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Variations in tongue pressure in relation to age, gender, body mass index, and oral conditions

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치의과학과 치과보철학 전공

Aein Mon

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지도교수 권 호 범

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Aein Mon

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Abstract

Variations in tongue pressure in relation to age, gender, body mass index, and oral conditions

Aein Mon, BDS, MDSc

Department of Prosthodontics

The Graduate School

Seoul National University

(Directed by professor Ho-Beom Kwon, DDS, MS, PhD)

Purpose

The purpose of this study was to determine the influence of age, gender, and body mass index (BMI) on tongue pressure and to evaluate the correlation between tongue pressure and oral conditions such as tongue volume (TV), the cross-sectional area (CSA) of the masseter muscle, the maximum occlusal force (MOF), and the occlusal contact area (OCA) in healthy individuals. Additionally, the correlation between maximum tongue pressure (MTP) and swallowing tongue pressure (STP) was also analyzed.

Materials and methods

10 healthy young individuals (5 males and 5 females; ≤ 40 years) and 10 healthy elderly individuals (5 males and 5 females; ≥ 60 years) with normal oral structures and swallowing function were included in this study. TV (cm^3) and CSA of masseter muscle (cm^2) were evaluated after 3D reconstruction of the tongue and masseter muscle by importing the DICOM data of each participant's MRI into the 3D image analysis software (Mimics 19.0; Materialise NV, Leuven, Belgium). MOF (N) and OCA (mm^2) were calculated using an occlusal force analysis system (Dental Prescale II, GC Corporation, Tokyo, Japan). MTP and STP (kPa) were measured by using the JMS tongue pressure measurement device (TPM-02, JMS Co., Ltd., Hiroshima, Japan). The student's t-test was used to compare the variables between the groups: the young adult and the elderly, or the male and female, respectively. To determine the influence of age, gender, and BMI on tongue pressure, multiple linear regression analysis for MTP and STP was performed. The correlations between tongue pressure and TV, CSA, MOF, and OCA, as well as the correlation between MTP and STP, were assessed using Pearson's correlation analysis. All statistical analyses in this study were performed using SPSS version 25.0 software. A p value of < 0.05 was considered statistically significant.

Results

The results showed that age had a significant effect on MTP (p = 0.012), with a mean value of 40.33 (± 8.15) kPa for young adults and 29.59 (± 9.08) kPa for the elderly. In multiple regression

analysis, it was indicated that 0.325 kPa of MTP was reduced when a year of age was increased, and it was statistically significant (p = 0.005). However, there were no significant differences in MTP for gender (p = 0.320) and BMI (p = 0.764). Concerning STP, neither age, gender, nor BMI had a significant effect on STP.

In correlation analysis, there were significant positive correlations between MTP and oral conditions such as right CSA of the masseter muscle (r = 0.485, p = 0.030), left CSA of the masseter muscle (r = 0.531, p = 0.016), and MOF (r = 0.544, p = 0.013). Regarding STP, no variables were significantly correlated with STP. However, there was a positive correlation between MTP and STP with a correlation coefficient of 0.496 and a p value of 0.026.

Conclusion

It can be concluded that MTP is age-dependent and STP could be sustained at a certain level for a lifetime, and there was a significant positive correlation between MTP and STP. Moreover, it can also be concluded that oral conditions such as CSA of the masseter muscle, and MOF had a considerable effect on MTP.

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Keywords : Tongue pressure, Tongue volume, Masseter muscle, Maximum occlusal force, Occlusal contact area.

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I. Introduction

Swallowing is a complex process that involves the coordinated activity of the oral cavity, pharynx, larynx, and esophagus and consists of four different phases: the oral preparatory, oral propulsive, pharyngeal, and esophageal phases.[1] The tongue plays a critical role in swallowing in terms of forming a bolus in the oral cavity during the oral preparatory phase and generating pressure that facilitates the propelling of the bolus from the oral cavity into the pharynx during the oral propulsive phase.[2] Therefore, tongue pressure generated by contact between the tongue and anterior palate is vital to swallowing.[3,4] Moreover, the base of the tongue produces swallowing pressure within the pharynx.[5]

Dysphagia is the term used to describe dysfunction in swallowing.[6] According to the reports of many clinical studies, oral dysphagia is significantly correlated with reduced tongue pressure.[7,8] Aging and aging-related degenerative diseases, cerebrovascular diseases, head and neck cancers, surgical interventions, and radiation therapy in head and neck regions are frequently related to oral dysphagia, and there is also a decline in tongue pressure in these clinical conditions.[9-11] Dysphagia is frequently associated with several complications, such as choking, aspiration pneumonia, dehydration, and malnutrition, which then lead to impaired quality of life (QoL) in patients.[12] In addition, it was mentioned that maxillary defect patients have impaired swallowing function, where tongue function is crucial to their ability to swallow, and the use of an obturator prosthesis during rehabilitation can aid in enhancing tongue pressure and improving swallowing function.[13] Tsuji et al.[14] also identified tongue pressure as a significant explanatory factor for impaired masticatory performance in patients with maxillary defects. Hence, the evaluation of tongue function is of paramount importance in the prosthetic rehabilitation of maxillofacial defect patients. To evaluate tongue function, tongue pressure can be quantitatively assessed using various devices; these include the Iowa Oral Performance Instrument (IOPI) (IOPI Medical LLC, Washington, USA)[15] and the JMS tongue pressure measurement device (TPM-01, JMS Co., Ltd., Hiroshima, Japan).[16] Both devices can display tongue pressure values in kPa, and tongue pressure measurements using these two methods were known to be correlated with each other.[17] Maximum tongue pressure (MTP) is a parameter used to assess the detrimental effects of aging on the tongue musculature.[18] Swallowing tongue pressure (STP) is considered to be the pressure generated between the tongue and anterior palate during the process of swallowing.

Many studies have examined changes in tongue pressure in healthy individuals based on demographic factors such as age, gender, body mass index (BMI), and so on.[19-21] Regarding age-related changes in tongue pressure, numerous studies have reported that MTP declines with age.[22-24] However, the impact of diminished tongue strength on swallowing capacity in elderly individuals is still unclear. Some evidence implied that swallowing generates submaximal isometric tongue pressure and that STP could be sustained for a lifetime while MTP deteriorates with age.[25,26] According to a study conducted by Nicosia et al.,[25] it was reported that middle-aged and elderly men exhibited STP values that were less than 50% of the recorded MTPs. Youmans et al.[27] also stated that 49% of their MTPs were used by men and 63% by women while performing a swallowing function. With regard to gender differences, Crow and Ship[22] mentioned that tongue function is gender-dependent and that males had greater tongue strength compared to females. Youmans and Stierwalt[28] also observed that male individuals tend to have a higher MTP than females. However, in another study by the same authors, no significant gender differences in MTPs were found, and instead, women generated significantly higher STPs than men.[27] Similarly, Steele et al.[29] reported that women had higher midpalate pressures during a swallowing task. Concerning alterations in tongue pressure in relation to BMI, in a five-year longitudinal study, it was found that there was no association between MTP and either baseline BMI or changes in BMI over time.[30] On the other hand, Suzuki et al.[19] analyzed the relationship between MTP value and BMI in 205 community-dwelling elderly and observed that there was a correlation between MTP and BMI values. Similarly, Yu and Gao[21] also stated that tongue pressure was significantly related to BMI and weight.

