Glottal Stop in Cleft Palate Speech (2nd report)
—dynamic alterations of laryngeal movement during production of voiceless stop CV syllables—

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INTRODUCTION

During production of normal voiceless stop CV syllables, a plosive noise is produced at each place of articulation with vocal folds abducted and then the intermembranous parts of glottic opening are adducted to produce the following vowel[1]. In contrast, during production of glottal stops, the vocal folds are firmly adducted prior to the release of plosive noise (pre-vocalic adduction), which is apparently different from the normal laryngeal movement mentioned above.

We reported that fiberscopic observation of the larynx revealed two types of laryngeal movement during glottal stop production[2]. In Type I glottal stops, the vocal folds were adducted prior to voice onset and plosive noise, which was similar to vowel production with the hard vocal attack, was produced without abduction of vocal folds. On the other hand, in Type II glottal stops, pre-vocalic adduction was followed by abduction of vocal folds which corresponded to plosive noise production and the vocal folds were adducted again to produce the following vowels, showing adduct-abduct-adduct pattern. Observing articulatory movement during production of /k/ sounds in both Types, we found that the tongue did not articulate with the palate in Type I but made contact with it in Type II. Type I corresponded to typical glottal stops which were produced at vocal folds, while, in Tpye II, plosive sounds were considered to be produced at either normal place of articulation or vocal folds, which enabled us auditory discrimination among /p/, /t/ and /k/ in most of the cases.

Furthermore, we observed the process by which glottal stop production was corrected and suggested that Type I glottal stops modified to normal production via Type II glottal stops[3]. However, it has not been clarified how pre-vocalic adduction,

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typical of glottal stops, disappears along with the transition from Type II to normal production. The present study deals with objective detailed analysis of laryngeal movement, such as measurement of abducting angle of vocal folds, to discuss with the improving process of glottal stops.

SUBJECTS

The subjects were seven cleft palate patients whose laryngeal movement during the production of voiceless stops showed adduct-abduct-adduct pattern. They were devided into two groups by the auditory impression at the time of fiberscopic assessment. Group A consisted of 4 patients whose voiceless stops in single syllables were auditorilly judged to be glottal stops. The distribution of glottal stops was as follows; Patient 1 substituted glottal stops for /p,t and k/, Patient 2 for /t and k/ (no record was found for /p/), Patient 3 for /t and k/ (/p/ was almost normal) and Patient 4 for /t/ (/p and k/ were almost normal). Group B consisted of 3 patients whose voiceless stops were auditorilly judged as normal during production of single syllables or words but occasional glottal stops were perceived during running speech. Looking at speech therapeudic situation, Patient 1 was in a state of pre-therapy, Patient 2,3 and 4 were under training of single syllables or words. In Group B, the therapy of Patient 5 was nearly completed and that of Patient 6 and 7 was already completed.

Regarding velopharyngeal function, four patients in Group A were judged to be insufficient or slightly insufficient, while Patient 5 in Group B was insufficient and secondary operation was planned. Patient 6 and 7 had gained sufficient velopharyngeal function after pharyngeal flap operation (Table 1).

Longitudinal study of laryngeal movement was also done on Patient 3 in Group A, before, during and after speech therapy.

Table 1.Subject characters

	patient	cleft type	age	V-P function	therapeutic situation at laryngo-fiberscopic observation
Group A (glottal stop perceived cases)	1	CP	36	incompetence	pre-therapy
	2	CL/P	20	incompetence	CV syllable
	3	CP	29	slight incompetence (post pharyngeal flap ope.	CV syllable,words
	4	CL/P	10	incompetence	CV syllable,words
Group B (normal stop perceived cases)	5	CL/P	26	incompetence	nearly completed
	6	CL/P	35	competence (post pharyngeal flap ope.)	completed
	7	CL/P	38	competence (post pharyngeal flap ope.)	completed

CP :cleft palate
CL/P:cleft lip and palate

Method

1. Laryngo-fiberscopic Assessment

The speech samples of voiceless stop syllables /p, t and k/ were chosen from the video recordings of laryngo-fiberscopy. Fiberscopic observation was done as follows. After inducing superficial anesthesia of nasal mucosa with 4% Xylocaine, a fiberscope was inserted into the nasal cavity until we obtained a good view of the larynx. The types of fiberscope we used were an end-view type OLYMPUS ENF type P (3.4 mm in diameter). The fiberscopic image was recorded on a U-matic videocassette recorder SONY VO-2960 (30 frames or 60 fields per second) through a video camera TOSHIBA BV2, simultaneously with sound.

