The purpose of the present study was to measure tongue pressure with the aim of characterizing the pattern of linguopalatal contact during articulating glossal sounds in normal subjects and glossectomy patients. Tongue pressures against the palate were evaluated in 13 normal subjects and 5 glossectomy patients by using three parameters: the duration from the onset of linguopalatal contact to the time of maximum pressure, the maximum pressure, and anterior posterior ratio of the maximum pressure. Three glossal sounds, [ti], [tʃi], and [ʃi], which have tendency of mishearing in glossectomy patients, were selected for test sounds. A unique characteristic was demonstrated in normal subjects. The score of the maximum pressure showed an apparent order among the three sounds, while the durations revealed the opposite order. Anterior posterior ratio of the maximum pressure also showed some relationship among three sounds. In glossectomy patients, these characters were not found. The loss of tongue volume or deterioration of tongue mobility causes these results.

Key words: tongue pressure, consonants, glossectomy

Introduction

Tongue cancer is the most common oral carcinoma and its treatment frequently involves surgical excision, radiation therapy, or both. In patients with extensive lesions, resections may include the floor of the mouth and the mandible in addition to the tongue. With only radiotherapy or limited resections, in which 50% or less of the tongue is removed, patients show little functional impairment. In patients with more extensive resection, however, impairment of function may occur.

Patients whose tongue or floor of the mouth has been resected usually undergo immediate reconstruction using local flaps, skin grafts, distant flaps or microvascular free tissue transfer. Although the shape of the tongue can be more or less rebuilt, its movement is restricted by defects of the body and the frenulum, the attachment of flaps, and residual tongue or postoperative scar ring. Each of these restrictions results in dysfunctions of mastication, deglutition and speech.

Articulatory function after glossectomy has been evaluated by means of dynamic palatography. The dynamic palatograph is an electrical apparatus that generates a visual display of constantly changing linguopalatal contact as a function of time, using an artificial palatal plate with affixed electrodes. Palatography can examine whether the tongue contacts the palate or not at each measuring point. However, the tongue is a mass of muscle and its movement during articulation is frequently complex. For example, glossal sounds, which are one of the most misheard sounds in glossectomy patients, are categorized into three types by type of articulation: stop plosive, affricate, and...
fricative. These sounds cannot be evaluated by observing simply whether or not the tongue contacts the palate. In glossectomy patients, the tongue and reconstructed flap move monolithically during use and cannot perform complex and delicate movements. Therefore, to assist with the rehabilitation of glossectomy patients, it is necessary to evaluate objectively the degree of linguopalatal contact.

Tongue pressure against the palate during articulation was measured in normal subjects, complete denture wearers, lisping children and cleft palate patients. Measuring tongue pressure during function appears to be one indications of degree of linguopalatal contact. However, we are not aware of any reports that focus specifically on tongue pressure in glossectomy patients before and after rehabilitation. Characterizing the tongue activity pattern of normal subjects and glossectomy patients should be helpful in evaluating the postoperative rehabilitation of glossectomy patients and increasing their quality of life. The aim of the present study is to measure the tongue pressure against the palate to characterize the pattern of linguopalatal contact during articulating [ti], [tʃi] and [ʃi], which are typical of the glossal sounds, in normal subjects and compare the pattern with glossectomy patients.

Materials and Methods

Subjects

Thirteen normal subjects (5 male and 8 female age range 25-32 years, mean age 27.2 years) and five glossectomy patients (4 male and 1 female, age range 56-76 years, mean age 64.4 years) participated in this experiment. All subjects were native speakers of Japanese with normal hearing and no observable abnormalities of the vocal cords. They are healthy dentate subjects and had sound dentition with stable occlusal contacts at the intercuspal position. Glossectomy patients had undergone immediate reconstruction with skin grafts, distant flaps (myocutaneous flaps), or microvascular free tissue transfer (Table 1). Though they are healthy dentate subjects or partial denture wearers, vertical dimensions were determined by their own occlusions. Informed consent was obtained from each subject prior to the experiment.

Measurement of tongue pressure

After obtaining a maxillary cast, a 2 mm-thick template was made using fluid resin. The outline of the template is placed in the palatal cervical line of each tooth. The posterior margin is based on the line guided with both hamular notch and fovia palatinae. The tongue pressures against the palate were measured during articulation with these templates. Yamada reported the tongue pressure during articulation and speech intelligibility fell immediately after delivery of experimental palatal plates, but one week after delivery, they could speak intelligibly in normal subjects. In the present study, each subject used this plate for a week to enable adaptation before the measurement was taken.

