Analysis of the Relationship between the Incisal Overjet in a Maxillary Denture and Phonetic Function Using a Speech Recognition System

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Clinical significance
The anterior teeth of maxillary dentures play an important role in pronunciation as well as appearance of the subjects. It has been suggested that assessment of the quality of pronunciation of the /S/ sound during the arrangement of the anterior teeth in maxillary wax dentures would be useful for facilitating speech adjustments with new dentures.

Abstract
Purpose: The purpose of this study was to investigate the relationship between the intelligibility of the /S/ sound and the incisal overjet of the anterior teeth of in a maxillary denture.

Methods: Five subjects who were fitted with maxillary dentures participated in this study. Using a speech recognition system for the evaluation of phonetic functions, the correct and incorrect ratios of the intelligibility of the sound of the monosyllable [Si] in five subjects were determined in relation to increases in the degree of incisal overjet of the anterior teeth in a maxillary denture by +0, +1, +2 and +4 mm relative to that of the dentures already in use.

Results: In association with increase in the degree of incisal overjet in experimental dentures from +0 to +4 mm, while the appearance ratio of the correct [Si] sound decreased from 73.0±8.6% at +0 mm to 48.5±7.8% at +4 mm, that of the incorrect [Si] sound increased from 17.4±4.7% at +0 mm to 36.0±10.6% at +4 mm.

Conclusion: Increasing distance between the incisal edges of the maxillary and mandibular incisors make correct pronunciation of [Si] progressively more difficult.

Key words: phonetic function, anterior teeth, overjet, speech recognition, phonetic segment labels

Introduction
Pronunciation of spoken words is an oral function indispensable for communication, and phonetic functions can be dramatically improved by prosthodontic treatment. On the other hand, if the prosthesis is inadequate in design, or if the retention and/or stability poor, articulation would be disturbed.1-7

The anterior teeth play an important role in the appearance of a subject and in his/her masticatory and phonetic functions. In routine clinical practice, the potential influence on the appearance of the subject is often given greater consideration than that of the oral functions mentioned above when determining the position of the anterior teeth in artificial dentures. However, the arrangement of the anterior teeth is closely linked with the pronunciation of spoken words, in particular, on the intelligibility of the /S/ sound produced by blowing expired air through the space between the anterior maxillary and mandibular teeth.

In the pronunciation of /S/, the sound is produced by pushing expired air through the space between the anterior maxillary and mandibular teeth.
teeth. Thus, the arrangement of the anterior teeth has such a marked effect on the pronunciation of the /S/ sound, called a sibilant consonant, that very precise clinical denture adjustments are required. In previous studies on the relationship between the arrangement of the anterior teeth and the phonetic functions, the influence of the incisal overjet on the phonetic functions has not been as well-documented as that of the occlusal vertical dimension and overlap.

Furthermore, conventional speech intelligibility tests require plural estimators or special equipment and environment, are time-consuming, and it is difficult to show the results of the assessments instantly. Hence, we developed a system for the evaluation of phonetic functions using a speech recognition system, which allows quantitative assessment of the intelligibility of spoken sounds at the dental chairside. Using this new system, we analyzed the relationship between the incisal overjet in a maxillary denture and the phonetic functions.

**Materials and methods**

1. **Subjects**

The subjects of this study consisted of five adult patients recruited among patients visiting the Faculty of Dentistry at the University Hospital, Tokyo Medical & Dental University, who had worn dentures without any complaints (two males and three females; 57-72 years old; average age, 65.6±5.5). Three of these patients (subjects A, B and C) wore complete maxillary dentures and the remaining two (subjects D and E) wore partial anterior maxillary dentures (Table 1). All of the edentulous patients enrolled for the study had relatively well-defined alveolar ridges and stable dentures.

In regard to the opposing dentition, patients with remaining anterior teeth were selected, because the pronunciation of [S] is strongly affected in the absence of the anterior teeth. The dentures for all of the selected patients had been prepared at our hospital more than a year previously, and none of the patients had reported any difficulties of speech. The experimental protocol was approved by the Ethics Committee of Tokyo Medical & Dental University (No.129).