The tongue is a muscular organ composed of intrinsic muscles such as the superior longitudinal, inferior longitudinal, transverse, and vertical muscles, as well as extrinsic muscles including the genioglossus, hyoglossus, styloglossus, and palatoglossus muscles.

Tongue volume (TV) can be changed with aging, loss of teeth, and dental arch pattern.[31,32] Although some studies have evaluated the relationship between tongue pressure and the volume, cross-sectional area (CSA), and thickness of the tongue, these studies are still limited in number.[31,33,34] According to the study by Nakao et al.,[33] the tongue pressure was not affected by TV; however, it was influenced by tongue lean muscle mass. On the other hand, it was implied that tongue pressure was significantly correlated with both the CSA and the thickness of the tongue.[31,34]

During mastication, the masticatory muscles and the tongue function together. It was reported that the hypoglossal motor neurons that supply the tongue muscles produce reflex discharges in response to mechanical stimulation of the teeth.[35] Moreover, the maxillary and mandibular teeth come into close contact during a swallowing task. The masseter muscle, one of the masticatory muscles that generate occlusal force during mastication, is a critical factor affecting the performance of the masticatory system.[36] One study noted a significant correlation between masticatory performance and both bite force and MTP.[37] Furthermore, Hara et al.[16] found a significant correlation between MTP and bite force, while Takahashi et al.[38] revealed a positive correlation between masseter muscle stiffness and maximum bite force. However, the relationship between tongue pressure and the CSA of the masseter muscle, a key determinant of masticatory system performance, remains unexplored.

Hence, the purpose of this study was to determine the influence of age, gender, and BMI on tongue pressure and to evaluate the correlation between tongue pressure and oral conditions such as TV, CSA of the masseter muscle, the maximum occlusal force (MOF), and the occlusal contact area (OCA) in healthy individuals. Additionally, the correlation between MTP and STP was also analyzed.

II. Materials and methods

Participants

This study was approved by the institutional review board of Seoul National University, School of Dentistry (IRB No. S-D20220001), and written informed consent was obtained from all participants. The study included 20 healthy individuals with normal oral structures and swallowing function. Individuals who have symptoms of dysphagia, neuromuscular and respiratory disorders, GI disturbances, and stroke, as well as individuals suffering from oral soft tissue diseases or who have a history of radiation therapy or surgical intervention in the head and neck region, were excluded from the study. The participants were divided into two groups: the young adult group (5 males and 5 females; ≤ 40 years of age) and the elderly group (5 males and 5 females; ≥ 60 years of age).[24]

Body mass index

BMI of each participant was calculated using the following formula.

Body mass index (BMI) = weight (kg)/ [height (m)]^2

MRI scans

An MRI scan was performed for all participants using an Ingenia 3.0T MRI system (Philips, Netherlands). The participants were instructed to keep their tongues in a relaxed position and not to move or swallow in order to avoid motion artifacts during the MRI scan. Both T1 weighted image (FOV – 300×300 or 225×225, TR –

8.3 ms, TE – 4.6 ms, FA – 8, matrix – 300×300, sagittal – 1.2 mm thickness, 0.6 gap, axial and coronal – 1mm reconstruction) and T2 weighted image (FOV – 300×300 or 225×225, TR – 2500 ms, TE – 195 ms, FA – 90, matrix – 300×300, sagittal – 1.2 mm thickness, 0.6 gap, axial and coronal – 1 mm reconstruction) were obtained.

Tongue volume measurement

For the measurement of TV (cm^3), the MRI DICOM data of each participant was imported into the 3D image analysis software (Mimics 19.0; Materialise NV, Leuven, Belgium). The MRI segmentations were performed by a single investigator who is well experienced in 3D reconstruction and based mainly on the sagittal and coronal views rather than the axial view, as the outline of the tongue is more obvious in these two orientations. TV was measured by using the volume measurement tool in the same software after the 3D reconstruction of the tongue (Figure 1).

Cross-sectional area of the masseter muscle determination

For the determination of the CSA of the masseter muscle (cm^2), right (Rt.) and left (Lt.) 3D masseter muscles were reconstructed after importing each MRI DICOM data into the 3D image analysis software (Mimics 19.0; Materialise NV, Leuven, Belgium) (Figure 2A). To determine the CSA of a muscle accurately, it is crucial to measure at an angle perpendicular to the actual long axis of the muscle.

Therefore, the angulation of the masseter muscle in the frontal plane was first determined using coronal scans across the hypophysis (Figure 2B).[39] The actual long axis of the masseter muscle was defined in the sagittal plane by drawing a line joining the uppermost and lowermost margins of the 3D reconstructed muscle with its position parallel to the frontal angle and perpendicular to the coronal plane (Figure 2C).[39] After that, the three cross-sections (1 mm intervals between them) perpendicular to this line were done by using the software (Meshmixer 3.5; Autodesk, San Rafael, CA, USA) (Figure 2D).The three CSAs of the masseter muscle were measured using the area measurement tool in the software (Visual-Mesh 18.0, ESI Group, Paris, France), and the average of these three CSAs was defined as the CSA of the masseter muscle.

Analysis of maximum occlusal force and occlusal contact area

MOF (N) and OCA (mm^2) were analyzed using an occlusal force analysis system (Dental Prescale II, GC Corporation, Tokyo, Japan). Each participant was asked to bite a pressure-sensitive sheet with a maximum force for 3 seconds. This sheet was scanned with a dedicated scanner (GT-X830, EPSON, Tokyo, Japan), and analysis of MOF and OCA was performed using the bite force analyzing software (Bite Force Analyzer, GC Corporation, Tokyo, Japan) (Figure 3).

Tongue pressure measurement

In tongue pressure measurement, MTP and STP (kPa) were measured using the JMS tongue pressure measurement device (TPM-02, JMS Co., Ltd., Hiroshima, Japan), consisting of a disposable probe, a connecting tube, and a digital meter (Figure 4).

The probe consists of a hard plastic ring and an air−filled balloon.