Pressure transducers (PS-2KA, Kyowa co., Japan) utilizing strain gauges were mounted on each side of anterior and posterior areas of the palatal plate where the tongue made contact. The anterior area was placed 5 mm from the cervical line of the basal tubercle of the canine. The posterior area was placed 5 mm from the cervical line of the mesiolingual cusp of the second molar. Those areas were selected in the light of the reported data of the palatogram. The transducers were fixed using light-cured composite resin (UniFil® Flow, GC, Japan). The conductor wire from the transducer passed the distal plane of the most posterior molar teeth and the buccal side of the molars and led from the corner of the mouth to prevent the wire from interfering with speech. Four channel signals were amplified using a PCD-300A sensor interface (Kyowa co., Japan) and recorded on the PC. The combined accuracy of this system is within ±1.47%RO. The tongue pressures were measured during monosyllabic utterances of the linguopalatal consonants. The linguopalatal consonants, [ti], [tʃi] and [ʃi], were selected as test sounds, since they produce palatal pressures by the tongue and have similar contacts areas on the
palate during articulation\(^{11}\). In addition, these sounds have a tendency of being misheard in glossectomy patients\(^{4}\). /i/ was selected as the following vowel, in which the tongue nearly contacts with the palate\(^{12}\). Pressures were recorded with subjects seated comfortably in an upright position. Subjects were asked to repeat each syllable briefly 5 times at a conversational level of volume while a dB level display was monitored. In this way, 5 data patterns were obtained for each syllable. Tongue pressure against the palate was evaluated by using three parameters: duration from the onset of linguopalatal contact to the time of maximum pressure, maximum pressure and AP ratio (Fig. 1). AP ratio is the ratio of anterior maximum pressure and posterior maximum pressure, which shows anterior-posterior balance of tongue mobility. Maximum pressure, the duration and AP ratio of each subject were determined as the mean value from three of five data, with the maximum and the minimum data being excluded.

**Statistical analysis**

Both individual data and group data of subjects after normalization were evaluated. A parametric test was applied to analyze the data. One-factor ANOVA measurements were used for the statistical data analysis. The Scheffe test was used to identify which group differences accounted for the significant \(P\) value. A \(P\) value of less than 0.05 was regarded as statistically significant. All statistical analyses were performed on a PC using the statistical package (Stat View v 5.0, SAS, Cary, NC, USA).

**Results**

**Normal subjects**

In normal subjects, there was no significant difference between left and right side for each parameter, which was consistent with the study of Yamada in 1987\(^{5}\). Therefore, the results were shown only right side.

The duration of [ti], [tʃi] and [ʃi] in normal subjects were shown in Fig. 2. The statistical analysis revealed that there were significant differences in the durations among the three consonants both on anterior and pos-

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**Fig. 1.** Data analysis of the measurement. A: Duration from the onset of linguopalatal contact to the time of maximum pressure B: Maximum pressure

\*AP ratio=Maximum Pressure at posterior portion / Maximum Pressure at anterior portion.

**Fig. 2.** A comparison of the durations of normal subjects among [ti], [tʃi] and [ʃi] in the anterior portion and posterior portion. In the anterior portion, [tʃi] was significantly greater than [ti] (\(P=0.0492\)), and [ʃi] was significantly greater than [tʃi] (\(P=0.0460\)) and [ti] (\(P<0.0001\)). In the posterior portion, [tʃi] was significantly greater than [ti] (\(P=0.0429\)), and [ʃi] was significantly greater than [tʃi] (\(P=0.0284\)) and [ti] (\(P<0.0001\)).
terior portion. The durations of monosyllables were longest in [ʃi], followed by [tʃi] and the shortest in [ti].

The maximum pressures of [ti], [tʃi] and [ʃi] in normal subjects were shown in Fig 3 (a). There were significant differences in the maximum pressure both on anterior and posterior portion. The maximum pressures of monosyllables were largest in [ti], followed by [tʃi], and smallest in [ʃi].

Figure 3 (b) shows the AP ratio. The ratio of [ʃi] was significantly bigger than those of [tʃi] and [ti], while there were no significant differences between those of [ti] and [tʃi].

Glossectomy patients

Generally, speech intelligibility in glossectomy patient improves for about six month after their operation and reaches a plateau thereafter. Therefore, speech abilities of patients in present study are accounted stable.

The durations in the glossectomy patients are shown in Fig. 4. There was no significant difference in the duration both on normal side and defect side. The maximum pressures in the glossectomy patients are shown in Fig. 5. There was no significant difference in the maximum pressure in each measuring point except for the posterior normal side. In the posterior normal side, [tʃi] is significantly greater than [ʃi].

