STUDIA PHONOLOGICA II (1962)

Studies on the Movement of the Nasopharyngeal Wall Related to Speech

Hiroaki TAKAHASHI
Iwao HONJO, Fumio AZUMA, Naoaki YANAGIHARA

The mechanism of velopharyngeal closure has been studied and described by many investigators. Passavant gave the first clear indication that the soft palate was a muscular structure which moved in a particular way. Hilton was one of the first to report a case of a "large bony tumor in the face completely removed by spontaneous separation", after which he made observations upon some of the function of the soft palate through the hole in the face. Since then, Einthoven, Hajak and other investigators described similar observations on the movement of the soft palate and pharynx during speech and swallowing.

To visualize the speech mechanism, Scheier first introduced the use of roentgen rays. During the last thirty years, many roentogenographic studies of speech mechanism have been reported, and new experimental methods, for example: tomography, high voltage radiography, cineradiography, were employed for the evaluation of the movement of speech organ during phonation.

With the development of the roentgen image amplifier, high speed cinematography of articulatory movement has been made possible without exposing the subject to excessive roentgen dosage. The use of cineradiography with electronic image intensification for the evaluation of normal or abnormal speech mechanism has been studied by Cooper, Calanan, Truby, Kirkpatirick, Umeno and others. Truby studied consonant articulation with help of the image intensifier combined with sound spectrography. Recently Nylen reported the movement of the soft palate during connected speech in normal and operated cleft palate patients by means of cineradiography and synchronized sound spectrography. Although knowledge of the dynamic movement and function of the soft palate and tongue during phonation is increasing, little is known about the articulatory movement and function of nasopharynx. Astley and Bosma pointed out that most cineradiographic studies was concerned with the movement of the lateral view of speech organ chiefly confined to oropharynx, and that the nasopharynx and particularly its lateral wall had received little attention.

Hiroaki TAKAHASHI : From the Oto-larygological Department of Amagasaki Hyogo-prefectural Hospital 高橋宏明：兵庫県立尼ヶ崎病院耳鼻咽喉科.
Iwao HONJO, Fumio AZUMA, and Naoaki YANAGIHARA : From the Oto-laryngological Department, University of Kyoto (Director : Prof. Mitsuharu Goto) 本庄厳，東文生，柳原尚明：京都大学耳鼻咽喉科教室（主任　後藤光治教授）.

The present investigation presents information on the movement of soft palate and lateral wall of the nasopharynx during phonation, which was observed directly in a patient, by means of cinematography and synchronized sound recording.

MATERIAL AND METHOD

An experimental study was made of a patient of forty-nine years old man whose external nose, nasal sepum, left laterl wall of the nasal cavity had been resected for the radiation cancer of the nose. However, the quality of nasal resonance was distorted, his articulatory organ was unimpaired except the scar tissue around the lip due to past irradiation. Through the defect in his face, frontal view of the nasopharynx was readily and directly observed in this case. In order to study the complex speech movement, this case was thought to be quite favorable and to be of special value. Taking motion pictures of the movement of nasopharyngeal wall during phonation, observation on slow motion projection of film and frame by frame analysis was attempted.

A Volex H 16 mm motion-picture camera was employed at a film speed of 32 frames per second. A Canon f 1.9 lens with 85 mm focal length was chosen because of its excellent resolution and to reduce the distortion of view which was resulted from the short length of focus. Simultaneously with exposure of film, the voice of the patient was recorded on tape using the dynamic microphone (FP-1 Sony) and tape recorder (KP-3 Totsuko). The experimental set-up is schematically illustrated in figure 1.

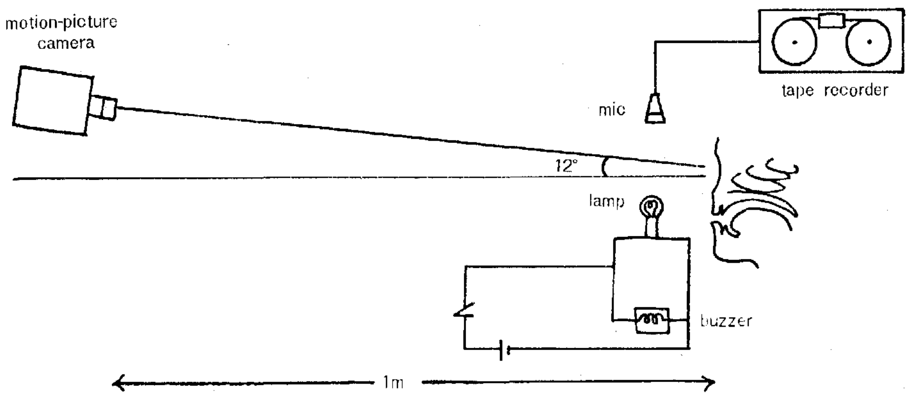


Fig. 1 Schema of the arrangement to take motion-pictures and to record sounds.

To evaluate the correlation between sound and articulatory movement, a fixed point of measurement must be recorded on both film and tape at the same time. For this purpose, a buzzer and a miniature bulb which was connected in parallel and controlled by a switch, was provided. Previous to the recording of articulatory movement and sound, motion-pictures of the miniature bulb placed in front of the face were taken and buzzer sounds were recorded on position of switch.