Before measuring tongue pressure, internal pressure was set at a value of 19.6 kPa by pushing the pressurization button in the digital meter. This pressure was regarded as the pre−set value, and the measurements were performed after zero calibration. The participants were seated in an upright position where the Frankfort horizontal (FH) plane is parallel to the floor. The air−filled balloon was inserted into the mouth with a position the participant biting the hard plastic ring between maxillary and mandibular incisors.

Regarding the measurement of MTP, the participants were instructed to push the probe of the JMS device with their tongue against the anterior palate at its maximum strength for 7 seconds. For the measurement of STP, the participants were instructed to hold 5 ml of water in their mouths and to perform normal swallowing function after placing the probe into their mouths in the position described previously.

A new probe was used for each participant for hygiene purposes and to minimize the measurement errors occurring from the repeated use of the probe. To ensure accurate measurement, each measurement was taken three times, and the mean value of these three trials was recorded as the MTP and STP of each participant, respectively. The participants were allowed to take a 30−second rest period between every two measurement trials.

Statistical analysis

The student's t−test was used to compare the variables between the groups: the young adult and the elderly, or male and female. To determine the influence of age, gender, and BMI on tongue pressure, multiple linear regression analysis for MTP and STP was performed. The correlations between tongue pressure and TV, CSA, MOF, and OCA, as well as the correlation between MTP and STP, were assessed using Pearson's correlation analysis. All statistical analyses in this study were performed using SPSS statistics software (SPSS version 25; IBM, USA). A p value of < 0.05 was considered statistically significant.

III. Results

The distribution of the demographic variables among the study population is shown in Table 1. In the comparison of variables between the age groups, the mean MTP value of the elderly was significantly lower than that of the young adults ($p = 0.012$), but no other variables showed a statistically significant difference (Table 2). In comparison between males and females, males had significantly higher TV ($p < 0.001$), Rt. CSA of the masseter muscle ($p = 0.007$), and Lt. CSA of the masseter muscle ($p = 0.020$) than females. However, there were no statistically significant differences for the other variables (Table 3).

In multiple linear regression analysis, the results showed that only the variable age had a significant impact on MTP. According to the data shown in Table 4, when a year of age was increased, 0.325 kPa of MTP was reduced, and it was statistically significant with a p value of 0.005. In the gender difference, the MTP of a female was 5.093 kPa less than that of a male, but it was not statistically significant ($p = 0.320$). Moreover, when BMI was increased by 1 kg/m^2, MTP was increased by 0.313 kPa. However, it was also not statistically significant ($p = 0.764$). Concerning STP, neither age, gender, nor BMI had a significant effect on STP (Table 5).

In the correlation analysis, Rt. CSA of the masseter muscle ($r = 0.485$, $p = 0.030$), Lt. CSA of the masseter muscle ($r = 0.531$, $p = 0.016$), and MOF ($r = 0.544$, $p = 0.013$) were significantly correlated with MTP (Table 6), (Figure 5). Regarding STP, no variables were significantly correlated with STP (Table 6), (Figure 6). However, there was a positive correlation between MTP and STP with a correlation coefficient of 0.496 and a p value of 0.026 (Figure 7).

IV. Discussion

Impaired tongue function is a common issue in patients with maxillofacial defects, and it can have a considerable impact on their QoL, causing difficulty in speaking, mastication, and swallowing. Investigating how demographic factors and oral conditions of the patients affect their tongue pressure could be advantageous in the prosthetic rehabilitation of maxillofacial defect patients. The study analyzed the impact of age, gender, and BMI on tongue pressure (MTP and STP), as well as the correlation between tongue pressure (MTP and STP) and oral conditions such as TV, CSA of the masseter muscle, MOF, and OCA. Moreover, the correlation between MTP and STP was also analyzed.

The results of the study indicated that MTP is age-dependent, with a significant decline in the elderly, and it drops by almost 0.33 kPa when age goes up a year. This finding is consistent with that of many studies.[22-24] However, concerning the influence of gender on MTP, the results showed that gender had no significant effect on MTP, despite the fact that the MTP of a female was about 5.1 kPa lower than that of a male. Unlike this study, Crow and Ship[22] reported that there was an alteration in MTP with regard to gender and that males could produce significantly higher MTP in comparison with females. Moreover, Stierwalt and Youmans[40] also noted that males generally exhibit a greater MTP compared to females.

Regarding STP, the findings of the study showed that the age and gender of the individuals had no significant impact on STP.

Moreover, in our study, males used 37% of their MTPs during swallowing and females used 58%, which is consistent with the study conducted by Nicosia et al.[25] These findings indicate that swallowing is a submaximal task in tongue pressure production and that STP is independent of age and gender while MTP diminishes with age. However, in the correlation analysis of our study, there was a significant positive correlation between MTP and STP. It means that the STP of individuals increased along with the incline in MTP; however, it does not decline with age. In other words, it can be concluded that it is possible to reserve STP to the point of being able to perform a normal swallowing function throughout life.

Concerning the effect of BMI on tongue pressure, it had no significant impact on both MTP and STP in this study. Likewise, Higa et al.[30] reported that there was no correlation between MTP and baseline BMI or change in BMI in their five-year longitudinal study. However, on the other hand, some studies stated that tongue pressure was related to BMI and weight.[19,21]

With regards to TV, in our study, MRI DICOM data were used to reconstruct the 3D tongue in order to determine TV. During the 3D reconstruction of the tongue, the entire volume of the tongue, which includes its intrinsic muscles as well as extrinsic muscles such as the genioglossus and hyoglossus, was calculated from the MRI segmentation. The mean TV values for males and females were 116.63 (±11.24) cm^3 and 95.72 (±10.99) cm^3, respectively, and a significant difference was observed between them. Similar to our study, there are some previous studies using MRI data for the assessment of TV.[33,41] In a study done by Nakao et al.,[33] the mean tongue volumes were 20.1±2.3 cm^3 for males and 18.4±2.4 cm^3 for females in young individuals, and 22.0±2.8 cm^3 for males and 19.0±3.8 cm^3 for females in elderly individuals. These values of this study were much different from our study, as the authors divided the tongue volume by the hard palate length in order to normalize the tongue volume after the 3D reconstruction. In another study, mean TV values were 138±16.92 cm^3 for normal adults and 131.26±20.0 cm^3 for patients with obstructive sleep apnea syndrome, and the values were larger than those of our study as they included pharyngeal muscle during tongue segmentation.[41]

In this study, the correlation between tongue pressure and TV was examined. The findings of the study revealed that TV was not significantly correlated with MTP. Likewise, the study of Nakao et al.[33] reported that TV was not significantly associated with tongue pressure, and they highlighted the impact of tongue lean muscle mass rather than TV on tongue pressure. However, one study found that there was a positive correlation between tongue pressure and CSA.[31] Moreover, another study stated that tongue pressure was significantly correlated with tongue thickness.[34]