**2. Fabrication of the experimental dentures**

The experimental dentures were fabricated by duplicating the original maxillary dentures using a self-curing resin (self-curing denture repair resin, Repairsin, GC Dental Products Co, Tokyo, Japan). The experimental dentures consisted of anterior teeth section (from the left canine to the right canine) with varying degrees of incisal overjet and the denture base (Fig. 1). The anterior teeth section with the same incisal overjet as that in the patients’ original denture was designated as +0 mm. Experimental dentures were constructed with the degree of incisal overjet increased by 1 mm, 2 mm and 4 mm (defined as +1 mm, +2 mm and +4 mm, respectively). All anterior teeth sections were fabricated by duplicating the original maxillary dentures using self-curing resin. Three female rubber attachments (Female Rubber, OP Anchor Attachment, Inoue Attachment Co, Tokyo, Japan) were fixed to the anterior teeth section of each of the experimental dentures (+0, +1, +2 and +4mm), and three male attachments (Male Pattern, Inoue Attachment Co,

<table>
<thead>
<tr>
<th>subject</th>
<th>gender</th>
<th>age</th>
<th>maxilla</th>
<th>mandible</th>
<th>occlusion</th>
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<tbody>
<tr>
<td>A</td>
<td>female</td>
<td>67</td>
<td>resin complete denture (CD)</td>
<td>7−5 4−7 bilateral resin removable partial denture (RPD) (with lingual bar)</td>
<td>edge-to-edge bite</td>
</tr>
<tr>
<td>B</td>
<td>female</td>
<td>67</td>
<td>resin CD</td>
<td>5−7 left resin RPD</td>
<td>normal</td>
</tr>
<tr>
<td>C</td>
<td>male</td>
<td>72</td>
<td>resin CD</td>
<td>7−6 6−7 bilateral resin RPD (with lingual resin-up)</td>
<td>edge-to-edge bite</td>
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<td>D</td>
<td>male</td>
<td>65</td>
<td>34 4 resin RPD</td>
<td>647 remaining</td>
<td>deep overbite</td>
</tr>
<tr>
<td>E</td>
<td>female</td>
<td>57</td>
<td>44 resin RPD</td>
<td>7−4 4−7 bilateral resin RPD (with lingual resin-up)</td>
<td>normal</td>
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Tokyo, Japan) were fixed to the denture base, so as to enable the anterior teeth sections to be easily changed. Thus, only the overjet of the experimental dentures was changed while the overbite and incisal inclination remained constant. In cases with a plus(+) value of the overjet, the space between the anterior teeth section and the denture base was filled with resin, and the boundary was smoothly shaped.

3. Recording of speech sample
The test sound was determined as the syllable [Si]. This sound includes the sound /S/, which is susceptible to changes in the anterior overjet, and the vowel [i], which requires a high tongue position. In the system used by us for evaluating the phonetic functions, recognition of the first syllable was variable. In order to avoid the variation, [iShimatsu] was selected as the test word, with the second syllable as the object of recognition, which allowed easy separation of [Si] from the preceding and following syllables during the analysis.

Each subject was instructed to pronounce the test word [iShimatsu] once with respective overjet. The test word pronunciation was measured by 5 times with respective overjet. During the measurements, the subjects were instructed to keep the speed and volume of their pronunciation constant. The measurements with each experimental denture were made in random order, and all the measurements were obtained on the same day. Each sound was recorded with a head-set type microphone and a laptop computer (PA-C9214LDEW, TOSHIBA Corporation, Tokyo, Japan), and analyzed in real-time using a speech recognition program.

4. Evaluation of speech intelligibility
The flow of the basic processes in the phonetic function evaluation system (TOSHIBA Corporation, Corporate Research & Development Center, Tokyo, Japan) was as follows. Recordings of each test sound were entered into the system, and the phonetic signals were subjected to acoustic analysis. The acoustic time-frequency pattern was accentuated in local changes in the frequency and time directions, and the pattern of multiple acoustic-feature planes (MAFP) was extracted. In a comparatively long segment of 48 ms, corresponding to six frames of the MAFP pattern, the phonetic segment pattern was matched to the standard phonetic segment pattern. The results were labeled and displayed as information for every 8 ms.

Figure 2 illustrates the image of the acoustic analysis pattern and the label extraction of the phonetic segments during the phonation of [iShimatsu]. From the power spectrum of the [Si] sound, a characteristic pattern with accentuated local changes was extracted. This pattern was matched against the standard pattern of each phonetic segment, and the pattern showing the greatest similarity was selected from among 213 different patterns. The pattern was then converted to a phonetic segment labeled “$$”.

