Influence of the Width and Cross-Sectional Shape of Major Connectors of Maxillary Dentures on the Accuracy of Speech Production

Junichiro Wada a  Masayuki Hideshima b  Shusuke Inukai a  Hiroshi Matsuura c  Noriyuki Wakabayashi a

a Section of Removable Partial Prosthodontics, Department of Masticatory Function Rehabilitation, Graduate School of Medical and Dental Sciences, and b Dental Clinic for Sleep Disorders (Apnea and Snoring), Oral and Maxillofacial Rehabilitation, University Hospital of Dentistry, Tokyo Medical and Dental University, Tokyo, and c Graduate School of Management and Information of Innovation, University of Shizuoka, Shizuoka, Japan

Key Words
Major connectors · Maxillary dentures · Speech production

Abstract
Objective: To investigate the effects of the width and cross-sectional shape of the major connectors of maxillary dentures located in the middle area of the palate on the accuracy of phonetic output of consonants using an originally developed speech recognition system.

Patients and Methods: Nine adults (4 males and 5 females, aged 24–26 years) with sound dentition were recruited. The following six sounds were considered: [ʃi], [tʃi], [ɾi], [ni], [ɕi], and [ki]. The experimental connectors were fabricated to simulate bars (narrow, 8-mm width) and plates (wide, 20-mm width). Two types of cross-sectional shapes in the sagittal plane were specified: flat and plump edge. The appearance ratio of phonetic segment labels was calculated with the speech recognition system to indicate the accuracy of phonetic output. Statistical analysis was conducted using one-way ANOVA and Tukey’s test.

Results: The mean appearance ratio of correct labels (MARC) significantly decreased for [ni] with the plump edge (narrow connector) and for [ki] with both the flat and plump edge (wide connectors). For [ɕi], the MARCs tended to be lower with flat plates. There were no significant differences for the other consonants. Conclusion: The width and cross-sectional shape of the connectors had limited effects on the articulation of consonants at the palate.

Introduction

Speech production, which is essential for human communication, can be dramatically improved by prosthetic treatment in partially and fully edentulous patients [1–3]. Many studies have evaluated the influence of complete dentures on speech production from various viewpoints: the positioning of the artificial teeth [4–9], the vertical dimension [10, 11], and the effectiveness of the complete denture [12–14]. Regarding removable partial dentures, some studies have investigated the design of major connectors [15–18] by focusing on the positions, shapes, and sizes of the covered area. According to these studies, a connector located in the middle area of the palate is historically recommended from the viewpoint of speech production.

With regard to the evaluation of speech production, several methods have clinically and experimentally been considered in dental therapy. Auditory evaluations by
speech therapists [19], sound spectrography [20], and palatography [21–27] are the standard methods. Sound spectrography can evaluate physical properties using a sonogram constructed from the frequency, time progression, and amplitude of sounds. Palatography can be used to evaluate the contact patterns of the tongue on the palate during pronunciation. These methods are effective to evaluate structural and physiological mechanisms, but have limitations because they evaluate only one aspect of speech production. First-hand physical properties from sound spectrography are difficult to understand for most clinicians. Additionally, special equipment that is not typically found in general dental offices is required for an evaluation by sound spectrography. Palatography, and especially electropalatography, is effective for evaluations of palate shapes and/or contact areas between the tongue and palate for research purposes [21–23]. On the other hand, regarding its use in clinical applications, palatography is available only for edentulous patients with full dentures or partial dentures with large denture bases similar to those of full dentures. Thus, for most clinicians and in most clinical situations, these standard methods rarely indicate which sound is disturbed or whether the pronunciation disorder is actually caused by the prosthetic appliance. Meanwhile, although auditory evaluations by speech therapists have been clinically recommended, the perceptual evaluation of speech production often lacks reliability and reproducibility because of differences in the experience levels of speech therapists. Hence, several listeners must be recruited for an auditory evaluation. In practice, an evaluation by several listeners is rather time-consuming and its use is mainly restricted to research projects. Therefore, in a clinical chairside situation, one expert or one dentist usually evaluates a patient’s speech production.