Additionally, the tongue and the masticatory muscles perform the masticatory function together. During mastication, the tongue plays a crucial role in maneuvering the bolus for adequate chewing. Maruyama et al.[37] stated that masticatory ability was significantly related to bite force and MTP. The masseter muscle is the most important muscle for masticatory performance. Therefore, this study also evaluated the correlation between the tongue pressure and CSA of masseter muscle. To our best knowledge, this study is the first study validating the association between tongue pressure and CSA of the masseter muscle. The results of the present study indicated that MTP was significantly correlated with both Rt. and Lt. CSA of the masseter muscles. According to one study, the position of the tongue affected the masseter muscle activity, which varied depending on whether the tongue was in the resting or anterior position.[42] Moreover, another study also stated that a higher muscle activity was observed at the masseter while the tongue produces pressure against the palate rather than it positioning at the floor of the mouth.[43] This could explain the current finding of a relationship between the MTP and CSA of the masseter muscles. Additionally, the present study found that there was a positive association between MTP and MOF, which is consistent with the previous study done by Hara et al.[16] Many previous studies reported about the association between the masseter muscle stiffness and MOF.[36,38] Therefore, the respective findings of our current study about the relations between MTP and CSA of the masseter muscles and between MTP and MOF were consistent with each other.

During the act of swallowing, the maxillary and mandibular teeth come into direct contact. A previous study showed that dentulous individuals had three times higher tongue pressure than edentulous individuals.[44] Moreover, it has been reported that swallowing function deteriorates due to the loss of tongue–palate contact when complete dentures are removed in edentulous older adults.[45] These studies indicate the important of tooth contact during swallowing. In this study, the influence of OCA on tongue pressure was also analyzed. However, it was not found that OCA had an impact on MTP. The reason could be that in this study, almost all participants had a normal occlusal status with no missing teeth, which consequently gave rise to no significant change in OCA. Hence, further studies with participants who have a significant loss of teeth should be conducted.

Furthermore, in this study, the correlation between STP and oral conditions such as TV, CSA of the masseter muscle, MOF, and OCA was evaluated. The results showed that neither of these was significantly correlated with STP. This finding indicates that STP did not vary depending on the oral conditions in a healthy individual, while MTP underwent changes in relation to oral conditions. However, on the other hand, STP was significantly correlated with MTP, which had a positive correlation with oral conditions. Therefore, it can be concluded that oral conditions might affect STP indirectly.

There are some limitations to this study. First, regarding the distribution of the variables BMI, the majority of the participants had a normal BMI. In addition, in this study, STP was only measured, which was defined as the pressure between the tongue and the anterior palate during a swallowing task. During swallowing, the tongue also moves posteriorly to contact the pharyngeal wall, which produces pressure at the base of the tongue. With the limitations of the JMS tongue pressure measurement device, it was not possible to measure the pressure at the base of the tongue. Therefore, the STP value of our study might not fully represent the entire swallowing function.

V. Conclusion

Within the limitations of the study, it can be concluded that MTP is age-dependent and STP could be sustained at a certain level for a lifetime, and there was a significant positive correlation between MTP and STP. Moreover, it can also be concluded that oral conditions such as CSA of the masseter muscle and MOF had a considerable effect on MTP.

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Tables

Table 1. Distribution of the demographic variables among the study population (n=20)

Variables	Frequency (%)	Mean (SD)
Age (years)		
Young adults (22−36)	10 (50)	28.3 (5.0)
Elderly (60−67)	10 (50)	64.1 (2.3)
Gender		
Male	10 (50)	
Female	10 (50)	
Body mass index (BMI)		
Normal (18.5−24)	18 (90)	
Overweight (≥25)	2 (10)	
Number of teeth		
No missing tooth (≥28)	16 (80)	
At least one missing tooth (< 28)	4 (20)	

Table 2. Comparison of variables between young adults and elderly

Variables	Young adults (n=10) Mean (SD)	Elderly (n=10) Mean (SD)	*p* value
TV (cm^3)	104.74 (19.65)	104.61 (13.36)	0.986
Rt. CSA (cm^2)	5.01 (1.03)	4.47 (0.98)	0.245
Lt. CSA (cm^2)	5.64 (1.18)	4.58 (1.11)	0.053
MTP (kPa)	40.33 (8.15)	29.59 (9.08)	0.012*
STP (kPa)	17.71 (7.68)	14.5 (12.84)	0.506
MOF (N)	851.4 (266.2)	725.2 (307.4)	0.340
OCA (mm^2)	22.43 (6.63)	19.99 (10.11)	0.531

TV: tongue volume; Rt. CSA: right cross-sectional area of masseter muscle; Lt. CSA: left cross-sectional area of masseter muscle; MTP: maximum tongue pressure; STP: swallowing tongue pressure; MOF: maximum occlusal force; OCA: occlusal contact area.

Table 3. Comparison of variables between male and female

Variables	Male (n=10) Mean (SD)	Female (n=10) Mean (SD)	*p* value
TV (cm^3)	116.63 (11.24)	92.72 (10.99)	< 0.001*
Rt. CSA (cm^2)	5.32 (0.94)	4.16 (0.74)	0.007*
Lt. CSA (cm^2)	5.73 (1.10)	4.49 (1.08)	0.020*
MTP (kPa)	38.19 (11.97)	31.73 (6.82)	0.155
STP (kPa)	14.08 (7.63)	18.13 (12.74)	0.400
MOF (N)	873.2 (256.4)	703.4 (304.1)	0.194
OCA (mm^2)	22.75 (6.71)	19.67 (9.96)	0.428

TV: tongue volume; Rt. CSA: right cross-sectional area of masseter muscle; Lt. CSA: left cross-sectional area of masseter muscle; MTP: maximum tongue pressure; STP: swallowing tongue pressure; MOF: maximum occlusal force; OCA: occlusal contact area.

Table 4. Multiple linear regression analysis for maximum tongue pressure (MTP)

Model	B	Std. Error	β	p value
(Constant)	50.766	27.443		0.083
Age	−0.325	0.101	−0.608	0.005*
Gender	−5.093	4.959	−0.260	0.320
BMI	0.313	1.022	0.078	0.764

Dependent Variable: MTP.

Table 5. Multiple linear regression analysis for swallowing tongue pressure (STP)

Model	B	Std. Error	β	*p* value
(Constant)	−46.652	34.245		0.192
Age	−0.142	0.126	−0.255	0.276
Gender	11.977	6.188	0.589	0.071
BMI	2.338	1.276	0.564	0.086

Dependent Variable: STP.

