The Repeated Pronunciation of Plosives by a Cleft Palate Patient and Normal Controls: A Clinical Study to Design the Proper Prosthesis

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Abstract: This study was undertaken to establish a method for evaluating speech disorders by determining the constancy of articulatory activity during the repeated pronunciation of plosives. Tested and compared were the speech patterns of 10 normal controls and one cleft palate patient tested at different stages, i.e., before prosthetic treatment (stage A), while wearing a temporary overdenture (stage B), at insertion of the final prosthesis (stage C), and at six months after insertion of the final prosthesis (stage D).

All tested subjects were instructed to repeatedly pronounce /pa/, /ta/, /ka/ and /pataka/ as rapidly as possible until running out of breath. These vocal patterns then were analyzed by a sound spectrograph (DSP Sona-Graph, Model 5500, Kay Co. USA) and studied on an expanded time-wave CRT display to measure three items: the characteristics of the spectrographic pattern, the number of the repetitions, and the duration of the sound. The duration of the consonants and vowels were measured, as well as the intervals between each syllable. Further, each consonant was divided into two parts: the duration of the plosive spike, and the damping of this spike to the beginning of the next sound.

Results revealed that the sound patterns of the cleft palate subject during stage A varied greatly from those of the normal subjects, but that these differences gradually diminished during stages B and C and became remarkably similar at stage D, almost resembling the patterns of the normal controls.

While the number of repetitions that the cleft palate patient was capable of was limited during stage A, the ability to repeat plosives increased as the prosthetic treatment progressed. Similarly, the duration of the consonant and the plosive spike of the /k/ of the patient at stage A was much longer than that of the controls, but this difference also decreased.

Based on the results of this study, it was concluded that to improve the speaking capability of cleft palate patients, the designed dental prosthesis must not only achieve naso-pharyngeal or naso-oral closure but also must include a compatible occlusal vertical dimension and a proper maxillary dental arch.

Key words: speech disorder, cleft palate, plosives, repeated pronunciation, time factors

The aims of prosthetic treatment for a maxillary defect are to improve the speaking and masticatory capabilities of the patient, as well as to improve the patient’s aesthetic appearance, and to insert a prosthesis constructed only to improve the appearance may adversely affect the patient’s ability to speak and be understood. To enable such patients to speak effectively, a proper oral and/or pharyngeal prosthesis is essential, especially cases manifesting an abnormal intraoral condition, such as a malocclusion, a cleft lip and/or palate, or some other physical defect causing the nasopharyngeal and/or naso-oral incompetence\(^1\).
The ultimate goal is that the prosthesis helps the patient to produce all sounds not only accurately when each syllable is separately pronounced but also when these sounds are combined. Therefore, to evaluate the effectiveness of the prosthesis, a detailed analysis of the patient's speaking capability while using the prosthesis is essential. To achieve the best possible prosthetic design, keeping a numerical record of the patient's speech disturbance rate while wearing different prostheses is also important, so as to compare the longitudinal differences when speaking.

In this regard, it is especially difficult to assess the intelligibility of plosive sounds due to their short duration. Although it is possible to assess the acoustical accuracy of each phoneme by sound spectrographic analysis, delicate disturbances that may affect the production of plosives are difficult to detect by this method. Therefore, using another approach, the durational characteristics of these plosives were studied, so as to determine the type of prosthesis to be provided. To accomplish this, the duration of the components of each syllable and the duration between the word segments were assessed, since the constancy of these durations is thought to indicate the patient's ability to coordinate articulatory movements.

As this temporal aspect of plosive production has not been investigated, this study was undertaken to evaluate speech disorders in a cleft palate patient by determining the articulatory activity during the repeated pronunciation of plosives at different stages during the patient's prosthodontic treatment.

