

Change in Tongue Morphology in Response to Expiratory Resistance Loading Investigated by Magnetic Resonance Imaging

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Abstract. [Purpose] The purpose of this study was to investigate the effect of expiratory resistance load on the tongue area encompassing the suprahyoid and genioglossus muscles. [Subjects] The subjects were 30 healthy individuals (15 males, 15 females, mean age: 28.9 years). [Methods] Magnetic resonance imaging was used to investigate morphological changes in response to resistive expiratory pressure loading in the area encompassing the suprahyoid and genioglossus muscles. Images were taken when water pressure was sustained at 0%, 10%, 30%, and 50% of maximum resistive expiratory pressure. We then measured tongue area using image analysis software, and the morphological changes were analyzed using repeated measures analysis of variance followed by post hoc comparisons. [Results] A significant change in the tongue area was detected in both sexes upon loading. Multiple comparison analysis revealed further significant differences in tongue area as well as changes in tongue area in response to the different expiratory pressures. [Conclusion] The findings demonstrate that higher expiratory pressure facilitates greater reduction in tongue area.

Key words: Expiratory resistance load, Tongue area, Magnetic resonance imaging

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INTRODUCTION

The known effects of expiratory muscle strength training (EMST) include improved respiratory muscle strength¹⁻⁴⁾, exercise tolerance⁵⁾, and increased speech loudness⁶⁾. Recent reports, that EMST can improve cough capacity^{3, 4, 7, 8)} and swallowing function⁹⁻¹³⁾, have drawn attention to this method as an effective means for stimulating the suprahyoid muscles, which play a role in swallowing, and thus as a preventive measure against aspiration pneumonia.

Wheeler et al.¹¹⁾ compared the activities of the suprahyoid muscles under positive expiratory pressure loading while swallowing saliva and water. They found that pressure loading resulted in a significantly longer duration of muscle activity and larger maximum and mean amplitudes¹¹⁾, suggesting that EMST improves the contraction characteristic and neuromodulatory mechanism of the suprahyoid muscles involved in swallowing. Furthermore, Pitts et al.⁹⁾ and Troche et al.¹⁰⁾ performed EMST studies of patients with Parkinson's disease and reported improved cough capacity and higher penetration-aspiration scale scores. These results

indicate that EMST affects swallowing function by directly stimulating the suprahyoid muscles. However, these findings were all based on surface electromyography (SEMG) studies, and because of the potential involvement of the genioglossus muscle in SEMG of the suprahyoid muscles¹⁴⁾, many uncertainties about the beneficial effects of pressure loading remain. Therefore, we conducted a morphological study using magnetic resonance imaging (MRI) to investigate the influence of expiratory pressure on the area encompassing the suprahyoid and genioglossus muscles.

SUBJECTS AND METHODS

Subjects

This study recruited employees at Health Insurance Naruto Hospital who had no known health problems and who provided informed consent to participation in the study. Thirty participants (15 males, age 31.4±4.2 years; 15 females, 26.5±4.8 years) were examined to determine the effects of pressure loading on tongue morphology (Table 1).

Methods

To determine the levels of expiratory pressure used during MRI, a Micro RPM respiratory pressure device (Mi-

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cro Medical Ltd., United Kingdom) was used to measure the maximum expiratory pressure (MEP) of participants in the sitting position according to the method of Black and Hyatt¹⁵. Although respiratory muscle strength is generally measured in the sitting position, MEP measurements obtained in this position cannot be used to interpret MRI data taken in the supine position because respiratory muscle strength is affected by body position¹⁶. Therefore, we also measured MEP in the supine position. The threshold was set at 100% MEP in the supine position and experiments were performed at 10%, 30%, and 50% MEP. In addition, a water pressure-type device¹⁷ was used instead of the commonly used spring-type device because MRI generates a magnetic field that would affect the functionality of a spring-type device.

Unlike computed tomography (CT), MRI poses no risk of radiation exposure. Participants wore a head coil and were placed in the supine position during an MRI session performed using a Vantage XGV 1.5T MRI scanner (Toshiba Medical Systems Co., Tochigi, Japan) with a gradient echo sequence and other imaging parameters set according to How et al.¹⁸ (Fig. 1). Sagittal plane images were taken at rest and at 10%, 30%, and 50% MEP in random order (Table 2). The interval between scans was 3 min, and the tongue area was measured using Synapse[®] (FUJIFILM Medical Systems U.S.A. Inc., Tokyo, Japan). The tongue area was

defined as the area encompassing the suprahyoid and genio-glossus muscles according to Stuck et al.¹⁹.

SPSS Statistics version 17 was used for statistical analysis. Because MEP changes in response to different body positioning, MEP measured in the sitting and supine positions was compared between sexes using the paired t-test. Sex-specific morphological changes in response to expiratory loading were analyzed using repeated measures analysis of variance (ANOVA) followed by Bonferroni post hoc comparisons. A two-sample test was also performed to compare differences in tongue areas between the sexes. Results were considered significant at $p < 0.05$.

This study was approved by the Ethics Review Board of Health Insurance Naruto Hospital (approval number 1103) and was performed in accordance with ethical standards on human experimentation and the Helsinki Declaration of 1975, as revised in 1983.

RESULTS

In both sexes, MEP measured in the supine position was significantly lower than that in the sitting position ($p < 0.01$, Table 1).