Table 6. Correlation between tongue pressure and TV, CSA of the masseter muscle, MOF, OCA

Tongue pressure	Variables	Correlation coefficient (*r*)	*p* value
MTP	TV	0.202	0.392
	Rt. CSA	0.485	0.030*
	Lt. CSA	0.531	0.016*
	MOF	0.544	0.013*
	OCA	0.437	0.054
STP	TV	−0.033	0.889
	Rt. CSA	0.047	0.843
	Lt. CSA	0.118	0.620
	MOF	0.263	0.263
	OCA	0.299	0.200

TV: tongue volume; Rt. CSA: right cross−sectional area of masseter muscle; Lt. CSA: left cross−sectional area of masseter muscle; MTP: maximum tongue pressure; STP: swallowing tongue pressure; MOF: maximum occlusal force; OCA: occlusal contact area.

Figures

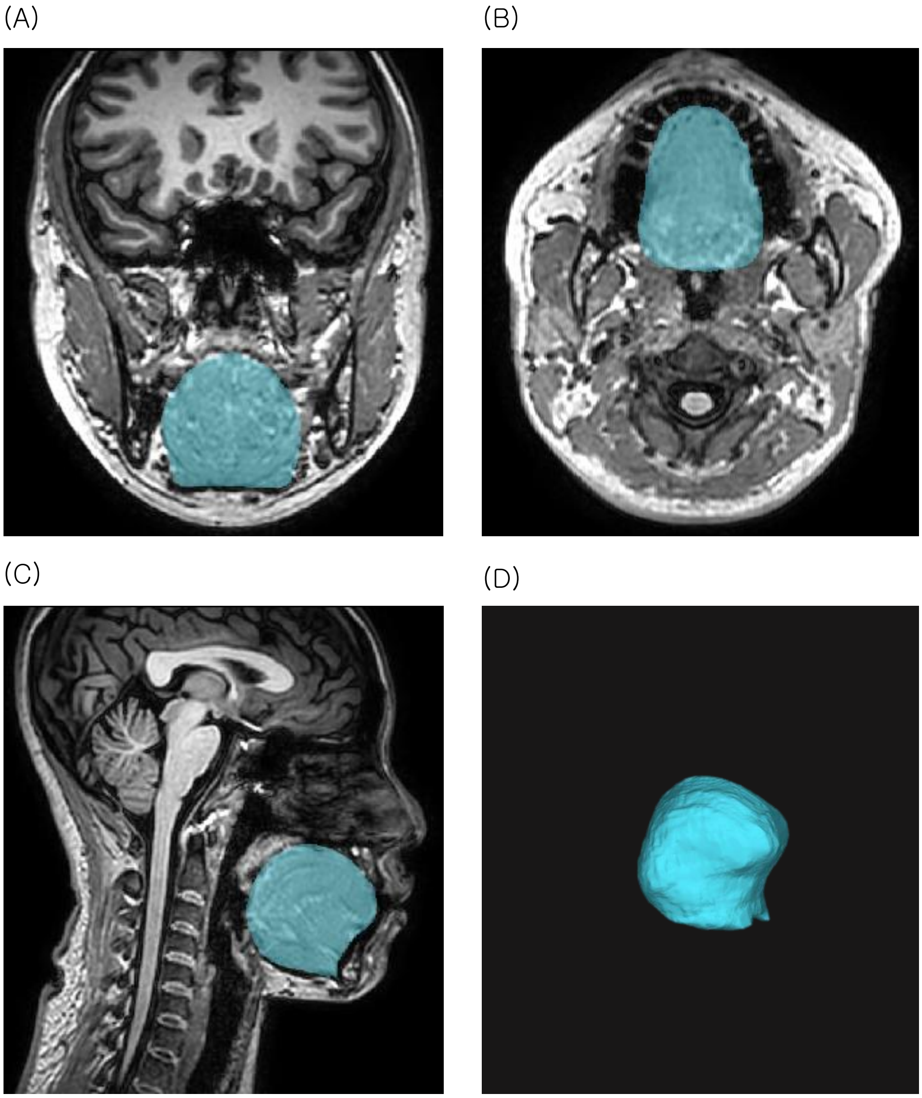

Figure 1. Tongue volume (TV) measurement after segmentation and 3D reconstruction of the tongue using MRI data: (A) coronal view, (B) axial view, (C) sagittal view, (D) 3D image of the tongue.

