT. Nevertheless, the EMG activities recorded from the human superior head were fairly inconsistent even under CT verification of the electrode placement in a series of investigations by the same research group²³⁻²⁶. Although the authors inter-

preted this as functional heterogeneity within the superior head, it is still difficult to rule out the influence from the deepest part of temporalis adjacent to the superior head.

Fine-wire electrode has been the major electrode used in EMG investigations of the lateral pterygoid, but there are some disadvantages. Displacement and deformation of the fine-wire electrode during EMG recording from the lateral pterygoid have long been argued²⁸⁻³⁰. The disparity in EMG activities from the superior head is obvious even under CT verification²³⁻²⁶. For example, under CT verification of the electrode placement, the EMG recording from the medial part of the superior head showed activity in jaw opening (64%) and/or jaw closing (20%). EMG from the lateral part of the superior head in two out of eight sites showed activity in ipsilateral movement, retrusion, jaw closing, and clenching in the intercusp position; two sites demonstrated activity resembling those recorded from the medial part, and the other four sites showed activity in various patterns²⁴.

Such a disparity may not be convincingly interpreted only as functional heterogeneity within the superior head. Since the tips (without insulation for 1–2 mm) of the fine wires were bent back 1.5 and 3 mm respectively in the EMG studies^{23-26,51} and there was some magnification of the wire on the CT radiograph due to scatter, it would still be difficult to precisely locate the tip of the fine-wire electrode by CT. Furthermore, it was also pointed out that it may not be suitable to carry out an EMG study on the lateral pterygoid with an intramuscular electrode due to the penniform structure of the muscle of humans³¹.

The function of the superior head based on EMG data still remains obscure. In contrast, MRI has been shown to have some advantages in detecting recruitment of subvolumes of the flexor digitorum during specific finger exercises, with little or no spatial overlap in areas of increased SI⁴⁰. MRI should reveal if there was functional heterogeneity within the lateral pterygoid during the resistance exercises. Since heterogeneity of SI from the lateral to medial part of the two heads was not observed after the exercises in all subjects, the present results would probably not support functional heterogeneity within the two heads during mouth-opening and jaw-protruding movements.

Conclusively, MRI data from humans is provided in the present paper to demonstrate that performing the mouth-opening or jaw-protruding resistance exercises significantly and homogeneously increased the SI of two heads of the lateral pterygoid, suggesting that the two heads were activated synergistically and homogeneously during mouth-opening and jaw-protruding movements.

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