The patient was instructed to speak in succession to offset the buzzer sound and removal of the bulb from the front of his face. He spoke at the most natural pitch level, keeping his head in a constant position. Exposure of film and recording of sound started before the previous procedure and ended after completion of articulatory movement. Thus, about 400 feet of exposed film available for study were produced. The moment of the switch-off was easily detected on one frame of film as a failure of the light of the bulb and on recording tape as a sudden stoppage of the sound of the buzzer.

Frame countings were made on the measused time which was taken between offset of the sound of the buzzer, and the beginning and the end of the voice. Soundspectrograph (Sona-graph) and cathode ray oscilloscope were used for the measument of this time. To observe the dynamic movement of nasopharyngeal wall in a slow manner, each film strip was projected at the rate of sixteen frames per second. For direct tracing, frame by frame, prolonged projection of individual frames without damaging the film were made using a "Master" projector.

Results

Slow motion projection of the film revealed that the effective velopharyngeal closure during phonation was attained by two different components of action. One was an elevation of the soft palate and the other was an inward movement of the lateral wall of nasopharynx. Figure 2 A shows the resting state of nasoharynx during quiet respiration. Figure 2 B and 2 C illustrate the state of maximal velopharyngeal cloure during phonation of vowels "o" and "i" respectively. It was observed that the elevation of the soft palate started from lateral portion and the elevation extended toward the middle and posterior part. Simultaneously with

Table 1 Correlation between the movement and sounds phonated of five Japanese vowels. Time in msec.

	a	i	u	e	o
onset of the movement to onset of the sound	80 msec. ≀ 110 msec.	80 ≀ 110	80 ≀ 110	50 ≀ 80	110 ≀ 150
onset of the movement of maximal velopharyngeal closure	320	180	200	190	180
onset of the sound to maximal velopharyngeal closure	210 ≀ 240	70 ≀ 100	90 ≀ 130	110 ≀ 140	30 ≀ 60
offset of the sound to onset of reduction	270 ≀ 300	230 ~ 260	170 ≀ 200	250 ≀ 280	230 ≀ 260
offset of the sound to resting position	530 ≀ 560	520 ≀ 550	490 ≀ 520	730 ≀ 770	470 ≀ 500