Materials and Methods

1. The subjects and the prosthetic procedures

Tested and compared were 10 normal subjects and one cleft palate patient during different stages of the patient's prosthodontic treatment. The norma
subjects, consisting of 8 males and 2 females ranging from 22 to 32 years old (mean age: 27 years), were naturally dentulous and spoke standard Japanese. The cleft palate patient, a 29-year-old female with a residual fistula on the right side of the hard palate (Fig. 1a and b), had been given no speech therapy and had not yet undergone surgery to close the residual fistula. The existing prosthesis obturated the residual fistula (Fig. 1c and d), and the patient’s facial appearance was remarkably collapsed when the mouth was closed in centric occlusion with this prosthesis in position. The patient’s maxillary and mandibular teeth were widely separated when the mandible was at physiologic rest position.

A temporary overdenture was fabricated to determine the proper occlusal vertical dimension and site for the artificial maxillary dental arch (Fig. 2). Since the occlusal vertical dimension had to be increased and the discrepancy between the position of the residual teeth and the intended artificial dental arch had to be adjusted, the design selected for the final prosthodontic obturator was a complete overdenture supported by telescope retainers (Figs. 3 and 4).

The cleft palate subject underwent 4 recording sessions during the stages of therapy that follow: stage A, without an existing denture or obturator prior to treatment; stage B, while wearing a temporary overdenture; stage C, at insertion of the final prosthesis; and stage D, at six months after insertion of the final prosthesis.

2. The speech samples
Three consonant-vowel syllables were created by varying the plosive consonant /p/, /t/, and /k/ with the vowel /a/.

The speech tests consisted of each patient repeating the same plosive consonant (SC), i.e., a continuous repetition of the sound /papa/; and
a combinations of different plosive consonants (DC), i.e., /pataka/.

The subjects were instructed to repeat the syllables as rapidly as possible until running out of breath. Each of the speech samples was recorded in a soundproof chamber (AT-30, Rion Co. Ltd., Tokyo, Japan) through a dynamic microphone (F-500, Sony Co., Tokyo, Japan) connected to a tape recorder (TC-D5M, Sony Co., Tokyo, Japan). The microphone was positioned about 15 cm from the mouth of each subject.

3. The sound spectrographic analysis

The speech tests of each subject were analyzed with a sound spectrograph or sonagraph (DSP Sona-Graph, model 5500, Kay Elemetric Co., Pine Brook, USA) (DSP-SG) and studied on an expanded time-wave CRT display. Further, a continuous three-dimensional spectrogram (3D-sonagram, SG) and a time-wave drawing were recorded by a Gray scale printer (Model 5511, Kay Elemetric Co., Pine Brook, USA) to investigate the repetition times and the time factors that included the duration of the components of the consonants, vowels, and the interval between each syllable.

Based on a procedure of Ohtani (1967), the spectrograms (SGs) of each subject were analyzed for the clarity of the oral silent period prior to the plosive, the spike fill, and the transitional part of the formant to the succeeding vowel. Aberrations were graded on a numeric scale, with a three representing the least aberrant pattern, and a zero the most aberrant pattern. The resulting value, which was converted into a percentage, was termed “the rate of resemblance to a normal SG pattern.”

4. The durational analysis

The start and end time of each consonant and vowel sound were determined according to the method of Kitamura (1970). For analytical purposes, criteria were developed for designating the beginning and termination of each phoneme by considering the first vertical striation occurring after the end of the final vowel of the each syllable as being the beginning of the following plosive phoneme. The phoneme was considered terminated on the initiation of the formant structure for the start of the subsequent vowel sound.

The following segment durations of each time factor were measured: the duration of each consonant (CT) and vowel (V), as well as the interval between each syllable (I). The CT is the interval between release of the stop gap and the onset of the vibration of the vocal cords. This is the equivalent to the voice onset time. Further, each CT was divided into two parts: the duration of the plosive spike (consonant, part 1: C1), and the damping of this spike to the beginning of the next sound (consonant, part 2: C2). A spike is defined as the duration needed for air to produce a plosive. Examples of spectrograms with segmentation of these measurements are shown in Fig. 5.