2. Analysis of VTR

The vocal fold images, recorded at 60 fields, were printed successively from several fields ahead of the beginning of adductor movement to the field of initial adjustment of the membranous part of the vocal folds following a time code indicater. The tips of both sides of the vocal processes and anterior commissure were marked, then scanned and transported to a personal computer. An imaginary line connecting the vocal process and anterior commissure was drawn on the screen of the computer, which was done on both side of the vocal folds. Then, an angle made by the two lines was measured in degrees.

Simultaneous recordings of speech sounds were superimposed on the videotapes as a sound wave using a videograph HOUEI VG-40 to identify the onset of plosive noise and following vowel.

Degree of laryngeal constriction was depicted graphically in relation of time and the following items were measured (Fig. 1) :1) adducting duration prior to voice onset (pre-vocalic adduction time), 2) the maximum abducting angle after pre-vocalic adduction (miximum angle), 3) the onset of plosive noise production, 4) the onset of the following vowel production and 5) longitudinal study of the preceding items on Patient 3.

Result

Figures 2, 3 and 4 show characteristic trials of each sound on representative case in each group and the longitudinal change on Patient 3. For convenience, we named the period from pre-vocalic adduction to maximum abduction "abducting period", the period of maximum abduction "maximum abduction period" and the period from maximum abduction to adduction of vocal processes "adducting period".

1. Pre-vocalic adduction time and a state of closed vocal folds

Concerning pre-vocalic adduction time, there was not the significant difference between auditorilly perceived glottal stop cases (Group A) and auditorilly normal cases (Group B) (Table 2). However, incomplete closure was observed in Group B (Fig. 3).

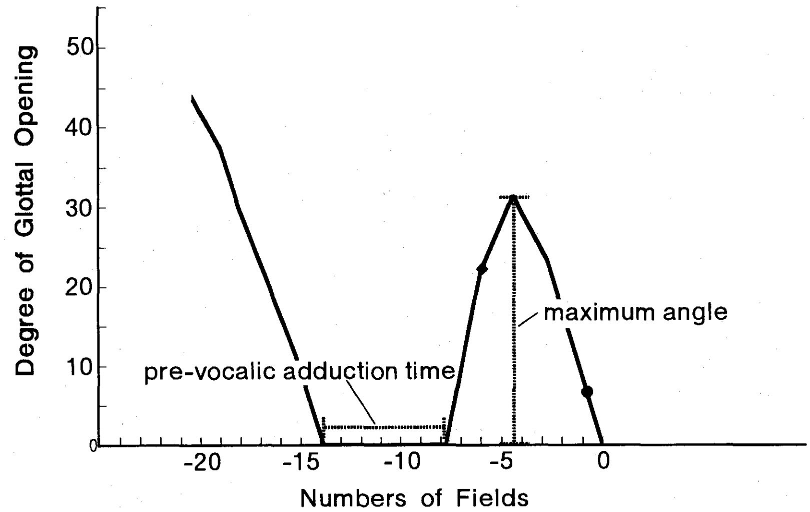

Fig. 1. Degree of glottal opening & time axis devided by the number of fields.
0: the contact period of both sides of vocal prosesses
◆: onset of plosive noise
●: onset of the following vowel

2. The maximum abducting angle of vocal folds

There was a significant tendency for the maximum abudcting angle which was larger in Group A than in Group B (Table 3).

3. The onset of plosive noise production

In Group A, the plosive noise production synchronized with the vocal folds abduction (Fig. 2).

On the other hand, in Group B, the production of plosive noise lagged several fields (Fig. 3).

4. The onset of the following vowel production

It was found in some case of Group A that the following vowel production started with the vocal folds opened about twenty degrees angle before vocal folds closure in adducting period (Fig. 2).