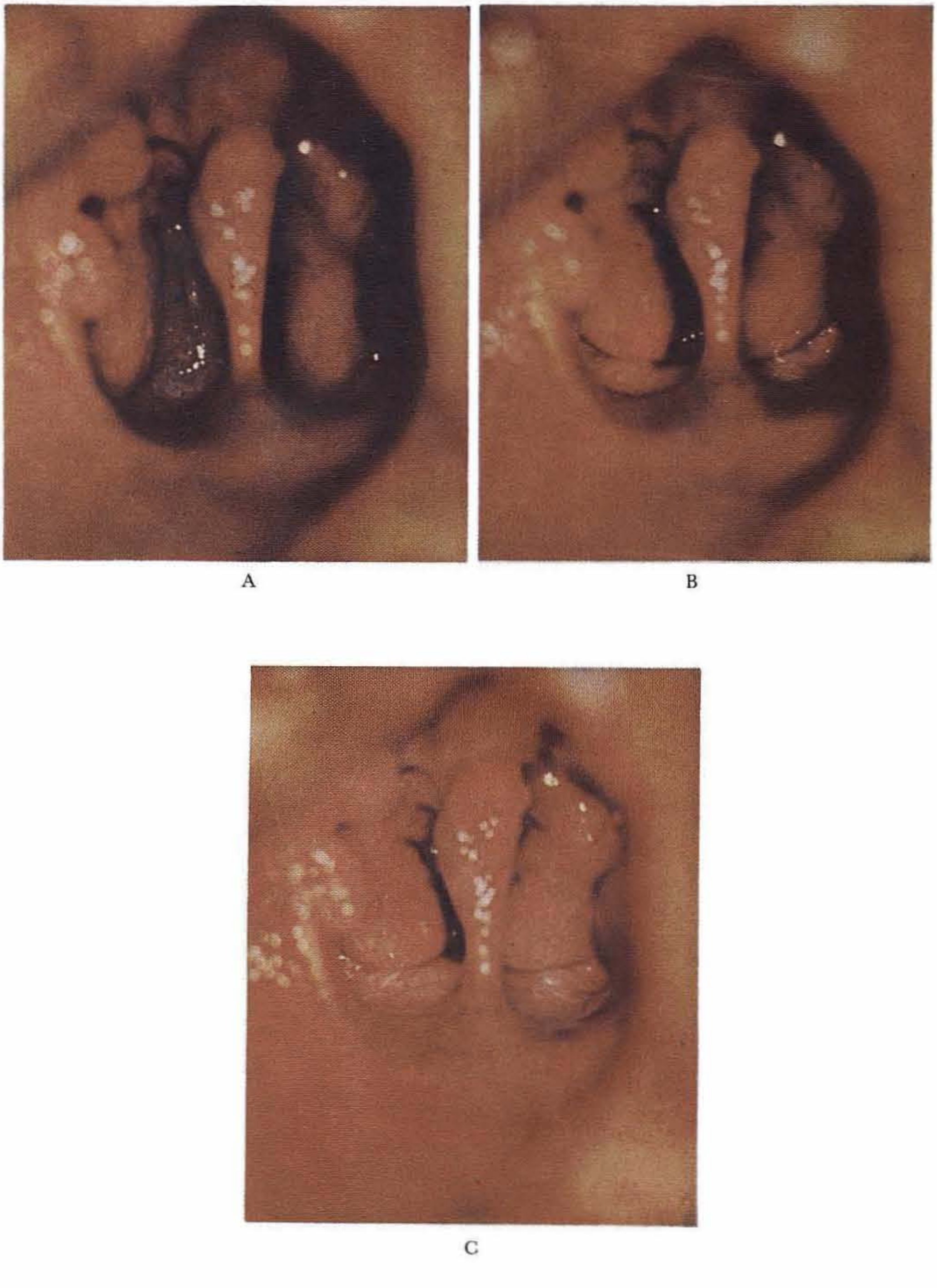


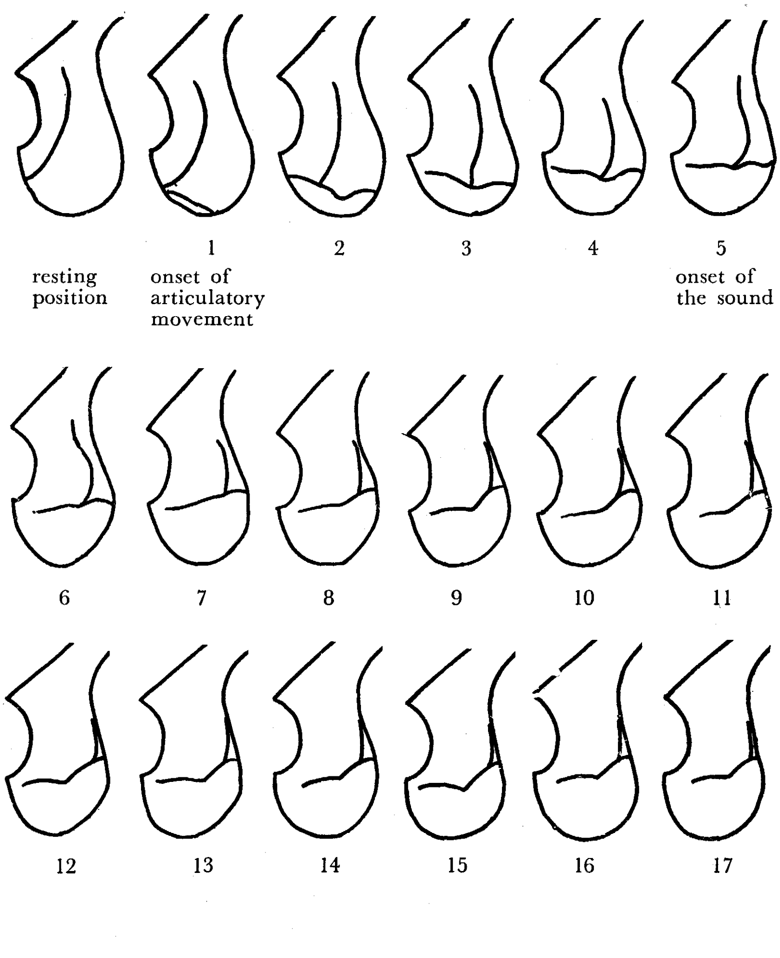
Fig. 2 Direct frontal view of the nasopharynx.
A; Resting state during quiet respiration.
B; Maximal velopharyngeal closure during phonation of vowel "o".
C; Maximal velopharyngeal closure during phonation of vowel "i".

the elevation of the soft palate, progression of inward movement of the lateral wall of nasopharynx was noted. This inward shift was most remarkable at the lower potion of the torus tubaris.

1) Movement of the nasopharyngeal wall during phonation of vowel syllable:

Table 1 shows the correlation between the phonatory movement and sound phonated of five Japanese vowels. It was known that the closure of velopharynx began prior to the onset of sound and reached to the maximal degree at about the initial portion of vowel sound. The time delay between actual movement and phonated sound was approximately the same value of 100 msec in pronouncing "u", "o", "a", and "i", in this case. From the start of the movement to the maximal velopharyngeal closure, about 170 to 200 msec was taken in pronouncing "u", "o", "e" and "i".

Figure 3 illustrates a sequence tracing of the articulatory movement of the soft palate and the lateral wall of the nasopharynx in frontal view in pronouncing the vowel "a". A simultaneous movement of both structures is clearly demonstrated in this figure. The individual frame shows that the soft palate and the lateral wall do not remain in a constant state throughout the complete velopharyngeal