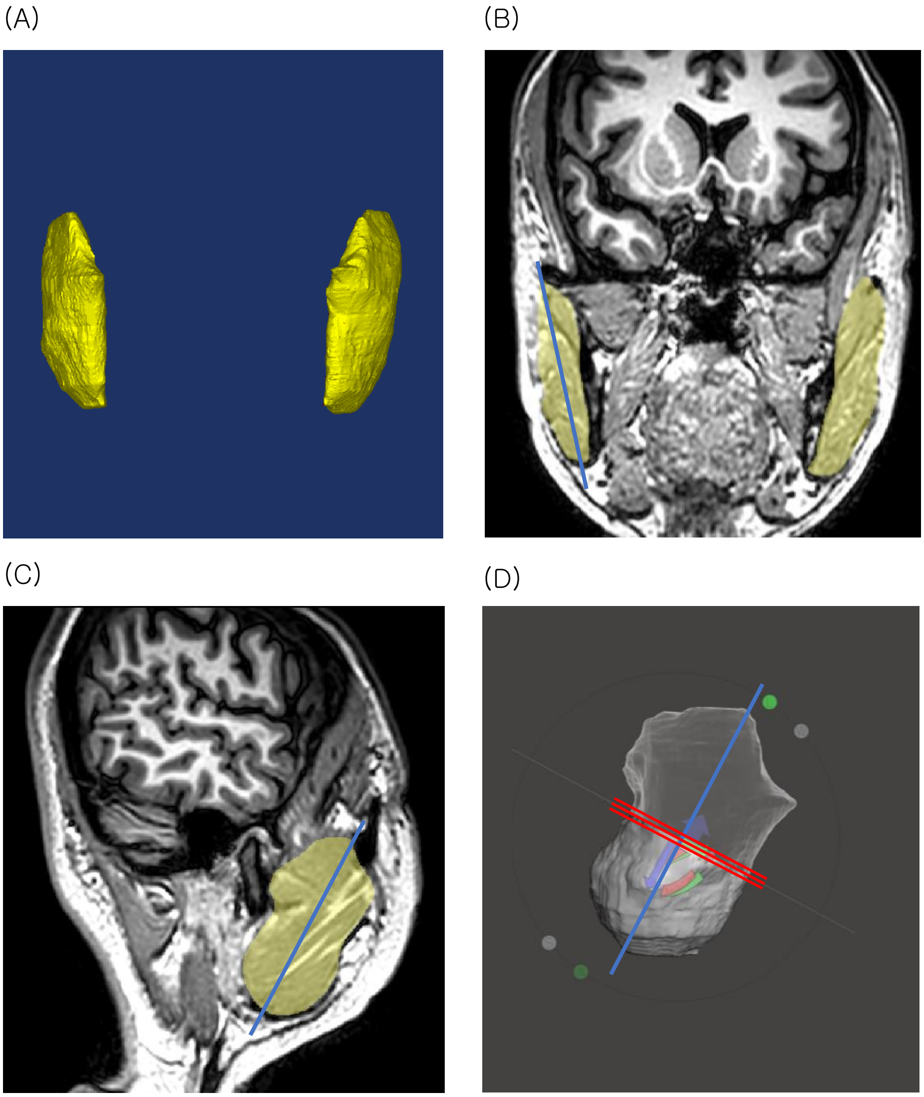

Figure 2. Determination of cross-sectional area (CSA) of the masseter muscle following 3D reconstruction using MRI data: (A) 3D image of the Rt. and Lt. masseter muscles; (B, C) defining muscle angulation in the coronal and sagittal plane; (D) cutting three cross sections perpendicular to the muscle's long axis in the sagittal plane at 1 mm intervals.

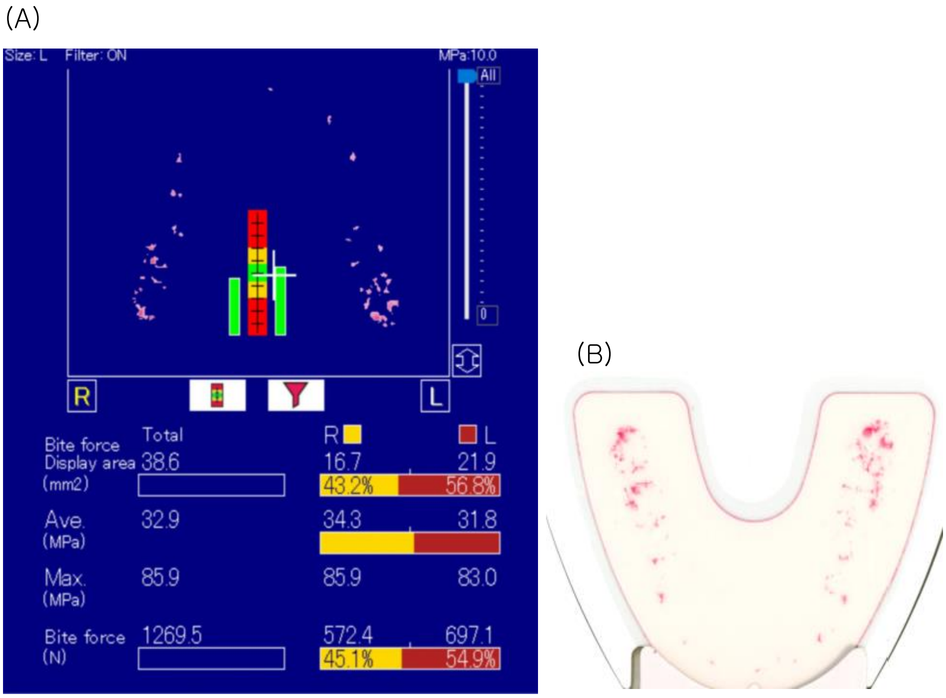

Figure 3. Analysis of maximum occlusal force (MOF) and occlusal contact area (OCA): (A) an image of analyzing bite force; (B) a pressure sensitive sheet with bite marks.

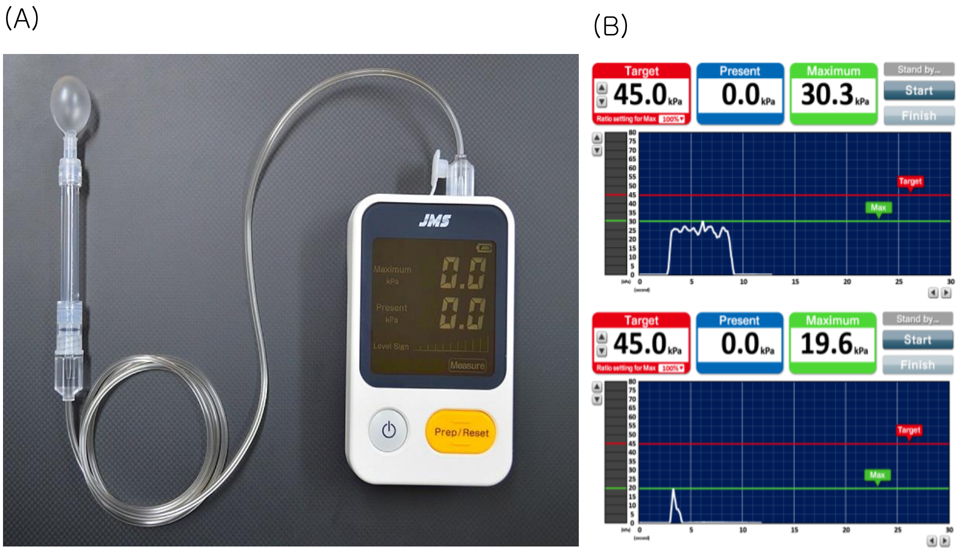

Figure 4. Measurement of tongue pressure: (A) JMS tongue pressure measurement device; (B) an image showing maximum tongue pressure (MTP) (above) and swallowing tongue pressure (STP) (below) of a participant.