We developed an evaluation system using speech recognition to establish an easy-to-use clinical evaluation method for speech production [28]. In contrast to traditional methods, this system can evaluate the accuracy of phonetic output specifically and objectively. The phonetic segment is labeled with pattern-matching processing that represents the phonetic features of the speech data. One analysis frame of 8 ms is used to summarize the relevant information of the surrounding 79 ms. This system identifies which syllable was pronounced according to the appearance ratio of various segment labels. Therefore, micro-time scale information reflecting macro-time scale flow information from recorded speech data can be provided. In addition, this evaluation can be conducted immediately using only a laptop computer with specific software and a headset microphone. With this system, we tried to analyze the influences of the incisal overjet [29] and palatal contour [30] of a maxillary complete denture on alveolar consonants as well as the influence of the position of the major connector in a maxillary removable partial denture on several consonants, in addition to the alveolar consonants [31]. In particular, we found that locating the major connector in the middle area of the palate results in a smaller disturbance than in other areas from the viewpoints of accuracy of phonetic output, a shorter duration of consonants, and the tendency to change to other consonants. These studies also suggested that this system is more appropriate to be applied at chairside than traditional methods and can be used to evaluate more detailed information regarding phonetic output disorders caused by a prosthetic appliance.

Since the major connector should be strong enough to transmit chewing force from the chewing side to the indirectly abutting teeth, a palatal plate with a width >20 mm is preferred for the major connector in a removable partial denture. In addition to the width, it is suggested that the cross-sectional shape of the major connector in the sagittal plane affects oral sensation [32]. As compared to other designs, major connectors located in the middle area of the palate have been reported to hardly affect speech production, and they are applied as easy-to-speak designs in clinical practice. However, there are a certain number of patients who suffer from a pronunciation disorder, even if they wear partial dentures with such connectors. While these patients may be more sensitive to oral appliances, the details of the connector designs may affect pronunciation. Practically at the same time, if the phonetic output disorder caused by a denture is greater in the initial phase, treatment of the patient may lose momentum from refusal to use it. The influence of the width and cross-sectional shape of the major connector on speech production has scarcely been discussed, and we considered that our system could be used to evaluate it. Thus, it is thought-provoking to investigate the influences of major connectors located in the middle area of the palate, which is generally thought to be appropriate for speech production. The findings might lead to new strategies for the treatment of patients who are not satisfied with traditional prostheses.

The purpose of this study was to investigate the influence of the width and cross-sectional shape of the major connector of a maxillary removable partial denture, located in the middle area of the palate, on the accuracy of phonetic output and changes in Japanese consonants. The consonants included alveolar, palatal, and velar con-
sonants, which are easily disturbed by removable den-
tures in the initial phase. The null hypothesis was that the
width and cross-sectional shape of the major connector
would have no influence on speech production.

Materials and Methods

Subjects
Nine subjects (4 males and 5 females, aged 24–26 years, mean
age 24.7 ± 0.87 years) were recruited for this study. Approval of the
Ethics Committee of Tokyo Medical and Dental University was
obtained (No. 129). All subjects were selected for this study based
on the following inclusion criteria: (i) Japanese adults; (ii) normal
speech and hearing; and (iii) normal occlusion with sound denti-
tion. Exclusion criteria were: (i) history of orthodontic therapy; (ii)
missing teeth, except for the third molars; (iii) severe periodontal
disease and caries; (iv) severe malocclusion, and (v) hearing or
speech impairment. Each subject received a written and verbal de-
scription of the study, and provided informed consent prior to
enrollment.

Fabrication of the Experimental Major Connectors
The experimental major connectors were fabricated in Co-Cr
(COBLTAN; Shofu Co., Kyoto, Japan) from casts made from sil-
icone impressions of the subjects’ maxillae. Two different widths,
8 mm (a narrow connector defined as a ‘bar’ in the dental field)
and 20 mm (a wide connector defined as a ‘plate’ in the dental
field), were selected for the connectors, and the thickness was 0.5
mm at the thickest part. Two types of cross-sectional margin
shapes in the sagittal plane were specified: flat and plump edge. The
cross-sectional shape of the margin was acutely angled for the flat
edge and moderately curvilinear for the plump edge margin
(fig. 1). These major connectors were constructed such that the
midline of the connector conformed to a straight line connecting
the contacts of the second premolars and the first molars.