The method of extraction of the consonant in [Si] from the phonetic segment [iShimatsu] is shown in Figure 3. First of all, we selected the sections enclosed between the labels indicating the glide from [i] to [Si] and from [Si] to [ma]. Then the vowel component of [Si] was removed. The remaining section was defined as the consonant of [Si] and its features were extracted.

The labels “$$”, “SS” and “SI” were defined as the correct labels for the sound [Si]. On the other hand, the labels “CC” and “CI” were defined as being incorrect, corresponding to the affricate [Chi], while “##” and “HI” corresponded to the breathy sound [HI] (Table 2).

Out of the segments corresponding to the consonant part of [Si] extracted from the phonetic segment [iShimatsu], the ratio of “$$”, “SS” and “SI” was regarded as the appearance ratio of the correct labels, and that of “CC”, “CI”, “##” and “HI” was regarded as the appearance ratio of incorrect labels. The mean value of the appearance ratio based on five measurements was considered for the analysis.

We used a statistical analysis software (SPSS 11.5J for Windows, SPSS) to analyze the data. Comparisons of the appearance ratios of correct and incorrect labels among the experimental
dentures with different incisal overjets were made by one-way analysis of variance and multiple comparisons (Tukey’s HSD test). The significance level was set at 5%.

Results

1. Distribution of the correct labels for different degrees of incisal overjet

The mean appearance ratios of the correct labels of [Si] in the word [iShimatsu] in the five subjects were 73.0±8.6%, 68.2±7.1%, 56.7±12.6% and 48.5±7.8% for overjet values of 0 mm, +1 mm, +2 mm and +4 mm, respectively (Fig. 4). Thus, the appearance ratio of the correct labels decreased with increasing degree of overjet. The results of the statistical analysis revealed significant differences in the appearance ratios between overjet values of +0 and +4 mm (P<0.05).

The mean appearance ratios in the five subjects of [Chi] and [Hi] are shown in Table 3. The results revealed no significant difference in the appearance ratios between overjet values of +0 and +4 mm ([Chi]: P=0.60, [Hi]: P=0.42). In addition, other labels, including “Ji” and “Ki” appeared at frequency ratios of 1~6%.

2. Distribution of incorrect labels for different degrees of incisal overjet

The mean appearance ratios of the incorrect labels of [Si] in the word [iShimatsu] in the five subjects were 17.4±4.7%, 24.2±4.6%, 25.7±10.7% and 36.0±10.6% for overjet values of 0 mm, +1 mm, +2 mm and +4 mm, respectively (Fig. 5). Thus, the appearance ratio of the incorrect labels increased with increasing degree of overjet. The results of statistical analysis revealed a significant difference in the appearance ratio between overjet values of +0 and +4 mm (P<0.05).

The mean appearance ratios in the five subjects of [Chi] and [Hi] are shown in Table 3. The results revealed no significant difference in the appearance ratios between overjet values of +0 and +4 mm ([Chi]: P=0.60, [Hi]: P=0.42). In addition, other labels, including “Ji” and “Ki” appeared at frequency ratios of 1~6%.

Discussion

When the five subjects were wearing their original dentures, the mean appearance ratio of the correct labels of [Si] in the word [iShimatsu] was 75.0±7.8%, while the mean appearance ratio of incorrect labels was 17.6±6.0%. The results of Wilcoxon’s signed rank test revealed no significant differences in appearance ratio of either the correct or incorrect labels between the original denture and the +0 mm experimental denture. Based on this result, we inferred that there was no difference in the degree of intelligibility of the [Si] sound between the +0 mm experimental denture and the original denture, thus confirming the accuracy of the speech data.

Regarding the test sound, previous studies
have shown how the /S/ sound is affected by changes in the position of the anterior teeth. Fu-ruya reported that a large overjet caused pronunciation disorders. Tomomatsu reported that in a totally edentulous patient, phonetic dysfunction occurred when dentures were constructed with an increased degree of overjet rather than with normal occlusion. On the other hand, Pound and Murrell et al used the accuracy of pronunciation of /S/ as the method to determine the vertical dimension and the overjet of the anterior teeth, but did not investigate to what extent changes in the overjet affected the pronunciation of /S/. Moreover, the denture base exerts an extremely powerful effect on the pronunciation of spoken sounds followed by a vowel produced within a particularly narrow region of articulation.