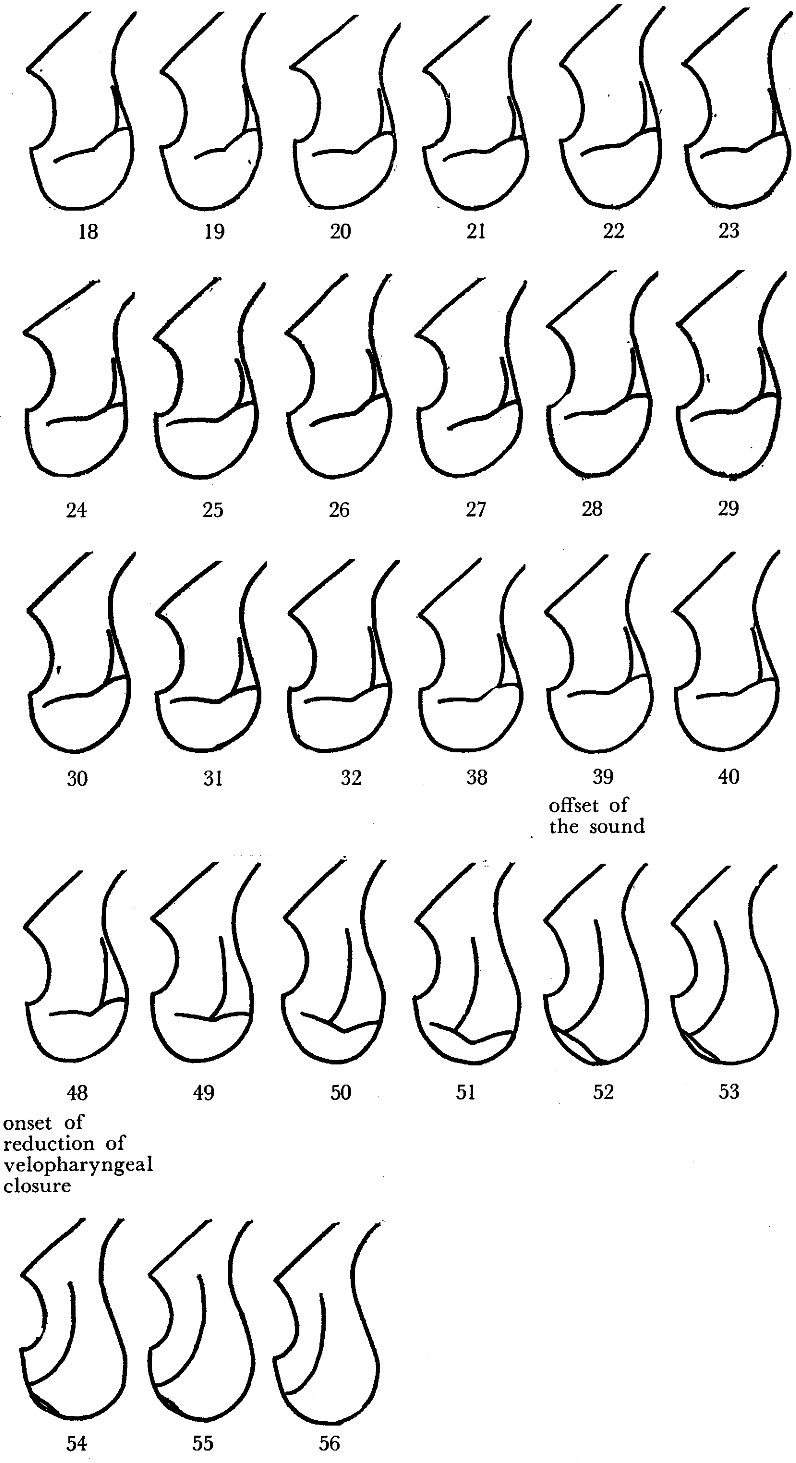
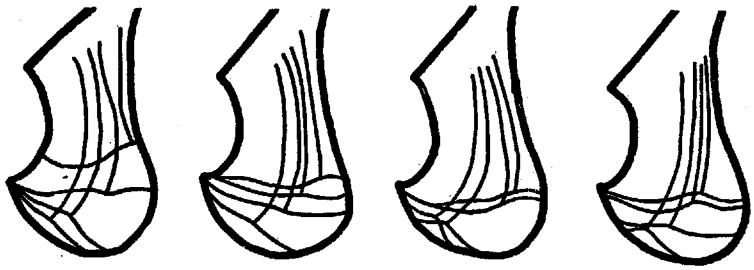


Fig. 3 A sequence tracing of the movement of the soft palate and the lateral wall of nasopharynx in pronouncing vowel "a". The numbers below each trace denote the number of frame counted from the onset of articulatory movement. The time taken between each frame is 31 msec.

closure. An oscillatory movement of both soft palate and lateral wall during phonation is seen clearly. Figure 4 presents representative traces of the phonatory movement during the progression of velopharyngael closure in pronouncing "u", "o", "e", and "i". Compared with each trace, it is noted that the course of the movement and the degree of the closure differs from vowel to vowel in some degree. In pronouncing the vowels "i" and "u", stronger closure was marked.



i u e o

Fig. 4 Representative traces of the movement during progression of velopharyngeal closure in pronouncing "u", "o", "e" and "i".

Concerning the reduction of velopharyngeal closure, there was also the time delay between the offset of the sound and the onset of the relaxation of velopharyngeal closure. Approximately 500 msec was taken to return the resting position from the offset of the sound.

2) Movement of the nasopharyngeal wall during phonation of discrete CV syllable (consonant vowel syllable):

Table 2 shows the correlation between actual the phonatory movement and the onset of sound, voiceless and voiced CV syllable. There was no significant difference in this correlation in pronouncing voiceless CV syllable compared with that of the vowel syllable. It was considered to be a feature that a relatively long time was taken from the onset of phonatory movement to the onset of sound of voiced CV syllable, "ga," "da," and "ba." In pronouncing voiced CV syllable, the closure of velopharynx reached a maximal degree during phonation of voiced consonant or the transient part between consonant and vowel. When voiceless

Table 2 Correlation between the movement and sounds phonated of voiceless and voices CV syllable. Time in msec.

	ka	ta	sa	ha	ga	da	za	ba
onset of the movement to onset of the sound	180 msec. ~ 220 msec.	160 ~ 190	200 ~ 230	130 ~ 160	320 ~ 360	240 ~ 270	130 ~ 170	380 ~ 410
onset of the movement to maximal velopharyngeal closure	340	400	250	280	400	310	340	470
onset of the sound to maximal velopharyngeal closure	160 ~ 190	210 ~ 240	−10 ~ 20	120 ~ 150	50 ~ 80	10 ~ 40	180 ~ 210	50 ~ 80

CV syllable was phonated, the maximal degree of the closure was attained during rising portion of vowel part.