Recording of Speech Samples
The second moras (/shi/: [ʃi], /chi/: [tʃi], /ri/: [ri], /ni/: [ni], /hi/
[çi], and /ki/: [ki]) of the six Japanese test words (/i/shi/kawa,
i/chi/ro, i/ri/gami, /ko/ni/shiki, /e/hi/meken, and /o/ki/nawa) were
chosen as the six test sounds (table 1). These test sounds can be
classified into three groups according to the position of articula-
tion: (1) alveolar: [ʃi], [tʃi], [ri], and [ni]; (2) palatal: [çi], and (3)
velar: [ki]. The sounds can also be classified into five groups ac-
cording to the manner of articulation: (1) fricative: [ʃi] and [çi];
(2) affricate: [tʃi]; (3) plosive: [ki]; (4) tap: [ri], and (5) nasal: [ni].

These sounds include the vowel [i], which requires the highest
tongue position among the Japanese vowels. The six test words
were real Japanese words, which included test sounds with an ac-
cent on the second mora. There were five recording conditions:
without a connector (control), wearing the narrow connector with
a flat edge (flat bar), wearing the narrow connector with a plump edge
(plump bar), wearing the wide connector with a flat edge (flat
plate), and wearing the wide connector with a plump edge (plump

![Fig. 1. Width and cross-sectional shape of the experimental major connectors.](image-url)
Each subject was required to pronounce a test word 5 times under the five above-described recording conditions. The order of the recording conditions was random. Each subject was instructed not to vocalize the test words before the recording, and the recordings were initiated as soon as the connectors were worn stably. Small breaks were provided after every five recordings.

During the measurements, the subjects were asked to maintain their pronunciation at a constant speed and volume as in their daily life. Speech data were recorded with a headset-type microphone and a laptop computer (PAC9214LDEW; Toshiba Co., Tokyo, Japan) and analyzed using a speech evaluation system.

### Evaluation of Speech Data

The speech evaluation system (Voice Analyzer; Toshiba Digital Media Engineering Co., Tokyo, Japan) uses speech recognition based on 213 types of integrated phonetic segments that represent phonetic features and features of transitions from one phoneme to another [30]. The acoustic analysis was performed using a fast Fourier transform that transformed the speech data of eight analytical frames (79 ms) into 64 ms of information (fast Fourier transform parameters). Then, the multiple acoustic feature plane pattern emphasizing local changes in frequency and time frame was extracted. Finally, the six multiple acoustic feature plane patterns (48 ms) were quantized with statistical pattern-matching processing, and the integrated phonetic segment was labeled every 8 ms. Thus, this system performs micro-period (8 ms) evaluations on a frame-by-frame basis and is therefore able to record time scale information (fig. 2). It also performs macro-period quantitative sound evaluations using the ratio between the numbers of correct and incorrect integrated phonetic segment labels during the evaluation period.

The flow process of the speech evaluation system is shown in figure 2. The pattern is extracted from the power spectrum and matched to a phonetic segment of the reference pattern, and the results are labeled and displayed. As an example, the method to extract the consonant part of the test sound $\int_i$ from the speech data of the test word /shi/ is shown in figure 3. The top border of the range of $\int_i$ sound was the transition from [i] to $\int_i$, and the bottom border was the transition from $\int_i$ to [ka]. The vowel part of $\int_i$ was then removed, and the remaining section was defined as the objective part. The extractions of other test sounds were accomplished in the same manner.

### Table 1. Test sounds and words used in this study

<table>
<thead>
<tr>
<th>IPA</th>
<th>Test sound</th>
<th>Japanese test word</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ʃi]</td>
<td>/shi/</td>
<td>i/i/shi/kawa/: one of the prefectures of Japan</td>
</tr>
<tr>
<td>[ʃi]</td>
<td>/chi/</td>
<td>i/i/chi/ro/: the name of a Japanese baseball player</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>/o/ri/gami/: the traditional Japanese art of paper folding</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>/ko/ni/shiki/: the name of a Japanese sumo wrestler</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>/e/hi/meken/: one of the prefectures of Japan</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>/o/ki/nawa/ : one of the prefectures of Japan</td>
</tr>
</tbody>
</table>