As for the measurement methods, a pilot experiment on a healthy dentate subject showed that the mean appearance ratios of correct labels based on measurements repeated 3, 5 and 10 times during vocalization of the word [iShimatsu] were 81.5±20.2% (CV: 0.251), 78.9±14.9% (CV: 0.189) and 78.1±14.7% (CV: 0.188), respectively. Since the speech recognition system was occasionally unstable at the first measurement, we determined that five measurements might be adequate.

In addition, it is generally believed that patients take 1~3 days to adapt their pronunciation to newly fitted dentures. However, since the present study required the use of the same denture base for the four experimental dentures with different degrees of overjet, all the measurements were performed on the same day.

Phonetic function has been investigated in a number of studies using both subjective and objective approaches. These approaches could be roughly divided into tests of auditory perception, such as questionnaire tests of conscious speech and speech intelligibility test, and recording of mandibular or tongue movements during articulation using the palatogram and movement measuring instruments, and others. For example, the objectivity of the speech intelligibility test was ensured by using multiple listeners or more carefully selecting the listeners. However, because of the confounding by auditory psychological factors, these measures were not sufficiently reliable for objective assessments. Such confounding by auditory psychological factors can be eliminated by using a speech recognition system with personal computers.

Our system is equipped with a speaker-independent speech recognition system and does not
require speaker adaptation. It can also yield information about phonemes as labels every 8 ms. With this labeling system, the listeners can obtain information simultaneously about whether or not the speech is of an adequate time-length. Furthermore, quantitative assessments of phonemes is possible on the basis of the appearance ratios of correct and incorrect labels within the range of the assessment objective.

With increasing degree of overjet from the +0 mm to +4 mm in the experimental dentures, the appearance ratio of the correct labels of [Si] decreased, whereas that of the incorrect labels increased. Hence, with an increase in the distance between the incisal edges of the maxillary and mandibular incisors, correct pronunciation of [Si] became difficult, and it tended to be erroneously recognized as the breathy voice [Hi] or plosive [Chi].

While pronouncing the /S/ sound, we generally move the mandible forward, create a space of about 1 mm between the incisal edges of the maxillary and mandibular incisors, touch the inside of the dentition with the tongue, produce a space by depressing only the midline of the dorsum of the tongue, and exhale air with a strong expiratory force. With alteration of the degree of overjet, it was inferred that changes would occur in the forward movement of the mandible, the touching of the inside of the teeth with the tongue, and the pattern of expiratory air flow. The larger the degree of overjet, the more difficult the response to changes would become, resulting in a decrease in the appearance ratio of correct labels and an increase in the appearance ratio of incorrect labels.

Runte undertook a frequency analysis using an experimental denture with the maxillary central incisor inclined 30° toward the labial aspect, and reported a slight disorder in the pronunciation of /S/. Ritchie performed a sonographic analysis using an experimental denture with the maxillary central incisor shifted labially, and reported that a shift of 4 mm exerted greater influence on the production of the /S/ sound than a shift of 2 mm. In both of these studies, differences were found in some parameters of the frequency analysis, such as the noise band range, power spectrum and high frequency energy. The same tendency was observed in our study with changing incisal overjet, and the results were quantified based on the appearance ratios of the correct and incorrect labels.

Tanaka used a monosyllable speech intelligibility test to investigate different degrees of overjet created by placing bilateral experimental pontics on the maxillary central incisors, and reported no changes in pronunciation that caused miscomprehension of other sounds. Furuya used a monosyllable speech intelligibility test immediately after inserting experimental bridges with 3.3 and 4.4 mm increases in the overjet, and reported noticing a slight distortion in the phonation of /S/ and /∫/. When the results of the speech intelligibility test using human auditory perception were compared with the results of the present study, distinct differences were noted, since the intelligibility could be expressed by the appearance ratio of the correct and incorrect labels in the speech recognition system.

It was suggested that assessment of the quality of pronunciation of the [Si] sound during the arrangement of the anterior teeth in maxillary wax dentures would be useful, as this procedure would be expected to decrease the number of adjustments for speech required at the time of delivery of the dentures.

Further investigations in this area of this subject should involve detailed analysis of other morphological factors in the prosthesis affecting speech function, including the influences of changes in the ledge of the S curve on the palatal surface of the maxillary denture.

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