Concerning the articulatory action of the nasopharyngeal wall during phonation of nasal CV syllable (na, ni, nu, ne, no; ma, mi, mu, me, mo,), significantly different articulatory mechanisms were observed. Figure 5 illustrates representative traces of the nasapharyngeal wall in pronouncing these syllables. As illustrated in these figures, a slight degree of elevation of the soft palate and little inward shift of the lateral wall of nasopharynx were commonly observed. During phonation of vowel part, these phenomena were well observed. Table 2 and Table 3

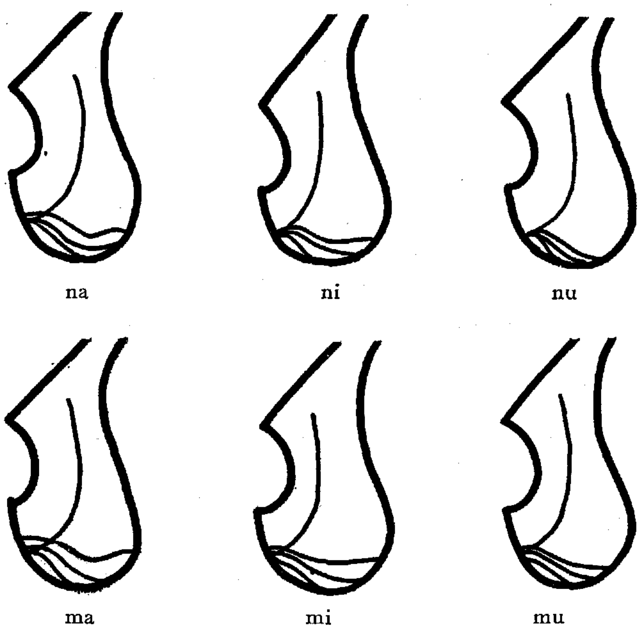


Fig. 5 Representative traces of the velopharyngeal closure in pronouncing nasal CV syllable.

Table 3 Correlation between the movement and sounds phonated of nasal CV syllable. Time in msec.

	na	ni	nu	ne	no	ma	mi	mu	me	mo
onset of the movement to onset of the sound	220 msec.	190 ≀ 220	90 ≀ 130	190 ~ 220	190 ~ 220	90 ≀ 130	90 ≀ 130	60 ≀ 90	60 ≀ 90	90 ≀ 130
onset of the movement to maximal velopharygeal closure	190	160	130	190	220	220	160	160	130	90
onset of the sound to maximal volopharygeal closure	−30	−60 ≀ −30	0 ≀ 30	−30 ≀ 0	0 ≀ 30	90 ≀ 130	30 ≀ 60	60 ≀ 90	30 ≀ 60	−30 ≀ 0
offset of the sound to onset of reduction	−690 ≀ −660	−690 ≀ −660	−630 ≀ −600	−780 ≀ − 50	−600 ≀ −560	−410 ≀ −380	−630 ≀ −600	−690 ≀ −660	−600 ≀ −560	

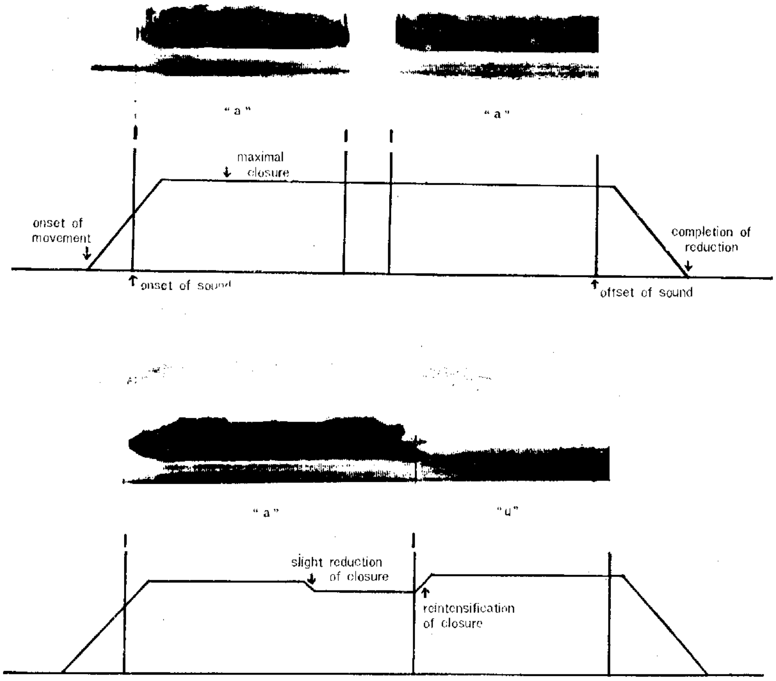


Fig. 6 Sonagrams and diagrams illustrating the correlation between pronounced sounds and velopharyngeal closure in pronouncing "aa" and "au" successively.

