Abstract

Purpose: The purpose of this study was to investigate the relationship between the echo intensity (EI) on ultrasound images of the tongue, tongue thickness, and tongue pressure to examine the effectiveness of EI measurement for assessing the tongue function.

Methods: A total of 100 elderly outpatients were enrolled. Tongue thickness and EI were measured using ultrasonography. The distance from mylohyoid muscle surface to dorsal surface of the tongue was measured for tongue thickness. Subsequently, this area was vertically divided into four areas: top of tongue dorsal side (DT), bottom of tongue dorsal side (DB), top of basal tongue side (BT), and bottom of basal tongue side (BB), and the EI was measured in each area.

Results: The mean EIs of DT and DB were lower than those of BT and BB. In the three areas apart from BB, the EI decreased with an increase in tongue thickness. In particular, a significant correlation between the EI in DB and tongue thickness was found. In all areas, the EI decreased with an increase in tongue pressure.

Conclusion: The results of this study suggested that the measurement of EI could be an important indicator for assessing the tongue function in the elderly.

Keywords: echo intensity, elderly, tongue pressure, tongue thickness, ultrasonography

Introduction

With an increase in the elderly population worldwide, increasing medical and nursing care costs have become a major social problem [1,2]. Concomitantly, the concepts of “sarcopenia,” a decline in the muscle mass of the skeletal muscles of the limbs with aging and the associated loss of muscle strength and function; and “frailty,” which is classified into physical, mental, and social frailty, have also attracted considerable attention [3,4]. Regarding oral function, the relationship between the decline in oral function and systemic function has been examined [5-7], and the concept of oral hypofunction in elderly people has also been proposed [8]. In addition, Watanabe et al. investigated the relationship between the EI of the anterior compartment of the right thigh and muscle strength; which is the maximum isometric torque of knee extension in elderly men and found a negative correlation between the EI and the muscle strength [15]. The EI of the tongue has also been investigated in several previous studies. Ogawa et al. examined the relationship between the prevalence of dysphagia due to sarcopenia as classified by the food intake level scale and the mean EI of the whole tongue and proposed that the EI of the tongue was a significant independent variable predicting dysphagia [16]. Chantaramannee et al. demonstrated that there was a significant correlation between the mean EI of the whole tongue and tongue thickness, and that the EI of the tongue was a significant independent variable predicting the rate of oral diadochokinesis [17]. Although it is expected that EI assessment of ultrasonography is effective for the assessment of tongue function, and previous studies have suggested that the EIs of the ultrasound images are related to muscle mass and function, little information exists about the detailed relationship of the EI with tongue morphology and tongue pressure. Consequently, a more detailed analysis is needed.

In this study, the EI on ultrasound images of the tongue was focused on, and the relationship between the EI, tongue thickness, and tongue pressure was investigated to examine the effectiveness of EI measurement for assessing the tongue function in elderly people.

Materials and Methods

Subjects

The study participants were 100 elderly individuals aged 65 years and over (52 men and 48 women, mean age = 75.4 ± 6.5 years), who visited the dental division of Tokushima University Hospital between January 2017 and April 2017 and who were able to participate in this study. Inclusion criteria included participants who were able to walk independently and follow the instructions of the examiner. Individuals with a serious systemic disease or a maxillofacial defect were excluded. This study was approved by the clinical research institutional review board of the Ethics Committee of Tokushima University Hospital (Approval No. 2225) and was carried out in compliance with the Declaration of Helsinki. Measurements were taken after providing sufficient explanation about the study to all participants and obtaining consent. In addition, age, sex, and body mass index (BMI) were recorded as baseline characteristics. The individuals in this manuscript gave written informed consent to the publication of these case details.

Although historical data from the previous study [18] were used for the analysis of this study, the mean EIs of the images were uniquely analyzed. A power analysis was performed to determine the number of subjects needed in this study using a statistical power analysis software (G* power 3.1.9.7, Heinrich-Heine-Universität, Düsseldorf, Germany, free software). The significance level (α), power (β), and moderate effect size were set to

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Original article

Measurement of ultrasonic echo intensity predicts the mass and strength of the tongue muscles in the elderly

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0.05, 0.80, and 0.3, respectively. A total of 84 subjects were found to be required, and the number of subjects in this study was confirmed to exceed this standard.