Fig. 6 shows AP ratio in the glossectomy patients. There was not significantly difference between the ratio of [ʃi] and [ti], or [tʃi] and [ti] in the glossectomy patients.

Discussion

The tongue is the major articulator during the production of all phonemes except bilabials, labio-dentals and glottal sounds. The tongue movements modify the shape of oral cavity and change the resonance characteristics that produce the different consonants. This coordination of tongue muscle and nerve is impaired in glossectomy patients even after the tongue has reconstructed by the flap. In this study we examined tongue-alveolar orientation during glottal sounds articulation by measuring tongue pressures and duration from onset of linguopalatal contact to the time of maximum pressure. A unique characteristic among [ti], [tʃi], [ʃi] was demonstrated in normal subjects. The score of the maximum pressure showed apparent order among the three sounds. In contrast the durations revealed the opposite order (Figs. 2, 3).

In glossectomy patients, those characters were lost, and no relationship was shown in the duration, maximum pressure or AP ratio (Figs. 4, 5, 6).

There are various manners in production of consonants. Some consonants are produced by means of a period of complete obstruction of the vocal tract, whereas others are produced with only a narrowing of

![Fig. 3.](a) A comparison of the maximum pressures in normal subjects among [ti], [tʃi] and [ʃi]. In the anterior portion, [ti] was significantly greater than [tʃi] (P<0.0003) and [ʃi] (P<0.0001), and [tʃi] was significantly greater than [ʃi] (P=0.0024). In the posterior portion, [ti] was significantly greater than [ʃi] (P<0.0001) and [tʃi] (P<0.0001), and [tʃi] was significantly greater than [ʃi] (P=0.0492).

(b) A comparison of AP ratio in normal subjects between [ti], [tʃi] and [ʃi]. [ʃi] was significantly greater than [ti] (P=0.0404) and [tʃi] (P=0.0493), while there were no significant differences between the AP ratio of [tʃi] and [ʃi] (P=0.9959).
the vocal tract. We selected [t], [ʃ] and [i] as test sounds which require linguopalatal contact. [t] is a stop plosive produced by instantaneous complete closure and release by the blade portion of the tongue. Therefore, the tongue needs to contact strongly and move quickly to articulate [t]. [ʃ] is a fricative by making a constriction somewhere in the vocal tract, and forcing air at high velocity through a constriction made with the blade and mid-portion of the tongue. The essential articulatory feature of a fricative is a narrow constriction maintained somewhere in the vocal tract. [ʃ] is an affricate produced by two phases of vocal tract closure followed by a noisy release with the blade and mid-portion of the tongue. The basic theory of affricate production is a modification of that presented for stops and fricatives. Thus, the manner of contact and contact portion of the tongue are different, whereas each test sound has a similar contact area with the palate during

Fig. 4. A comparison of the durations in glossectomy patients among [t], [ʃ] and [i]. There was no significant difference in the duration in both the anterior portion (normal side $P=0.8762$, defect side $P=0.6305$) and the posterior portion (normal side $P=0.7642$, defect side $P=0.4824$).

Fig. 5. A comparison of the maximum pressures in glossectomy patients among [t], [ʃ] and [i]. There was no significant difference in the duration in both the anterior portion (normal side $P=0.8610$, defect side $P=0.2419$) and the posterior defect side ($P=0.6280$) except for the posterior normal side. In the posterior normal side, [ʃ] is significantly greater than [i] ($P=0.0237$).

Fig. 6. A comparison of AP ratio in glossectomy patients among [t], [ʃ] and [i]. There was no significant difference (normal side $P=0.2417$, defect side $P=0.3448$).
articulation\textsuperscript{11}. Therefore, our results are consistent with those theories: [ti] had the biggest value of maximum pressure when producing the complete closure and the shortest duration when producing instantaneous release and [ji] had the smallest value for the maximum pressure to produce the constriction and the longest duration in maintaining it.

To date, two basically different approaches have been used to test devices for measuring tongue pressure, both with considerable success. In the first, the pressure is mechanically transmitted to outside the mouth where the pressures are measured. Robbins et al.\textsuperscript{17} and Poudreux & Kahrilas\textsuperscript{18} measured tongue pressure during deglutition using the Iowa Oral Performance Instrument (IOPI). The amount of pressure generated by squeezing an air-filled bulb attached to a pressure transducer with the tongue is displayed on a digital readout that is calibrated in Pascals. Although this bulb appears to be simulated a food bolus during deglutition, tongue pressure during articulation could not be measured physiologically using this method. In the other approach, intraoral pressures are first converted into electrical signals that are led via wires out of the mouth where they are amplified and recorded. Kydd\textsuperscript{19} experimented on tongue pressure using a resistive strain gauge to convert the elastic deformation of a metallic beam into electrical signals, which were amplified and recorded by means of a pen recorder. In the present study, we adopted an intraoral transducer to measure the tongue pressure physiologically.