Each subject’s screen data was stored and subsequently analyzed on a personal computer (Model 910, Acer Co., Taipei, Taiwan). The mean duration, standard deviation, and coefficients of variation (C.V.) were calculated, and the t-test was used to evaluate the time factor duration of each syllable to determine its significance.

Results

1. The sound spectrographic evaluation

The acoustical characteristics of the plosives /p, t, k/ in the cleft palate subject were investigated and compared with these same plosives produced by the normal controls.

Figure 6 shows examples of the subject’s spectrograms (the narrow band spectrogram: bandwidth 59 Hz) showing the /pataka/ results produced. Based on these spectrograms, it was found that the oral silent period, being the cessation of vocalization or fricative noise prior to the release of intraoral pressure associated with voiceless stop sounds, was clearer at stage D than at the previous stages. As can be noted, the stage D spectrograms are almost normal, with a sharp, heavy, vertical striation (spike) that initiates the plosive phoneme /p, t, k/.

Table 1 and Fig. 7 show that the rate of resemblance in the cleft palate patient to a normal SG pattern during stage A varied greatly, but that these differences gradually grew less during stages B and C, and became remarkably similar at stage D, almost resembling the normal SG pattern.

2. The number of repetitions

As Fig. 8 and Table 1 indicate, while the number of repetitions that the cleft palate patient was capable of was limited in comparison to the normal controls during stage A, an improvement was seen in the patient’s ability to repeat plosive phonemes as the prosthetic treatment progressed, and at stage D, the ability to repeat plosives almost equaled that of the controls.
Fig. 5  Examples of expanded spectrograms and time waves with segmentation for measurement of the sound /pa/. Time axis—(a) 3.12 ms/10 mm; (b) 12.5 ms/10 mm. V: vowel, I: interval, CT: total consonant duration, C1: consonant, part 1; C2: consonant, part 2.
Fig. 6 Spectrograms (narrow band) and time waves for the repeated sound of /pataka/ produced by the patient. Upper (a) During stage A; Lower (b) During stage D.
3. The durational measurements

Figures 9 and 10 and Tables 2 through 4 show the average duration and standard deviations in milliseconds (msec) of the time factors for the normal controls and the cleft palate patient. As these figures and tables indicate, in the normal controls the mean of one cycle for /pa/, /ta/ and /ka/ for the SCs was almost the same (from 211 to 223 msec), whereas for the DCs, they were generally shorter, especially the V and I. This also was true for the cleft palate subject. Figure 10 shows the SC and DC durations for /p/, /t/ and /k/. In the DCs of the cleft palate patient, the CT and the C1 of the plosive /k/ at stage A was much longer than that of the controls, but this difference decreased as the prosthetic treatment progressed.

Figure 11 indicates the coefficients of variation (C.V.s) for the C1, C2, V, and I of /pa/, /ta/ and /ka/ in the SC and DC results. In general, the C.V.s of the V and I of the patient showed little variation, whereas the C.V.s of the C1 and C2 of the plosive /p/ at stage A were remarkably high, but as the treatment progressed they decreased to levels that approximated that of the controls. Similarly, the C2 C.V.s of the plosive /t/ at stages A, B, and C were also higher than that of the controls, but at stage D they decreased. In contrast, the C.V.s of the plosive /k/ showed no noticeable change throughout the testings.

The DC C.V.s showed a more radical change
in contrast to the SC C.V.s especially with respect to the Cl and C2 data at every stage. The I C.V.s of /pa/ at stage A were remarkably high, but they decreased to a level approximating that of the controls at stages B, C, and D. Thus, in the cleft palate patient, the range of the C.V.s was generally greater for the DCs than for the SCs.

Discussion

A lack of lateral and vertical growth of the maxilla and overclosure of the vertical dimension are frequently seen defects in the cleft palate patient\(^1\). and to restore only the dental defects to improve the facial appearance is not enough; in many cases, increasing the occlusal vertical dimension (OVD) and expanding the maxillary dental arch are also needed. However, if there should be no supporting maxillary bone, an ideal alignment of the natural teeth can not always be accomplished only by surgical or orthodontic treatment and artificial teeth may be required.