Measurements of tongue thickness and echo intensity
Tongue thickness and EI were measured to a depth of 80 mm under like conditions using ultrasonography (Vscan with Dual Probe, GE Healthcare Japan, Tokyo, Japan) by a single examiner. During the measurements, the participants were seated in a dental chair with the headrest adjusted so that the Frankfurt plane was horizontal with the floor, and the head and back were secured to the backrest to prevent body movement. The ultrasound probe (frequency, 4.0-8.0 MHz; contact face size, 9 × 25 mm; mechanical index, 0.4; thermal index, 0.1) was positioned perpendicular to the Frankfurt plane and in the middle of the bilateral second premolars (Fig. 1a). After the patient had swallowed the saliva and taken the mandibular rest position, three still images were recorded once the tongue was in a stable position.

The distance from the mylohyoid muscle surface to the dorsal surface of the tongue was measured in still images and was defined as the tongue thickness (Fig. 1b). The 40 pixels (11.1 mm) wide area across the axis of distance measurement was vertically divided into four areas: top of the tongue dorsal side (DT), bottom of the tongue dorsal side (DB), top of the basal tongue side (BT), and bottom of the basal tongue side (BB). The mean EI was measured in each area (Fig. 1c). Image analysis software (ImageJ, NIH, Bethesda, MD, USA) was used to analyze the tongue thickness and EI in the ultrasound images. The thickness was measured after calibration with a known distance in the image and setting the units to mm.

Each measurement was performed in three still images for each participant, and the mean value of the three measurements was used as the representative value. The intraclass correlation coefficients (ICCs) of EI measurements in three images were calculated in four areas to evaluate the reliability of repeated measurements.

Measurement of tongue pressure
Tongue pressure was measured using a JMS tongue pressure measurement device (JMS, Hiroshima, Japan), as shown in Fig. 2. The measurement was performed after calibration outside the oral cavity, and by placing the tongue pressure probe between the tongue and palate. The rigid ring of the tongue pressure probe was lightly held with the incisors, and the participants were instructed to raise the tongue with maximum force against the palate for 7 s. The value displayed as the maximum pressure by the digital tongue pressure measurement device was recorded as the maximum tongue pressure.

Each measurement was performed three times and the mean value was used as the representative value.
Results

The Mann-Whitney U test was used to analyze the differences in age, BMI, tongue thickness, tongue pressure, and mean EI between men and women. Spearman’s correlation analysis was used to analyze the relationship between tongue thickness, tongue pressure, and mean EI. The participants were divided into two groups: with tongue pressure of 30 kPa and over, and with that of less than 30 kPa according to the criteria of oral hypofunction by the Japanese Society of Gerodontology [8], and the EIs in four areas were compared in the two groups. SPSS version 25.0 (IBM, Chicago, IL, USA) was used for all statistical analyses, and the risk rate was set to a significance level of less than 5%.

Discussion

In this study, the EI on ultrasound images of the tongue was focused on. Previous studies have reported that a higher EI is associated with lower muscle strength and lower muscle mass. Yamaguchi et al. have reported the tendency to show a negative correlation between the EI of the tongue and tongue thickness in healthy young subjects [21]. The similar preliminary results were found in this study: a negative correlation (correlation coefficient: −0.149) between the EI of whole tongue and tongue thickness, and a significant negative correlation (correlation coefficient: −0.217) between the EI and tongue pressure. In this study, the region from the mylohyoid muscle surface to the tongue dorsal surface was vertically divided into four areas and the EIs in the four areas were measured in more detail.