Generally, there is a wide variation of values in maximum pressure among subjects. McGlone, Proffit & Christiansen\textsuperscript{20} have reported that tongue pressure during high-speed articulation results in large values. Yamada\textsuperscript{2} reported that differences in volume caused variance in tongue pressure. McGlone & Proffit\textsuperscript{21} reported that there was little correlation between tongue pressures and oral cavity size. Kaires\textsuperscript{6} reported that the highest maximum pressure was seen in the correct vertical dimension of occlusion. Therefore, maximum pressure should depend on the volume, tone or speed of speech, shape of the tongue, dentition or occlusion.\textsuperscript{5} Thus, we didn't compare the score of tongue pressure among subjects because of this wide variation but examined the relationship of three glosal sounds in each subject in our study.

Many investigators measured peak tongue pressure and pressure-time integral as the chief parameters.\textsuperscript{6,20,22} In the present study, we carried out an analysis of the peak tongue pressure and the durations from the onset of linguopalatal contact to the time of maximum pressure so as to diminish the influence of the following vowel, since most Japanese syllables comprise consonants and a following vowel. In addition, since glossectomy patients cannot perform complex and delicate tongue movements, indication of tongue movement needed to be evaluated. For these reasons AP ratio was adopted as the parameter for movement balance.

In glossectomy patients, the glosal sounds are mostly misheard. [ki] and [gi] are mostly misheard for vowels or [hi] [pi]\textsuperscript{14}, sounds made without linguopalatal contact. The reason for this mishearing is simply that the tongue does not contact the palate. On the other hand, [ti], [tii] and [ji] are mostly mutually misheard among these 3 sounds. Each consonant requires a different manner of contact. Therefore, to discriminate between these consonants, we needed to examine not only linguopalatal contacts but also the durations and the maximum pressures.

In our results, the relationship shown in the duration of normal subjects was not seen in glossectomy patients. It was suggested that the residual tongue sutured with a flap or postoperative scar formation interfered with its flexibility. The relationship seen in the maximum pressure of normal subjects was not observed in glossectomy patients either except for posterior normal side. The surgical defect of the main part and/or the base of the tongue had accounted for the loss of appropriate linguopalatal contact, especially on the defect side. The AP ratio revealed the anterior-posterior balance of tongue pressure and was able to specify tongue mobility. The differences observed in normal subjects were not seen in glossectomy patients (Fig 3, 6). Wakimoto, et al reported in 1996 that glossectomy patients contacted the palate with a broad area of the tongue to obtain a sense of touch, confirmed by electropalatography, which showed a thick contact pattern\textsuperscript{23}. These results suggest that deterioration of tongue mobility and compensatory tongue movements cause a lack of balance between anterior and posterior movements.

Using palatography, it is usually possible to evaluate which area of the palate the tongue makes contact with during articulation. In glossectomy patients, because tongue movement is restricted, it is important to evaluate tongue mobility more precisely to assist rehabilitation. In the present study, we adopted the measurement of tongue pressure to evaluate linguopalatal contact during articulation more precisely, since palatography can be used to examine whether the tongue contacts the palate or not during articulation. There were significant
differences among [ti], [tʃi], and [ʃi], not only with respect to the maximum pressure but also in the duration. Our results suggest that both the factors of quantity and time are closely concerned with the articulation of glossal sounds. Our method has the potential to provide important insights for evaluating tongue mobility. In future, the tongue volume or the contact portion of the tongue needs to be considered in addition to our method. More and smaller measuring points are needed to gain a more detailed picture of the tongue pressure on the palate. Additional studies are required to reveal individual confound factors and long-term outcomes.

For successful rehabilitation of glossectomy patients, mutual cooperation between maxillofacial surgeons and prosthodontists is essential. The parameters presented in this study have the potential for a wide variety of applications, such as designing reconstructive flaps and prostheses in glossectomy patients.

Within the limitation of this study, there were some relationship among three test sounds in normal subjects while no relationship were shown in glossectomy patients using three parameters. The parameters of duration, maximum pressure and AP ratio would have possibility to evaluate tongue function in glossectomy patients.

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References