As for the restoration of oral functions in cleft palate patients, it is generally agreed that adaptation to change in the intraoral condition is often difficult, especially congenital malformations, and speech disturbances may later develop in spite of radical prosthodontic treatment.

With regard to the repair of the OVD, Yamagata et al.\(^8\) have reported on a method to physiologically predict a compatible OVD by observing the mandibular movement during speech. Further, Ohtani et al.\(^9\) have described a prosthono-
dontic procedure that not only improves the occlusion for speech but also the aesthetics of a cleft palate patient. By observing the mandibular positions during the pronunciation of /s/, /f/, /m/, they found that the mandibular position instantaneously changes with the OVD and in this way they were able to determine a suitable OVD range.

To calculate the degree of misarticulation in cleft palate patients undergoing prosthodontic therapy, Hata et al. have reported on the use of static palatography to identify the contact patterns of tongue-to-palate and tongue-to-teeth movements during the production of sounds. Their subsequent analysis of these palatograms by an image processor revealed that patterns indicating an abnormality were very apparent prior to prosthodontic treatment, and that these patterns almost instantaneously approximated normal patterns when the patients were able to use the final dental prostheses.

Thus, from the viewpoint of articulatory movement, both the OVD and the dental arch configuration are important to speech, and when cleft palate patients are given prosthodontic treatment that alters their oral environment, they can achieve a greater speaking clarity than is generally thought possible.

The most critical problem that affects the speaking capability of cleft palate patients is nasopharyngeal or naso-oral incompetence, and in this regard, Ohtani et al. have investigated the acoustical characteristics of plosive and flapped sounds by two methods: a speech intelligibility test, and a sound spectrographic analysis. Based on the duration of the plosive consonant, they reported that it is possible to assess changes in articulatory movements and the patient’s adapta-
1. The speech samples

With regard to evaluating speech defects through the quality of the sound, there have been many frequency domain studies using sound spectroscopy\(^6\),\(^11\),\(^12\), but time domain studies have been few\(^3\),\(^13\)–\(^15\). As for the merits of this time domain approach used for this study, the analysis of plosive sounds enabled a more precise evaluation of the patient’s speech disorders.

Persons who have delicate speech disorders can usually pronounce plosives at a slow tempo, but the rapid pronunciation of plosives can cause a breakdown in the temporal coordination of articulatory movement, thereby revealing a potential speech disturbance. That is why the tested subjects were asked to repeat the speech samples as rapidly as possible.

As our results have indicated, the DC C.V.s of the cleft palate subject showed far greater

### Table 2

Mean time duration for each time factor of /pa/. SC: Repetition of /papa . . . /, DC: /pa/ in combination with /pataka . . . /, N: Average of 10 normal subjects. Cleft palate subject, A: Before prosthetic treatment, B: While wearing a temporary overdenture, C: At insertion of the final prosthesis, D: Six months after insertion of the final prosthesis.

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### Table 3

Mean time duration for each time factor for /ta/. SC: Repetition of /tata . . . /, DC: /ta/in combination with /pataka . . . /.

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### DC

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Unit: ms
Table 4  Mean time duration for each time factor for /ka/. SC: Repetition of /kaka . . ./, DC: /ka/ in combination with /pataka . . ./.

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Unit: ms

Fig. 11  Coefficient of variation (C.V.) for each time factor. Upper row, repetition of the same consonant (SC) and lower row, a combination of different plosive consonants (DC).
variances, especially the C1 and C2 C.V.s during every stage of the testing (Fig. 11). For this patient, repetition of the same consonant was found to be easier than repeating a combination of different consonants.