Overall, the lower the EI, the greater the tongue thickness and tongue pressure. These results agreed with those reported by Chantaramee et al. [17]. In particular, the EI of DB showed a higher and significant correlation with the tongue thickness and tongue pressure. Considering the anatomical structures in the four areas in this study, the DT is just below the tongue dorsal surface and is mainly composed of the intrinsic muscles of the tongue such as the superior and inferior longitudinal muscles of the tongue, as well as the vertical and transverse tongue muscles. The DB is the deep layer under the DT and refers to the styloglossus muscle, which is an extrinsic muscle of the tongue. The BT predominantly includes the genioglossus muscle, the BB mainly refers to the geniohyoid muscle. Tongue pressure can be exerted by both the intrinsic and extrinsic muscles of the tongue. The function of the intrinsic muscles of the tongue is to change the shape of the tongue itself, while the extrinsic muscles can pull the tongue backwards and raise the dorsum of the tongue, and the genioglossus muscle can push the tongue forward [Brand RW et al., Anatomy of orofacial structures. 4th ed. C. V. Mosby Co., Maryland Heights, MO, USA, 1990]. The anatomical structure as well as results in this study suggest that the tongue pressure is affected by the intrinsic muscles of the tongue, as shown by the EI of DT and extrinsic muscles of the tongue, as shown by the EIs of DB and BT. The results of this study were also consistent with the findings of Chantaramee et al.; the EI of the middle of the tongue obtained by placing an ultrasound probe perpendicular to the Frankfurt plane, as in this study, was significantly related to the number of oral diadochokinetic /ka/ [17]. This suggests that only the mean EI of the whole tongue derived by placing the ultrasound probe in each direction was related to the function of the muscle in each direction. Therefore, the results of the present study verified that the measurement of EI following area segmentation of the tongue can provide an

Table 1 Characteristics of the subjects (mean ± standard deviation)

| Variable               | Men (n = 52) | Women (n = 48) | Average | P-value |
|------------------------|-------------|---------------|---------|---------|
| Age (years)            | 76.5 ± 6.3  | 74.2 ± 6.3    | 75.4 ± 6.5 | 0.085   |
| BMI                    | 23.0 ± 3.2  | 22.2 ± 3.4    | 22.6 ± 3.3 | 0.094   |
| Tongue thickness (mm)  | 50.8 ± 6.4  | 49.8 ± 6.1    | 50.3 ± 6.2 | 0.521   |
| Tongue pressure (kPa)  | 29.0 ± 7.5  | 27.2 ± 7.9    | 28.1 ± 7.7 | 0.262   |
| DT                     | 24.2 ± 9.6  | 28.7 ± 9.4    | 26.3 ± 9.7 | 0.001*  |
| DB                     | 29.4 ± 10.8 | 21.5 ± 9.2    | 30.4 ± 10.1 | 0.155   |
| Echo intensity         | 37.7 ± 10.2 | 42.3 ± 8.5    | 39.9 ± 10.1 | 0.034*  |
| BB                     | 34.8 ± 10.9 | 36.3 ± 10.9   | 35.5 ± 10.9 | 0.404   |

*P < 0.05

Table 2 Echo intensity of four areas in two groups: with tongue pressure of 30 kPa and over, and with less than 30 kPa (mean ± standard deviation)

| Variable               | <30 kPa (n = 59) | ≥30 kPa (n = 41) | P-value |
|------------------------|------------------|------------------|---------|
| Echo intensity         |                  |                  |         |
| DT                     | 28.0 ± 9.3       | 24.0 ± 9.9       | 0.064   |
| BB                     | 32.9 ± 10.3      | 26.7 ± 8.7       | 0.009*  |
| BT                     | 42.8 ± 9.1       | 35.8 ± 10.1      | 0.001*  |
| BB                     | 36.2 ± 10.1      | 34.5 ± 12.0      | 0.264   |

*P < 0.05

Overall, the lower the EI, the greater the tongue thickness and BMI showed a slight correlation.

Statistical analysis

The Mann-Whitney U test was used to analyze the differences in age, BMI, tongue thickness, tongue pressure, and mean EI between men and women. Spearman’s correlation analysis was used to analyze the relationship between tongue thickness, tongue pressure, and mean EI. The participants were divided into two groups: with tongue pressure of 30 kPa and over, and with that of less than 30 kPa according to the criteria of oral hypofunction by the Japanese Society of Gerodontology [8], and the EIs in four areas were compared in the two groups. SPSS version 25.0 (IBM, Chicago, IL, USA) was used for all statistical analyses, and the risk rate was set to a significance level of less than 5%.

The ICCs in the DT, DB, BT and BB were 0.799, 0.798, 0.752, and 0.925, respectively. Such ICC values of more than 0.75 showed a good reliability considering the guidelines by Koo et al. for the ICC: values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively [19].

Table 1 shows the means and standard deviations of the measurements in men and women. There were no significant differences in age and BMI between men and women. Moreover, the values of tongue thickness and tongue pressure were comparable to those reported by Chantaramee et al. [17] and Tamura et al. [20] in elderly people of the same age group. Therefore, the participants of this study can be considered to represent the common elderly population. No significant differences in tongue thickness and tongue pressure were found between men and women. Although the mean EIs of DT and BT in men were significantly lower compared to those of women, the EIs of other areas were not significantly different. The mean EIs of the tongue on the dorsal side (DT and DB) were lower than those of the submandibular side (BT and BB).