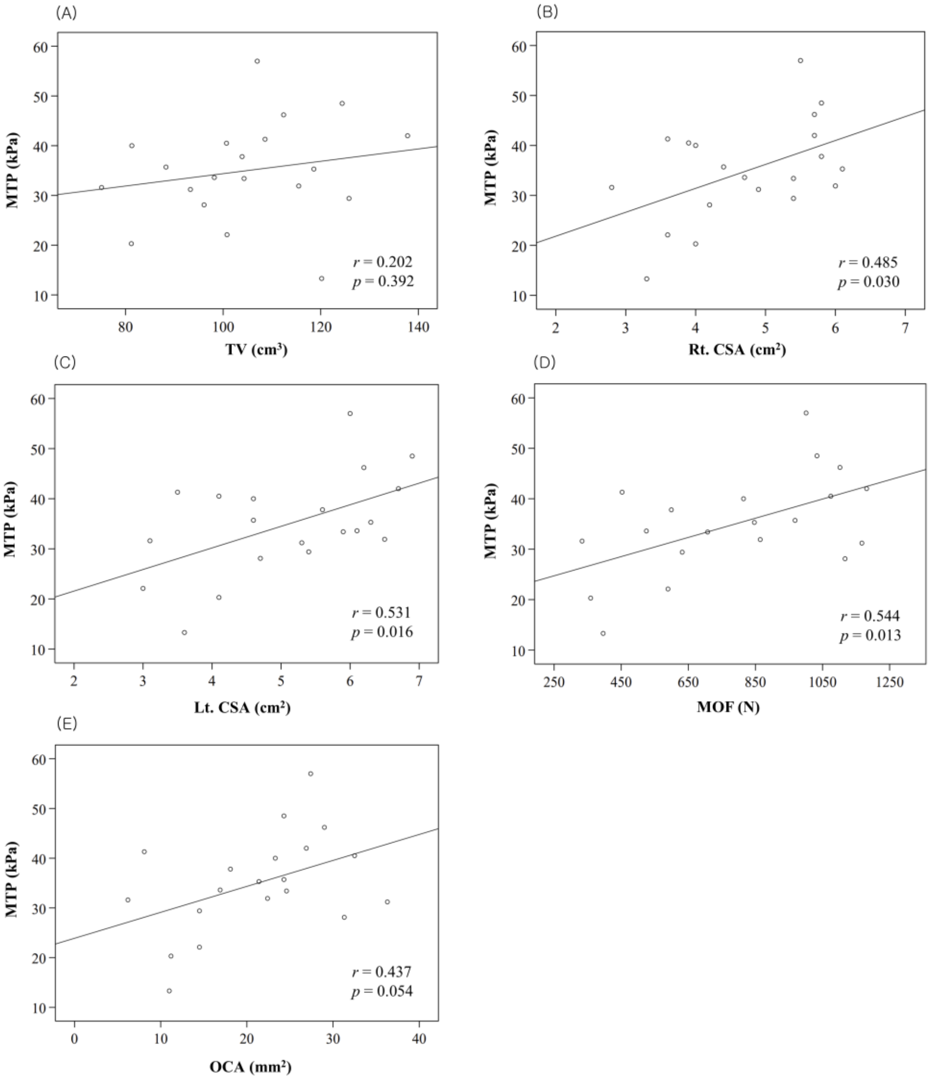

Figure 5. Correlation between maximum tongue pressure (MTP) and oral conditions: (A) tongue volume (TV); (B) Rt. cross-sectional area (CSA) of the masseter muscle; (C) Lt. cross-sectional area (CSA) of the masseter muscle; (D) maximum occlusal force (MOF), (E) occlusal contact area (OCA).

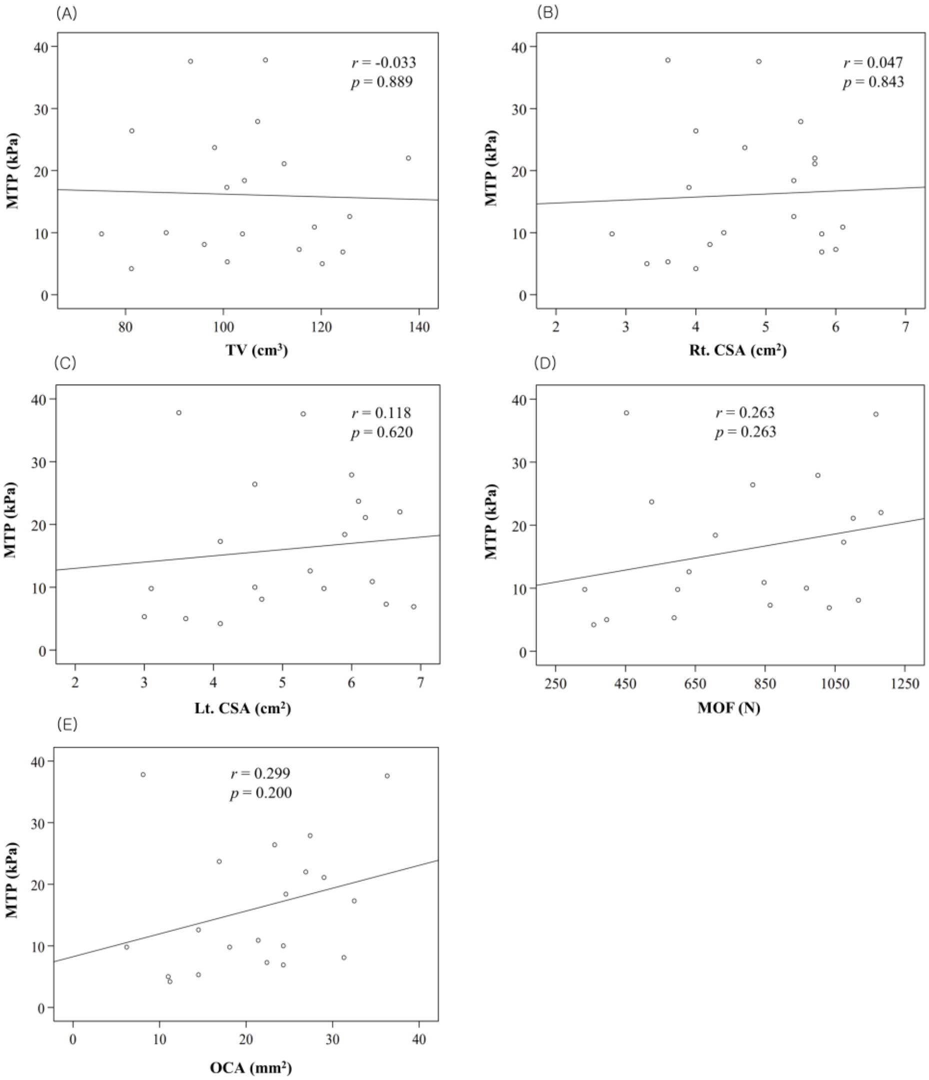

Figure 6. Correlation between swallowing tongue pressure (STP) and oral conditions: (A) tongue volume (TV); (B) Rt. cross-sectional area (CSA) of the masseter muscle; (C) Lt. cross-sectional area (CSA) of the masseter muscle; (D) maximum occlusal force (MOF), (E) occlusal contact area (OCA).