2. The qualitative and quantitative spectrographic analysis

One sound classification used by many authors is the term "spike," which describes the explosion of air needed to produce a plosive phoneme. The spike is always preceded by a voiceless gap that indicates a buildup of intra-oral air pressure, and this stop gap before plosive and affricative consonants is the most deviant individual acoustic segment\(^3,16,17\). It thus is reasonable to assume that an increased plosive phoneme duration and a decrease in the number of repetitions indicates the tested subject’s inability to produce and/or maintain this intra-oral air pressure.

In the voiceless plosive phonemes analyzed in this study, some alterations and/or additions to the spike occurred, thereby increasing the C1 duration even in the pronunciation patterns of the controls. In the cleft palate patient, this distortion took the form of either extra vertical striations preceding the spike or a drawn-out aspiration following the spike. As shown in Fig. 6a, this extra energy represents an impaired air pressure buildup that was apparently caused by a frictional emission of the airstream through the nasal passages. However at stage D, fewer horizontal striations were seen preceding the spike and drawn-out aspirations following the spike decreased (Fig. 6b).

In this cleft palate patient, a dramatic increase in the rate of resemblance to a normal SG pattern was seen when the final prosthesis was worn at stage D (Fig. 7). The number of repetitions that the cleft palate patient was able to produce at stage A were fewer than that of the normal controls (Fig. 8). However, this number increased at stage D, at which point the number of repetitions the patient was capable of equaled and sometimes even exceeded that of the controls, indicating that the patient was capable of uttering plosive sounds smoothly while wearing the final prosthesis. Thus, effective closure of the fistula by the prosthesis provided the capability of producing plosives.

3. The durational analysis

The duration of Japanese plosives has been previously studied\(^6,11,12\), and in many of these studies, the plosives were usually divided into two components: the spike or burst, and the aspiration that follows the spike. However, the methods used to distinguish the spike from the subsequent aspiration have varied and have not been clearly defined.

Kitamura\(^7\) has proposed measurement criteria that use the durational components of Japanese plosives, based on a detailed analysis of the time-wave display expanded about 100 times over that of the usual spectrogram. He divided the plosive consonant’s total duration (DT) into duration part I (DI) and duration part II (DII), and found that the DI component was significantly longer in the following order: /p/< /t/< /k/, so that these phonemes could be differentiated based on this factor. Kitamura’s findings coincide with our findings with regard to this time factor in normal controls.

Therefore, based on Kitamura’s method\(^7\), measurements of Japanese plosives followed by the vowel /a/ were made of C1, C2, and CT components, corresponding to the DI, DII, and DT of Kitamura’s method, and the V, and I components (Fig. 5). In uttering of a plosive, the I component includes the stop gap is especially important, since the spike and its preceding voiceless gap, or oral silent period, represents the buildup and release of the intraoral air pressure. An adequate buildup of the intraoral air pressure is a prerequisite for the production of a plosive, so that subjects who lose this intraoral pressure because of nasal air escape require more time to impound sufficient pressure for the release of the plosive.

Although an acoustical analysis does not define the underlying physiologic movements, the prolonged duration that was seen in the pronunciation of /k/ at stage A (Fig. 10) suggests that the patient had a delay of some velar movements. The trajectory of movement also may be disturbed\(^13\). However, a significant difference occurs between the durational measurements of the plosive phonemes /p/, /t/, and /k/ when the sound is produced with a proper prosthesis in place and when the sound is produced with a prosthesis that lacks an adequate nasopharyngeal or naso-oral closure.
Conclusion

To improve the speaking ability of cleft palate patients, it has been concluded that the designed dental prosthesis must not only achieve nasopharyngeal or naso-oral closure but also a compatible occlusal vertical dimension and a proper maxillary dental arch.

This study also found that the cleft palate patient's ability to pronounce plosives improved as the prosthodontic treatment progressed, thereby indicating that the methods used for this cleft palate patient are clinically useful for assessing speech disorders in others with congenital or acquired maxillary defects who require a properly designed dental prosthesis that will not only remedy their maxillary condition but also assist them in speaking more clearly.

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