In Group B, the vowel production started with vocal process almost closed (Fig. 3).

5. Longitudinal study of laryngeal movement

The changing course of laryngeal movement was analyzed on Patient 3 (Fig. 4).

Patient 3 was a 29-year-old female with cleft palate whose velopharyngeal function was slight incompetent although she had a pharyngeal flap operation at another hospital. The first laryngeal observation was done after about one month's speech therapy, whcih showed adduct-abduct-adduct pattern, viz., Type II glottal stops. Auditory assessment of single CV syllables revealed glottal stop substitution for /t and k/, and /p/ sound was judged to be normal. Although the onset of plosive

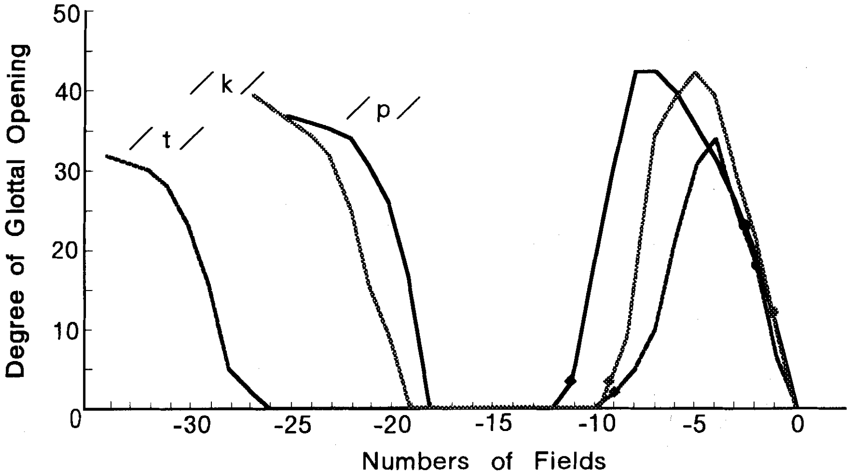

Fig. 2. Characteristic trials of each sound (Patient 1).
The maximum abducting angle was 30 to 40 degrees, comparatively wide opening. The plosive noise production synchronized with the vocal folds abduction. The following vowel production started with the vocal folds opened about twently degrees.

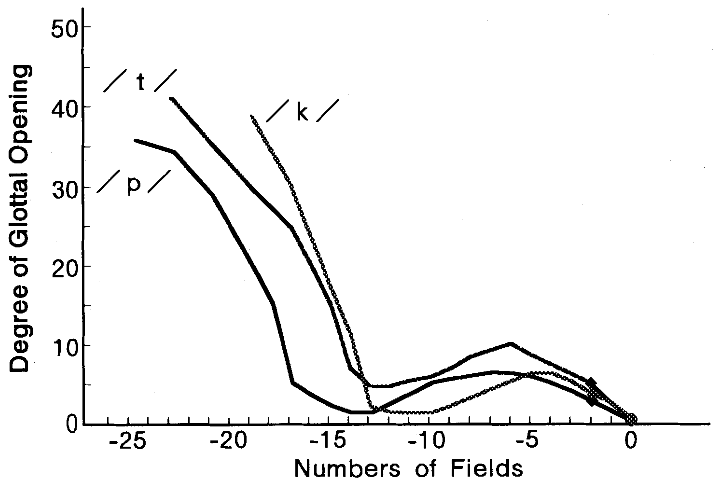

Fig. 3. Characterstic trials of each sound (Patient 7).
Pre-vocalic closure was incomplete. The maximum abducting angle was about 10 degrees, comparatively narrow opening. The plosive noise production coincided with the adducting period. The following vowel production started with vocal process almost closed.

Table 2. Pre-vocalic adduction time (msec)

	Group A				Group B		
patient	1	2	3	4	5	6	7
	198.8	104.8	94.4	113.3	293.9	91.7	86.6

Each number represents the mean of 2 to 12 trials.
The trials with incomplete adduction of vocal folds were omitted.