### Table 2. Characteristics of typical segment labels

<table>
<thead>
<tr>
<th>IPA</th>
<th>Sound</th>
<th>Place of articulation</th>
<th>Manner of articulation</th>
<th>Voiced/voiceless</th>
<th>Phonetic segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ʃi]</td>
<td>/shi/</td>
<td>alveolar</td>
<td>fricative</td>
<td>voiceless</td>
<td>$$, SS, $$</td>
</tr>
<tr>
<td>[ʃi]</td>
<td>/chi/</td>
<td>alveolar</td>
<td>affricate</td>
<td>voiceless</td>
<td>CC, CI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>alveolar</td>
<td>tap</td>
<td>voiced</td>
<td>RR, RI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>alveolar</td>
<td>nasal</td>
<td>voiced</td>
<td>N9, NI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>palatal</td>
<td>fricative</td>
<td>voiceless</td>
<td>$#$, HH, HI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>velar</td>
<td>plosive</td>
<td>voiceless</td>
<td>KI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>alveolar</td>
<td>fricative</td>
<td>voiced</td>
<td>ZZ, JI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>velar</td>
<td>plosive</td>
<td>voiced</td>
<td>GG, GI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>bilabial</td>
<td>nasal</td>
<td>voiced</td>
<td>M9, MI</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>/ɾi/</td>
<td>bilabial</td>
<td>plosive</td>
<td>voiced</td>
<td>BB, BI</td>
</tr>
</tbody>
</table>
Influence of the Major Connector of a Denture on Speech Production

**Fig. 2.** Schematic drawing of the extraction of phonetic segment labels and the corresponding parameters. Analytical frame = 23 ms; frame shift range = 8 ms; FFT = fast Fourier transform; MAFP = multiple acoustic feature plane.

**Fig. 3.** Flow chart of the extraction of the consonant part of [ʃi].
Statistical Analysis

The mean value for the appearance ratio of correct and incorrect labels of each test sound was calculated for the statistical analysis. One-way ANOVA was used to compare the mean values of the appearance ratios of correct and incorrect labels among the five recording conditions, and post hoc multiple pairwise comparisons were performed using Tukey’s test. The significance level was set at 5% (α = 0.05). Statistical Package for the Social Sciences (SPSS) software for Windows 11.5J (SPSS Japan, Inc., Tokyo, Japan) was used for all statistical analyses.

Results

The MARCs of the test sounds are shown in table 3. There were no significant differences among the five recording conditions (control, flat bar, plump bar, flat plate, and plump plate) for [ʃi] (p = 0.830), [tʃi] (p = 0.622), [ɾi] (p = 0.998), and [çi] (p = 0.900). The MARC of [ni] was significantly decreased with the plump bar (p = 0.019) and tended to be decreased with the flat bar (p = 0.051). The MARC of [ki] was significantly decreased with the flat plate (p = 0.010) and plump plate (p = 0.013). For the [çi] sound, the MARC tended to be lower with the flat plate (p = 0.193).

The mean appearance ratios of incorrect labels are shown in figure 4. Among the incorrect labels of the test sound [ʃi], three kinds of incorrect labels, [tʃi], [çi], and [ðʃi], appeared constantly under all conditions. In particular, the [çi] label tended to be increased with the plump bar (p = 0.113). For the test sound [tʃi], three types of incorrect labels, [ʃi], [ki], and [ðʃi], appeared constantly under all conditions. For the test sound [ɾi], [ni] and [gi] appeared constantly as incorrect labels under all conditions. Incorrect labels reflecting the disturbance of the following vowels such as [ɾe] also appeared constantly. For the test sound [çi], three types of incorrect labels, [mi], [gi], and [ðʒi], appeared constantly under all conditions. Incorrect labels reflecting a disturbance of the following vowels such as [na] also appeared constantly. For the test sound [çi], [ki] labels appeared constantly as incorrect labels under all conditions. Additionally, [ʃi] and [gi] appeared constantly with the plump bar, flat plate, and plump plate. For the test sound [ki], three types of incorrect labels, [çi], [tʃi], and [gi], appeared constantly under all conditions. Incorrect labels reflecting a disturbance of vowel parts such as [ke] also appeared constantly.

Discussion

As shown above, significant disturbances were observed for only two test sounds under a few recording conditions. Therefore, even if it was wide, a connector located in the middle area of the palate was suggested to have less influence on speech production than connectors located in other areas [31]. The connector in this location induced only a slight disturbance in the articulation of consonants at the posterior areas of the palate, regardless of width or cross-sectional shape. These findings suggest that the adequate widths and cross-sectional shapes that preserve phonetic output can vary.