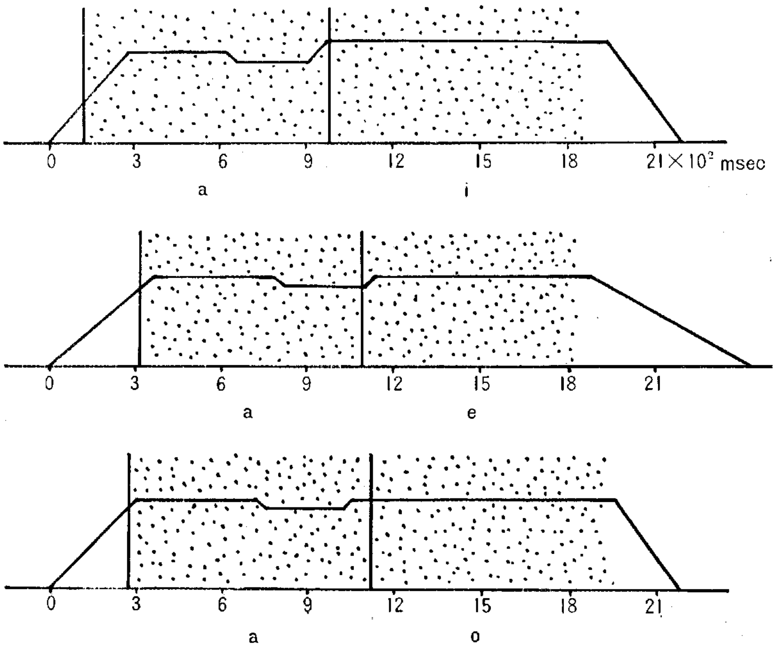


Fig. 7 Diagrams illustrating the correlation between the velopnaryngeal closure and phonated sounds of "ai", "au", and "ao". Dotted area corresponds with vowel part in the sonagram.

show the relationship between phonatory movement and onset of phonated sound. As shown in these tables, it was noticed that a comparatively short time was taken from the onset of sound to the maximal velopharyngeal closure and, in some syllables, the closure reached a maximum prior to the sound of nasal consonant. Above mentioned phenomena were characteristically observed in the phonatatory movement of nasal CV syllable.

3) Movement of the nasopharyngeal wall during phonation of two connected syllables:

To compare with the articulatory movement during phonation of single syllable, the movement of nasopharyngeal wall during phonation of two connected

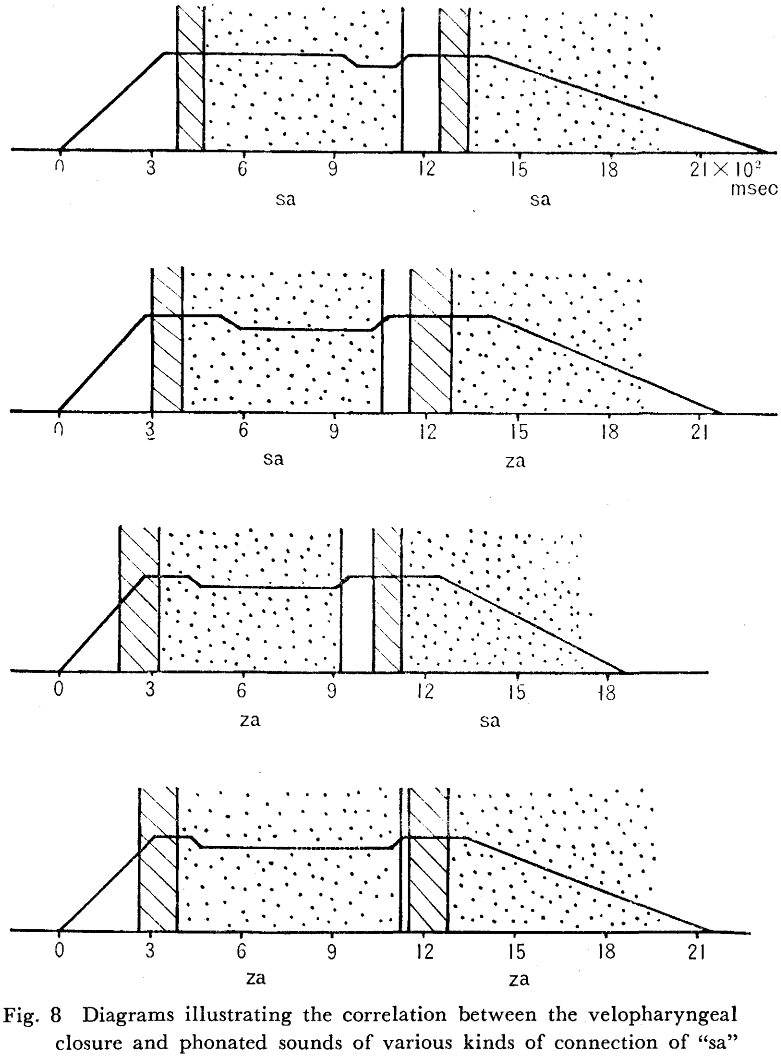


Fig. 8 Diagrams illustrating the correlation between the velopharyngeal closure and phonated sounds of various kinds of connection of "sa" and "za". Area bounded by oblique line corresponds with consonant and transitional part in the sonagram. Dotted area corresponds with vowel part in the sonagram.