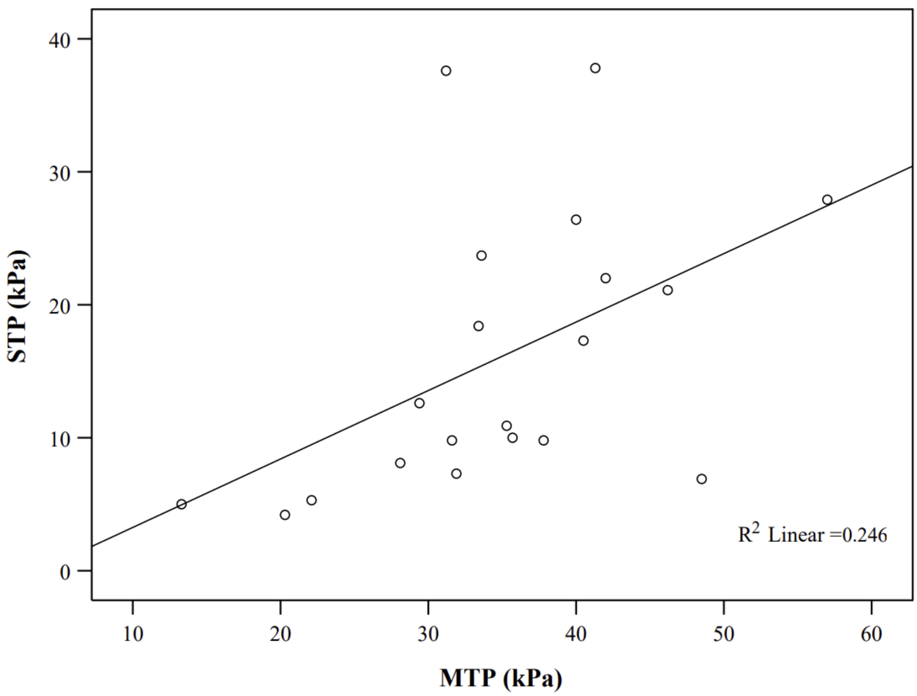

Figure 7. Correlation between maximum tongue pressure (MTP) and swallowing tongue pressure (STP) (r = 0.496, p = 0.026).

국문 초록

연령, 성별, 체질량 지수, 구강상태에 따른 성인의 혀 압력 변화

서울대학교 대학원 치의과학과 치과보철학전공

(지도교수 권 호 범)

Aein Mon

1. 목 적

본 연구의 목적은 연령, 성별, 체질량 지수, 그리고 혀 부피, 교근의 단면적, 최대 교합력 및 교합 접촉 면적과 같은 구강상태를 측정하여 혀 압력에 영향을 주는 요인을 찾아내는 것이었다. 또한, 최대 혀 압력(Maximum Tongue Pressure; MTP)과 연하 시 혀 압력(Swallowing Tongue Pressure; STP)을 각각 측정하여, 이 둘의 상관관계가 있는지 분석하였다.

2. 방법

정상적인 구강 조직과 연하 기능을 가진 건강한 성인 청년층 10명(만 40세 이하의 남자 5명, 여자 5명)과 고령층 10명(만 60세 이상의 남자 5명, 여자 5명)을 연구대상자로 선정하였다. 연구참여자들의 자기공명영상 다이콤파일 자료를 3D 이미지 분석 소프트웨어(Mimics 19.0;

Materialise NV, Leuven, Belgium)로 불러온 후 혀와 교근의 3D 모형을 제작하였고, 혀의 전체 부피(cm^3)와 교근의 단면적(cm^2)을 측정하였다. 최대 교합력(N)과 교합 접촉 면적(mm^2)은 교합력 분석 장비(GT-X830, EPSON, Tokyo, Japan)및 소프트웨어(Bite Force Analyzer, GC corporation, Tokyo, Japan)를 사용하여 값을 산출하였다. 최대 혀 압력(MTP)및 연하 시 혀 압력(STP)은 JMS 혀 압력 측정기(TPM-02, JMS Co. Ltd., Hiroshima, Japan)를 이용하여 측정하였다. 청년층과 고령층, 남성과 여성에 해당하는 변수들은 각 그룹 간 변수를 비교하기 위해 Student's t-test 를 활용하여 통계적 유의성 검정을 진행하였다. 연령, 성별, 체질량 지수에 해당하는 변수들의 경우, 혀 압력에 미치는 영향을 알아보기 위해 최대 혀 압력(MTP)및 연하 시 혀 압력(STP)에 대한 다중 선형 회귀분석(Multiple linear regression)을 사용하여 분석하였다. 혀 압력과 혀 부피, 교근의 단면적, 최대 교합력, 교합 접촉 면적이 상관성이 있는지 살펴보고, 최대 혀 압력(MTP)과 연하 시 혀 압력(STP)에 대해서 서로 유의미한 상관성을 가지는지 검정을 위해 피어슨의 상관관계분석(Pearson's correlation analysis)을 시행하였다. 통계분석은 SPSS(SPSS version 25; IBM, USA)을 사용하여 진행하였고, $p < 0.05$에서 유의성을 검정하였다.

3. 결과

연령은 최대 혀 압력(MTP)에 유의한 영향을 미치는 것으로 나타났으며($p = 0.012$), 청년층과 고령층의 평균값은 각각 40.33(±8.15) kPa와 29.59(±9.08) kPa이었다. 다중 선형 회귀분석에서는 연령이 증가할수록

최대 혀 압력(MTP)이 0.325 kPa 감소하였으며, 이는 통계적으로 유의하였다(p = 0.005). 그러나 성별과 체질량 지수에 대한 최대 혀 압력(MTP)은 유의한 차이가 없었다. 연하 시 혀 압력(STP)에 관련하여 연령, 성별, 체질량 지수 모두 연하 시 혀 압력(STP)에 유의미한 영향을 미치지 않았다. 상관관계 분석에서는 최대 혀 압력(MTP)과 좌측 교근의 단면적(r = 0.458, p = 0.030), 우측 교근의 단면적(r = 0.531, p = 0.016) 및 최대 교합력(r = 0.544, p = 0.013)과 같은 구강상태 간에 유의한 양의 상관관계를 보였다. 연하 시 혀 압력(STP)과 유의한 상관관계가 있는 변수는 없었다. 그러나 최대 혀 압력(MTP)과 연하 시 혀 압력(STP) 사이에는 상관계수가 0.496, p 값이 0.026로 양의 상관관계를 나타내며 유의미한 관련성을 나타냈다.

4. 결론

최대 혀 압력(MTP)은 연령과 관계 있으며, 연하 시 혀 압력(STP)은 평생동안 일정 수준으로 유지될 수 있는 것으로 보인다. 최대 혀 압력(MTP)과 연하 시 혀 압력(STP) 사이에는 유의한 양의 상관관계를 보였으며, 교근의 단면적, 최대 교합력과 같은 구강상태는 최대 혀 압력(MTP)에 유의미한 영향을 미치는 것으로 결과를 도출할 수 있었다.

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주요어 : 혀 압력, 혀 부피, 교근, 최대 교합력, 교합 접촉 면적
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