Using the same system as in our study, Matsuura et al. [28] indicated that the MARCs represented the accuracy of phonetic output, that they were not 100% accurate in normal speech samples of subjects with sound dentition, and that incorrect labels occurred at certain ratios. The phonetic segment for each 8-ms period is labeled directly from six frames (48 ms) of time-frequency patterns, as shown in figure 2. Human voice is produced by an articulatory organ and it is not always stable under control conditions because it changes sequentially depending on the

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Table 3. MARCs of the test sounds

<table>
<thead>
<tr>
<th>Test sound</th>
<th>Control</th>
<th>Flat bar</th>
<th>Plump bar</th>
<th>Flat plate</th>
<th>Plump plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ʃi]</td>
<td>87.5 (6.4)</td>
<td>84.3 (7.0)</td>
<td>85.0 (6.5)</td>
<td>85.3 (5.1)</td>
<td>81.3 (7.2)</td>
</tr>
<tr>
<td>[tʃi]</td>
<td>76.4 (13.0)</td>
<td>64.9 (18.8)</td>
<td>66.6 (15.7)</td>
<td>64.9 (19.7)</td>
<td>67.8 (18.1)</td>
</tr>
<tr>
<td>[ɾi]</td>
<td>79.8 (14.0)</td>
<td>77.3 (12.9)</td>
<td>77.6 (14.8)</td>
<td>75.3 (19.9)</td>
<td>74.3 (20.0)</td>
</tr>
<tr>
<td>[ni]</td>
<td>88.5 (5.9)</td>
<td>71.9 (16.3)</td>
<td>69.5 (15.8)</td>
<td>76.5 (12.9)</td>
<td>84.6 (7.2)</td>
</tr>
<tr>
<td>[çi]</td>
<td>83.4 (15.1)</td>
<td>77.4 (14.4)</td>
<td>79.2 (7.5)</td>
<td>68.3 (17.9)</td>
<td>71.6 (14.8)</td>
</tr>
<tr>
<td>[ki]</td>
<td>75.6 (11.1)</td>
<td>63.4 (20.7)</td>
<td>57.7 (17.8)</td>
<td>48.9 (14.5)</td>
<td>49.9 (15.1)</td>
</tr>
</tbody>
</table>

Values are presented as means and standard deviations. Significant differences from the control: \(a p < 0.05; \ b p < 0.01\).
previous or following phoneme. Figure 4 shows the appearance of incorrect labels under control conditions. Although several incorrect labels appeared in the objective part, the objective sound was recognized accurately if the appearance ratios of the correct labels were clearly higher than those of the incorrect labels. The reference patterns of the phonetic segments were constructed from analyzed speech data from 400 females and 400 males spending more than 40 min producing speech; these reference data take individual variability into account [33]. Regarding contact between the palate and the tongue, the effect of gender was reported to be inconsequential [34]. In this study, the pattern matching was conducted to be equal to speaker-independent recognition with the classifier based on Karhunen-Loeve/Generalized Probabilistic Descent (KL/GPD) competitive learning by females and males [35–37].

Honda et al. [38] reported that productions of [ʃa] and [tʃa] were usually correctly identified when auditory feedback was available using an air-controlled artificial palate. They asked the subjects to repeat each objective syllable. Jones and Munhall [39] indicated that the articulatory representation seemed to be overrun by the acoustic representation of the /s/ sound, with the occlusal splint covering only the maxillary incisor teeth. They also indicated that the subjects’ utterances improved with in-

![Fig. 4. Mean appearance ratio of incorrect labels.](image-url)
increased practice. The subjects could not produce utterances before they started the pronunciation of test sounds and had to wait for auditory feedback. On the other hand, Baum and McFarland [40] indicated that adaptation to a structural modification of the oral cavity can occur relatively quickly with intensive, target-specific practice using a palatal plate with a 6-mm width near the alveolar ridge. In our present study, subjects with normal hearing were recruited, and speech data were sampled in conditions with auditory feedback available. The order of the recording conditions, with or without connectors, was random. We used real Japanese words that include the objective syllable as test words as substitutes for monosyllables. Additionally, subjects were required to pronounce six test words sequentially during one recording set, and the recording conditions were alternated with each recording set. Compared with the above-mentioned studies [38–40], the subjects hardly recognized the modifications in their oral cavities, and the speech tasks were far from being repetitive practices of syllables. Therefore, this study was conducted under the condition that short-term adaptation in the initial phase had hardly started, although obvious disorders in speech production were not perceived. The experimental conditions were similar to the clinical situation soon after the insertion of a partial denture and were thought to be adequate to evaluate the influences of major connectors of partial dentures in the initial phase.