Table 3. The maximum abducting, angle of vocal folds (degrees)

	Group A				Group B		
patient	1	2	3	4	5	6	7
	36.6	29.0	30.9	53.7	13.7	10.6	6.0

Each number represents the mean of 6 to 13 trials.

noise production was synchronous with vocal folds abduction in /t and k/, i.e.,glottal stops, it was just before the maximum abduction period in /p/, i.e., normal sound. After eitht months of speech therapy, her plosives became auditorilly normal during production of single syllables and words, though velopharyngeal function remained slightly incompetent. The second laryngeal observation showed the same adduct-abduct-adduct pattern, however the maximum angle became smaller (Table 4). The onset of plosive noise production coincided with the maximum abduction period or adducting period. During production of sentences, her plosives remained to be perceived as glottal stops. One month later, another pharyngeal flap operation was performed and good velopharyngeal function was gained. One year after operation, speech therapy was completed and her plosives became almost normal even during running speech. The laryngeal observation at that time revealed that pre-vocalic adduction during /p, t and k/ sound production had dissapeared and laryngeal movement became normal. However a hesitating laryngeal motion was sometimes observed (Fig. 5).

Table 4. Changing course of the maximum abducting angle of vocal folds of Patient 3 (degrees)

occasion of laryngo-fiberscopy	the first assessment	after 8 months of speech therapy	completion of speech therapy
	30.9	22.8	

Each number represents the mean of 9 to 12 trials.

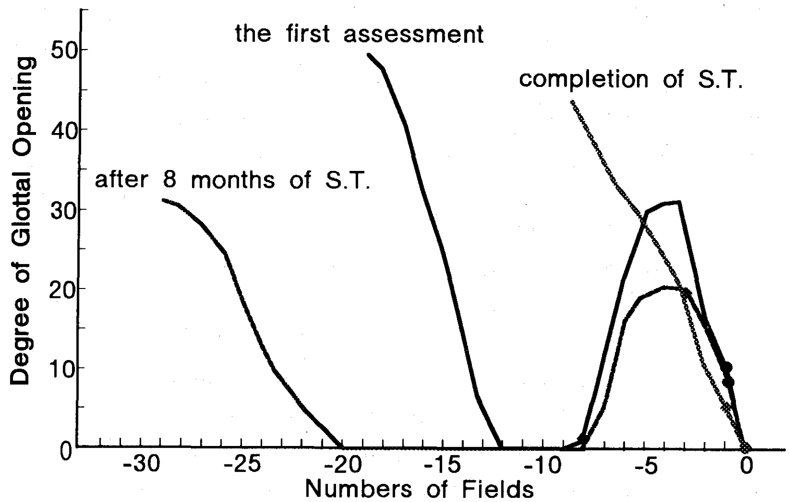

Fig. 4. Longitudinal change of laryngeal movement during production of /t/ (Patient 3). The maximum abducting angle became narrower and the onset of plosive noise shifted to adducting period after 8 months of speech therapy. At the completion of speech therapy, pre-vocalic adduction disappeared and laryngeal movement appeared normal. The same tendency was observed in /p, k/ sounds.

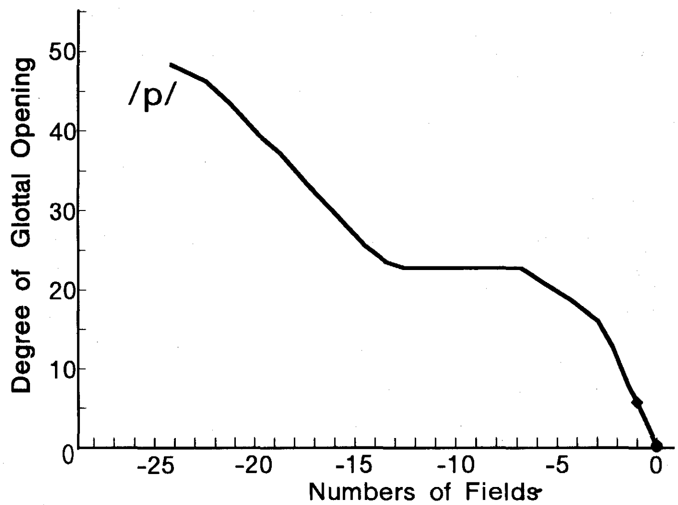

Fig. 5. Hesitating laryngeal motion on Patient 3.