syllables was observed. In figure 6, diagrams which illustrate the correlation between velopharyngeal closure and phonated vowel sound "aa" and "au" are schematically drawn under sonagrams of each sound. In these diagrams, the upward line represents progression of closure and downward line reduction of closure. While the horizontal line indicates that the closure remains constant at a certain degree. It is clearly demonstrated in this figure that the articulatory movement for phonation of the two connected syllables differs greatly from the movement for phonation of a single isolated syllable. In pronouncing "aa", velopharyngeal closure was kept steady even during the no-tonal period between each vowel, which was apparently shown by the sonagram. During the velopharyngeal closure in pronouncing "au", it was reduced to some degree during the last half portion of preceeding "a", and again more intensified within the initial portion of succeeding "u". The state of velopharyngeal closure and its relation to the sonagram of phonated sound in the pronouncing of "ai", "ae" and "ao" is schematically illustrated in Figure 7. On the basis of these observations the following assumption

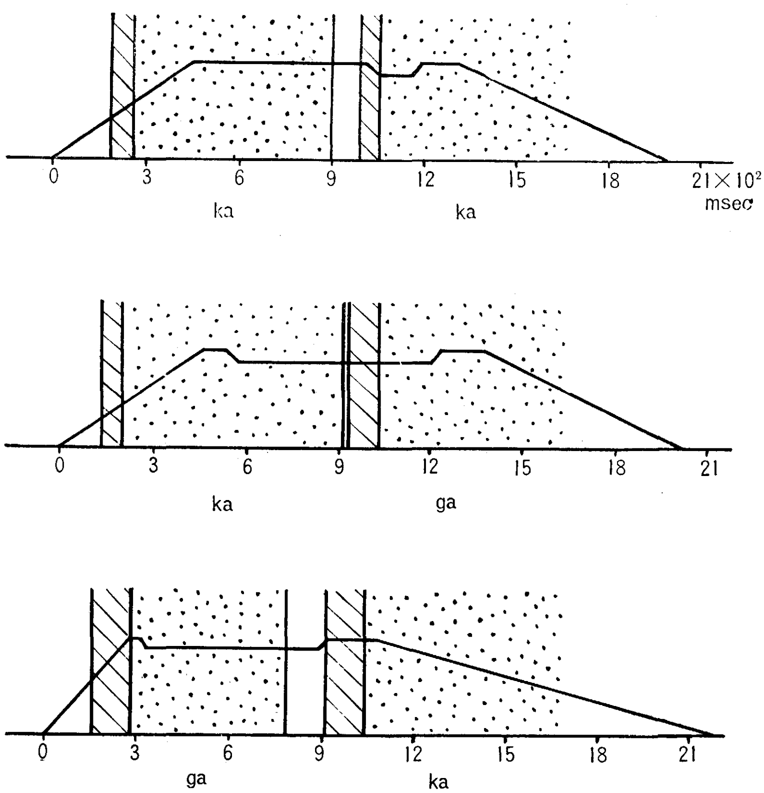
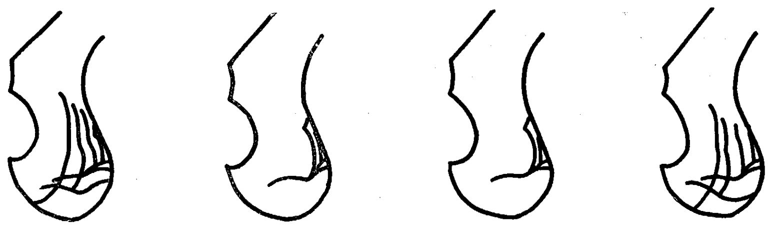


Fig. 9 Diagrams illustrating the correlation between the velopharyngeal closure and phonated sounds of various kinds of connection of "ka" and "ga". Area bounded by oblique line corresponds with consonant and transitional part in sonagram. Dotted area corresponds with vowel in sonagram.

is drawn: when two different vowels are spocken successively, a slight reduction of velopharyngeal closure takes place during phonation of preceeding vowel, and then, the reduced closure again intensifies during the transitional part or at the initial portion of the succeeding vowel. This intensification of closure was more markedly recognized in pronouncing the succeeding "i" and "u".

Dynamic states of the velopharyngeal closure in pronouncing various kinds of connections "sa and za", "ka and ga", are shown in Figures 8 and 9. These figures illustrate the pattern of a velopharyngeal closure varied with the combination of syllables. Tracing of representative frames in phonation of connected "sa sa" is drawn in figure 10, which demonstrates the degree of reduction and reintensification of the closure during phonation of the two connected syllable.



intensification of velopharygeal closure　　reduction　　reintensification　　reduction

Fig. 10 Tracing of representative frame in phonation of connected "sa, sa".

DISCUSSION

Astley reported that the lateral wall of the nasopharynx showed a pronounced inward shift during phonation of "ah", maximum at about the level of the palate. He noted also that speech was accompanied by a to and fro movement of the lateral wall of nasopharynx.

According to our investigation, it is quite clear that velopharyngeal closure is completed by two different components of motor mechanism which act simultaneously; one is an elevation of the soft palate and the other is an inward movement of the lateral wall of the nasopharynx. Maximal inward shift of the lateral nasopharyngeal wall is marked at the lower pole of torus tubaris.