Table 2 shows the mean EIs of four areas in the two groups: with tongue pressure of 30 kPa and over, and with that of less than 30 kPa. In the DB and BT, the mean EIs in the group with tongue pressure of 30 kPa and over were significantly lower than those with tongue pressure of less than 30 kPa.

Figure 3 demonstrates the relationship between tongue thickness and mean EI of each area. In the three areas apart from BB, which include a large part of the geniohyoid muscle, the EI decreased with an increase in the tongue thickness. In particular, the EI in DB exhibited a significant correlation with the Spearman’s rank correlation coefficient of −0.454. Figure 4 shows the relationship between the tongue pressure and mean EI of each area. In all four areas, the EI decreased with an increase in the tongue pressure, and the significant correlation coefficients of DT, DB, and BT were −0.198, −0.211, and −0.229, respectively. Age, sex, and BMI had less effect on the mean EI, tongue thickness, and tongue pressure. How-
assessments of the mass/performance of the tongue muscles based on the anatomical structure. The result, in which the mean EIs in the group with tongue pressure of 30 kPa and over were significantly lower than those with tongue pressure of less than 30 kPa in the DB and BT, also enhances the significance of EI measurements.

The result, in which the EIs in men, especially of DT and BT, were lower compared to those of women, might be explained by the gender differences in muscle changes with aging. It is reported that men have a greater change in muscle mass with aging, while women have more fat deposition and fat accumulation compared to men. Thus, the EI in women would be higher. As the muscles in DB and BB involved in swallowing are maintained, fewer gender differences might occur.
It is clinically known that the so-called “low tongue position”, in which the tongue looks thin, flat, and large, is often found in elderly people [18, 22] and is associated with a decline in the muscle strength of the tongue. However, the anatomical and functional meanings of the low tongue position remain unclear. The results of the present study suggest that a thin tongue is associated with a higher EI, especially of DB, which represents the intrinsic and extrinsic muscles of the tongue. Additionally, the height of the tongue may depend on the mass of the tongue muscles. While the correlation between tongue pressure and EI on ultrasound images was significant, it was lower than that between tongue thickness and EI. Fujimoto et al. reported that there was no significant correlation between tongue thickness and tongue pressure [18]. Tongue pressure may be attributed to factors other than the tongue muscles. In other words, tongue pressure may be affected not only by the extrinsic and intrinsic muscles of the tongue but also by the fixation of the mandible. Therefore, the tongue pressure might not be always proportional to only the muscle mass of the area where the EI was measured in this study. The EI is better suited for assessment of the muscles of tongue.

The measurement of the tongue pressure, which was the principal examination to estimate the tongue function in the present study, is based on active behavior and patient-reliant effort. Thus, it is difficult to measure in patients with higher-level dysfunctions such as dementia and aphasia. It is also difficult to measure in complete denture wearers and edentulous patients because the measurement probe has to be held with the incisors. In contrast, since ultrasonography is a passive test for patients, it can be applied to such patients. Furthermore, ultrasonography, especially the device used in the present study, can be easily equipped on the side of the dental chair. Considering the increase in the elderly population in the future, the EI measurement of the ultrasound images can provide the muscle mass and strength of the tongue in patients who cannot undergo conventional tongue pressure measurement.

The present study has several limitations. Firstly, it is impossible to identify each muscle from the ultrasound images. In this study, the analysis area was geometrically divided into the four as a substitute. The values of EIs in each area need to be discussed in relation to this point. Secondly, the EI measurement should be validated using additional external criteria. The participants in this study were outpatients receiving regular maintenance care at a university hospital; therefore, they were not representative of the general elderly population in Japan. Further clinical research is required to examine the effects of confounding factors, such as the number of remaining teeth and systemic and nutritional statuses, and to confirm the effectiveness of ultrasound for the assessment of tongue function.

In conclusion, the EI on ultrasound images of the tongue, especially in the area of DB, was related to both tongue pressure and tongue thickness. Therefore, the measurement of EI can be considered as an important indicator for assessing the tongue function.

Conflict of Interest
The authors declare no conflict of interest.

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