Discussion

Glottal stops in cleft palate speech is improved by speech therapy and the acquisistion of good velopharyngeal function after pharyngeal flap operation, etc. In general, the auditory impression of glottal stops improves stepwise from single syllables, words, sentences to conversation. However, it has not been clarified how laryngeal movements change corresponded with the improvement of auditory impression.

The present study shows that laryngeal movement during improving process of glottal stops can not be differentiated in two categories: "abnormal" laryngeal movement during glottal stop production and "normal" laryngeal movement during normal stop production. There seems to be several transitional types of laryngeal movement between "abnormal" and "normal". It is supposed that the normal laryngeal movement is seen during production of single syllables when normal stops are eventually perceived during conversation.

Now we are going to explain the improving process of laryngeal movement during single syllable productions. In Group A, air pressure has been built beneath the closed glottis prior to voice onset and an abrupt release of the impounded air helps to produce plosive noises. Because of the abrupt release of air pressure, vocal folds are abducted widely. As a result of speech therapy, the release of air pressure at the glottis disappears and plosive noise are produced at normal places of articulation, which enables us to perceive normal stops. In Group B, the maximum abducting angle are decreased, which seems to be related to the disappearance of an air-pressure release at the glottis.

As noted above, pre-vocalic adduction disappears when it is released from a role of impounding air pressure. However it does not instantly disappear but gradually changes, diminishes and disappears. In other words, pre-vocalic adduction changes from complete closure to incomplete closure, in accordance with it, the maximum degree of abducting angle becomes smaller. In such manner, various transitional types of laryngeal movements appear in the process of improvement. A hesitating laryngeal motion during adducting period, found in Patient 3, seems to be an intermediate type between the laryngeal movement found in Patient 7 and the normal movement. Such laryngeal movement, also found in normal cases[1], is considered to be one of the transitional types in the process of articulatory improvement of glottal stops.

Another important point in the process of improvement is the onset of plosive noise production during dynamic alterations of laryngeal movement. In Group A, the plosive noise production synchronized with the vocal folds abduction, however, it lagged behind the vocal fold abduction in Group B. The onset of plosive noise seems to change from abducting period to maximum abduction period and then to adducting period as the improvement proceeds. Considering that the normal plosives are produced during the adducting movement of vocal folds, the plosive noise production during adducting period is similar to that of normal stops.

When investigated the time lag between the onset of plosive noise and that of the following vowel production, viz., Voice Onset Time (VOT), it is inferred that VOT is reduced with the improvement of laryngeal movement. Analyzing VTR of /t/ sound of Patient 3 during an early stage of speech therapy, we counted 7 fields (117 msec) of VOT, which was apparently longer than normal values[4]. It is considered that coordination of speech organs might not be made smooth. In contrast, we counted 1 fields (17 msec) of VOT after eight months of speech therapy, which seemed within normal limit and co-ordination of speech organs was supposed to be normal.

Supplementary to the above, the following vowel production started with 10 to 25 degrees of abducting angle in Group A. This vowel production is supposed to be provoked by a rapid current of air through glottis after plosive sound production at the vocal folds. Thus, the manner of vowel onset might be one of the indications of improvement in transitional process from glottal stops to normal stops.

Conclusions

Fiberscopic analysis of glottal stops (voiceless stop CV syllables) was done to clarify the transitional process from adduct-abduct-adduct pattern to normal stop production and the following results were obtained.

1. Incomplete pre-vocalic adduction was found in auditorilly normal cases.
2. The maximum abducting degree was larger in glottal stop cases than in auditorilly normal cases.
3. The plosive noise production synchronized with the vocal folds abduction in auditorilly glottal stop cases but lagged behind the abducting period in auditorilly normal cases. It is considered that the onset of plosive sound is shifted from abducting period to adducting period in the improvement process of glottal stops.
4. It is suggested that pre-vocalic adduction and the degree of abudcting angle after pre-vocalic adduction gradually diminishes in transition to normal laryngeal movement.

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