There is a time delay, ranging from 100 msec to 400 msec, between the onset of the actual closure of velopharynx and the sound produced. It is possible to consider that this time delay differs from syllable to syllable. Nylen discribed this time delay as about 0.15 sec in pronouncing Swedish "Gatan". In the present case, the longest time delay at about 300 msec is marked in pronouncing a voiced CV syllable, and approximately 250 msec to 100 msec is taken in pronouncing a vowel syllable, voiceless CV syllable, and nasal CV syllable.

According to Nylen's measurement, the time which was taken to reach complete velopharyngeal closure from rest position in pronouncing "Gatan" was approximately 0.3 msec. In our present studies, this time ranged from 250 msec to 500 msec and varied with the syllable phonated. Hiroto and his co-workers made an electromyographic studies of the levator muscle of the soft palate during phonation. They reported that the action potential of this muscle appeared about 250 msec to 400 msec prior to the onset of the sound pronounced. Further studies on the correlation between muscle activity, actual movement of articulatory organ and pronounced sound will provide important information in understanding peripheral speech mechanism.

It was suggested by many investigators that the level of the soft palate during velopharyngeal closure differed in accordance with the kind of vowel. This difference exists in not only the elevation of the soft palate but also in inward shift of the lateral wall of nasopharynx. Among five Japanese vowels, more intense velopharyngeal closure is observed in phonation of "i" and "u". It is proved that the closure of velopharynx reaches the maximum after the onset of sound, except several nasal CV syllables.

Hoffman, using a motion analyzer, previously reported that the soft palate appears to have oscillatory movement during phonation. This oscillatory effect is seen quite clearly in the elevated soft palate and inward shifted lateral wall of nasopharynx. This evidence strongly suggests that the velopharyngeal closure does not remain constant, and whole muscle activity related to the closure fluctuates in a slight degree thoughout the complete closure.

Slight elevation of the soft palate, little inward shift of the lateral wall of the nasopharynx and early reduction of the velopharyngeal closure are characteristic features observed on the articulatory movement of nasopharyngeal wall in pronouncing of Japanese nasal CV syllable. From these findings, it is thought that the successive vowels in nasal CV syllable have the nasal quality of voice.

The movement of the wall of the nasopharynx during connected speech is largely unknown. The reports dealing with this field of research are very scanty. With the help of a soundspectrograph, we attempted to approach an outline of this unknown articulatory mechanism. It is observed that the movement of nasopharyngeal wall during connected speech is conspiciously different from that of an isolated phonation of individual syllables. The basic pattern in pronouncing two connected syllables is that there is a slight reduction of the closure during phonation of preceeding syllable and a reintensification just prior to a successive syllable or during phonation of transitional part between two syllables. It is believed that the repetion of these complex patters of the movement make up one of the bases of articulatory function necessary for commnicable speech of a human being.

Summary

In a post-operative case of nasal cancer, the direct frontal view of the nasopharynx was readily observed through the defect in the face. In order to evaluate

the complex phonatory movement of the nasopharynx, this case was a most favorable one. Authors made the cinematographic observations of the articulatory movement of the nasopharynx. The knowledge concerning the phonatory movement of this unaccessible structure is very scanty because of the difficulties of its visualization. Information on this subject can be obtained and described in some detail.

Acknowlegement: We wish to express our thanks to Prof. Mitsuharu Goto for his guidance in this investigation.

REFERENCES

1) Azuma, F. : Radiographic studies on articulatory mechanism, Review. The oto-rhino and laryngological clinic. 55 ; 191, 1962

2) Hiroto, et al. : An electromyographic studies on articulatory movement. The Japan journal of logopedics and phoniatrics. 2 ; 14, 1962

3) Kamamoto, Y. : Soundspectrographic analysis of Japanese syllables with reference to articulatory mechanism. The oto-rhino aud laryngological clinic. 51 ; 536, 1958

4) Yamawaki, Y. : An electromyographic study on the mechanism of phonation and articulation. Japan Society of O.R.L. 58 ; 31, 1955

5) Umeno, M. : A cineradiographic study on movements of the soft palate and the tongue during phonation. The oto-rhino and laryngological clinic. 55 ; 21, 1962

6) Bosma, J.F. et al. : The upper pharynx. The Annals of O.R. Laryng. 70 ; 951, 1961

7) Bosma, J.F. et al· : The upper pharyn. The Annals of O.R. laryng. 71 ; 1962

8) Hoffman, F. A. et al. : A cineradiographic study of velopharyngeal closure. Plastic and reconst. surg. 28 ; 656, 1961

9) Kirkpatrik, J.A. et al. : Cinefluorographic study of pharyngeal functions related to speech. Radiology 73 ; 557, 1959

10) Astley, R. : The movements of the lateral wall of the nasopharynx. A cine-radiographic study. J. otorhinolaryng. 72 ; 325, 1958

11) Nylen, B. O. et al. : Cineradiography with synchronized sound spectrum analysis. Plastic and reconst. Surg. 27 ; 397, 1961

12) Miet, J. et al. : Cineflurographic study of palatal incompetency cases during deglutition and phonation. Plastic and reconst. surg. 28 ; 347, 1961

13) Galzia, P.G. : 3000 Jahre Stimmoforshung, N.G. Elwert Verlag Marburg 1961