In the dental field, alveolar, palatal, and velar articulations are reported to be easily disturbed in patients wearing removable dentures [41]. The test sounds used in this study have previously been reported to be likely affected by wearing a denture [42]. We have also previously shown that connectors located in other areas of the palate easily affect these sounds [31]. When recording the speech samples, noises would occasionally occur with inspiration and would disturb the top parts of the speech samples of the test words, and the volume would decrease after the accented part of the test word. These phenomena make speech data difficult to evaluate. Further, Matsuki [43, 44] indicated that the influences of oral appliances such as dentures would easily appear on the second mora. Therefore, the Japanese test words used in this study had at least four moras (/i/chi/ro/ has only three syllables, but /ro/ is a heavy syllable counting as two moras), and we chose the second mora as the objective. Additionally, the accent of each word was on the second mora. Although the speech evaluation system focused on the consonant parts of the test sounds, the evaluation was conducted based on macro-period information from the 79 ms around a phonetic segment label (8 ms) reflecting an analytical frame. Thus, for some consonants, this system could evaluate the effect of the connectors on the following vowel. As shown in figure 4, changes were observed in [ri], [ni], and [ki]. With regard to [ri] and [ni], influences on the following vowels were more easily brought to the forefront relative to voiceless sounds. In contrast, the vowel following [ki] could easily shift from [i] to [e]. It is suggested that [e] easily appeared because the position of the tongue was similar to that of [ki].

The results of this study demonstrate that there were significant differences among some recording conditions in the MARCs of the two test sounds [ni] and [ki]. The [ni] sound was mainly affected by the narrow connector with a plump edge. In our previous study, the [ni] sound was easily disturbed because of the shortened duration of the consonant part [31]. Hamlet and Stone [45] indicated that the contact pattern was not important in plosive and nasal sounds for adaptation towards the artificial plate, while the tongue overshooting the alveolar fricatives was so severe that a stop was produced. They used a full-coverage artificial plate. In this study, the duration, which was calculated by counting the number of 8-ms segment labels, was not actually shortened, but the segment labels changed to incorrect labels such as [mi], [gi], and [ri].

For the [ki] sound, the MARCs were mainly affected by wide connectors with both flat and plump edges. Palate shape was reported to be correlated with speech production using electropalatography [21–23]. Brunner et al. [21, 22] indicated that speakers with a flat palate reduced their articulatory variability in order to preserve acoustic output. The palatal connectors in this study modified the vocal tract in the palatal region from a dome-shaped palate to a flat palate, as a full-coverage artificial plate would reduce the volume of the oral cavity. Thus, the influences of modification of the vocal tract by connectors could not be ignored. Further studies are needed to clarify the influence of palate shape on adaptation to the major connector of a partial denture in light of speech production.

In our study, the influences of the connectors on each consonant were varied with the contour of the palate. From the viewpoint of oral sensation, Tanaka et al. [32] reported that a connector with a plump edge produced discomfort more easily than a connector with a flat edge. They evaluated the subjective difficulty of the pronunciation of the four sounds [ʃi], [ri], [çi], and [ki] using a questionnaire. However, in our study, there were no significant differences between the flat and plump edge types. Additionally, for the [ni] sound, the wide connector with a plump edge had the smallest effect, and narrow
connectors severely disturbed phonetic output. Hence, we consider that the influence of a major connector on speech production is mediated by a different mechanism than that of oral sensation, and further studies are needed to clarify the relationship between the perception of the subject and an objective evaluation of speech production through clinical trials.

There are several limitations to our study. First, the effect of gender could not be discussed because the number of subjects was too low. Additionally, all subjects with sound dentition were young, when this study ideally should have enrolled partially edentulous denture wearers from a wide age range. Brunner et al. [21] referred to a certain effect of gender on speech production. Further studies are needed to clarify the influence of age and gender on adaptation to prosthetic appliances in light of speech production. Second, long-term compensation was not considered in this study because the experimental conditions were adequate to evaluate the influences of connectors in the initial phase, which simulated the situation after the insertion of denture. In addition, long-term compensation was hardly investigated [46], and its evaluation remains a future task.

Conclusion

The results of this study suggest that the width and cross-sectional shape of the connector has limited effects on the articulation of consonants at the posterior areas of the palate.

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