Significant changes in tongue area were detected in both sexes upon MEP loading (males, $F(3,42)=133.00$, $p < 0.01$; female, $F(3,42)=144.98$, $p < 0.01$), and multiple comparison analysis revealed further significant differences between the different expiratory pressures ($p < 0.01$, Table 3). The reductions in area at 10%, 30%, and 50% MEP were 13.0%,

Table 1. Subject characteristics

	Male (n=15)	Female (n=15)
Age (years)	31.4±4.2	26.5±4.8
Height (cm)	171.2±4.5	158.9±4.3
Weight (kg)	64.2±7.0	52.4±8.1
Sitting MEP	131.1±16.5	100.7±17.1
Supine MEP	122.8±16.5*	89.4±15.1*

MEP: Maximum expiratory pressure
Mean±SD. paired t-test; *: $p < 0.01$, compared with sitting MEP for each sex

Table 2. Magnetic resonance imaging parameters

Parameter	Sagittal value
Repetition time (ms)	5.8
Echo time (ms)	2.3
Acquisition time (s)	7.0
Field of view (mm)	250

Table 3. Dimensional change (mm²) in tongue area at different expiratory pressures

	Resting	10% MEP	30% MEP	50% MEP
Males	3169.4±342.0	2761.7±378.9*	2654.4±365.5*†	2582.2±381.2 *†#
Females	2687.6±291.1	2251.3±279.5*	2189.9±294.6 *†	2097.7±275.4 *†#

Mean±SD. Bonferroni post hoc comparisons; *: $p < 0.01$, compared with resting values. †: $p < 0.01$, compared with values at 10% MEP. #: $p < 0.01$, compared with values at 30% MEP

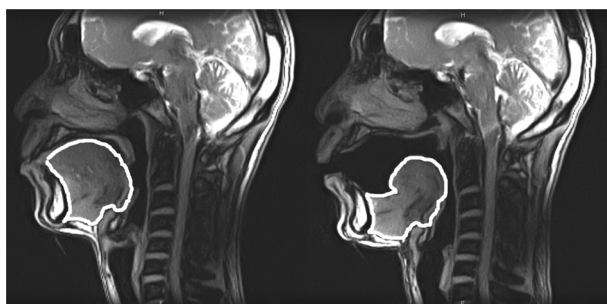


Fig. 1. MRI images taken at rest (left) and at 50% MEP (right)

Table 4. Percent reduction in tongue area at different expiratory pressures

	10% MEP	30% MEP	50% MEP
Males	13.0±5.4	16.4±5.0*	18.7±5.0*†
Females	16.2±5.4	18.6±5.8*	22.0±5.4*†

Mean±SD. Bonferroni post hoc comparisons; *: $p < 0.01$, compared with values at 10% MEP. †: $p < 0.01$, compared with values at 30% MEP.

Two sample test: no significant differences were detected in the rate of changes in pressure loading in males or females.

16.4%, and 18.7% in males and 16.2%, 18.6%, and 22.0% in females (Table 4), respectively, with statistical significance for each sex (males, $F(2,28)=33.79$, $p<0.01$; females, $F(2,28)=41.3$, $p<0.01$). Multiple comparison analysis revealed significant differences between all 4 conditions ($p<0.01$, Table 4), but not between sexes.

DISCUSSION

Pressure loads in EMST have been suggested to improve swallowing function by stimulating the suprahyoid muscles. Such studies however have used SEMG to investigate the effect of EMST on muscle activity. Because the suprahyoid muscles is a collective name for the digastric, mylohyoid, stylohyoid, and geniohyoid muscles, the problem associated with SEMG measurements of the suprahyoid muscles is that the activities of other muscles such as the genioglossus muscle, a large muscle adjacent to the suprahyoid muscles, may be included in SEMG recordings¹⁴. For this reason, the actual effect of expiratory pressure loads on the genioglossus muscle must be clarified. However, SEMG detects muscle activity, not morphological changes in internal structures. To the best of our knowledge, no previous studies have investigated morphological changes of the suprahyoid muscles or genioglossus muscle under pressure loading. Therefore, we used MRI to study the effect of pressure loading on the tongue from a morphological perspective. Because the boundary between the suprahyoid and genioglossus muscles (the target muscles of the present study) is not easily distinguished on MRI images¹⁹, we defined the area encompassing the two muscles as the tongue area according to Stuck et al.¹⁹.

In general, MEP measured in the sitting position is used as a threshold to determine other loading parameters. However, because MRI is conducted in the supine position, we compared MEP in both positions and found that MEP was significantly lower in the supine position than in the sitting position in both sexes. This is in agreement with the findings of Badr et al.¹⁶, who found that body position influences MEP. We therefore determined the experimental loading pressure on the basis of supine MEP.

ANOVA and multiple comparison analysis of the tongue area revealed significant differences between different pressures, demonstrating that the higher the pressure load, the greater the influence on the tongue area. As MEP increased from resting to 10% and 50%, the area was reduced by 13.0% and 18.7% in males and 16.2% and 22.0% in females, respectively, with no significant differences between the sexes. This suggests that tongue area decreases more with increasing pressure. Wheeler et al.¹¹ reported that pressure loading stimulates suprahyoid muscle activity, and according to Fukuoka et al.¹³, such activity at 75% MEP was significantly higher than that at 25% MEP. Thus, it is likely that contraction of the suprahyoid muscles as well as of the genioglossus muscle leads to morphological changes in the tongue area.

Although a decline in swallowing function can be caused by various factors, a few cases have shown worsening of swallowing function as a result of muscle atrophy due to disuse. Therefore, repeated application of EMST may en-

sure adequate contraction of not only the respiratory muscles, but also the genioglossal and suprahyoid muscles, resulting in the prevention or improvement of dysphagia.

Lastly, because of the unclear boundary between the genioglossus muscle and suprahyoid muscles on MRI images, we could not determine the detailed morphological changes occurring in each muscle. In addition, only two-dimensional images taken in the sagittal plane were used in the present study. We therefore plan to investigate the effects of pressure loading on individual muscles and evaluate morphological changes using three-dimensional images in the future.

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