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STUDIA PHONOLOGICA I (1961)

# Voice and Subglottic Pressure

Nobuhiko ISSHIKI

## I) INTRODUCTION

It has been generally accepted that the subglottic pressure is essential to the production of voice and regarded as a main source of energy of voice. One of the controversial points as to the subglottic pressure is whether or not it may play any role in pitch regulation and further how it does.

Those who are of opinion that the pitch rises as the blowing pressure increases are many, represented by Liskovius, Müller, Grützner, Katzenstein u. Du Bois Reymond, Gutzmann, Van den Berg, Negus and others. Franz Wethlo, based on his model experiment, demonstrates that the pitch decreases with increased blowing pressure, if the vocal cord tension is great as compared with the blowing pressure. On the contrary, if the blowing pressure is comparatively high, the pitch rises with increased blowing pressure. Dunker und Schlosshauer attach little significance to the effect of the subglottic pressure on the pitch. On the other hand, R. Husson and his collaboraters claim that the pitch is determined directly by nerve impulses of the recurrent nerve and the subglottic pressure takes part only in the intensity of voice.

Subglottic pressure during normal phonation in man was previously reported by Gutzmann u. Loewy, Schilling and Shiroiwa and others. Recently Strenger, investigated the relation between the subglottic pressure and the acoustic pressure of Swedish vowels and consonants. These previous investigations have been performed on the patients with tracheal fistula but never on normal man.

## II) MATERIALS and METHODS

Subjects of these experiments were healthy men and the tracheotomized with normal larynx. In normal man, a needle 5 cm in length with an internal bore of 1 mm was inserted into the trachea through the skin, its oblique section facing downwards. The needle was connected via rubber tube 1.5 m in length, 6 mm in internal diameter, to a metal tambour. The metal tambour is specially devised so as to have quite a small inertia and to respond almost linearly in wide-spread frequency range. It was established by calibration test that the pressure value is almost independent of the calibre of the needle used, if a constant pressure persists for a certain short period of time, and the error introduced by using the needle was practically only in respect of the time deviation, that is the delayed recording

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of pressure ranging from 0.05 sec to 0.2 sec. Therefore in the cases of the needle used, high frequency change in pressure corresponding to the pitch was not recorded. Mercury or water manometer is not appropriate for recording the pressure, because it introduces a non-negligible error due to its own inertia, as shown in Fig. 1. In the tracheotomized, opening of the fistula was connected to the metal tambour airtightly. Volume of voice was measured by sound level meter and expressed in "phon".

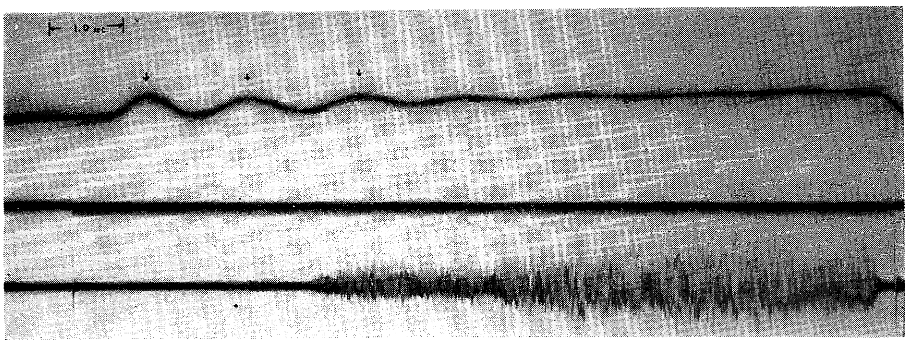

**Fig. 1** Artifact in recording the subglottic pressure due to the large inertia of mercury. Mercury-condensor manometer is used which has a linearity in response to the pressure.

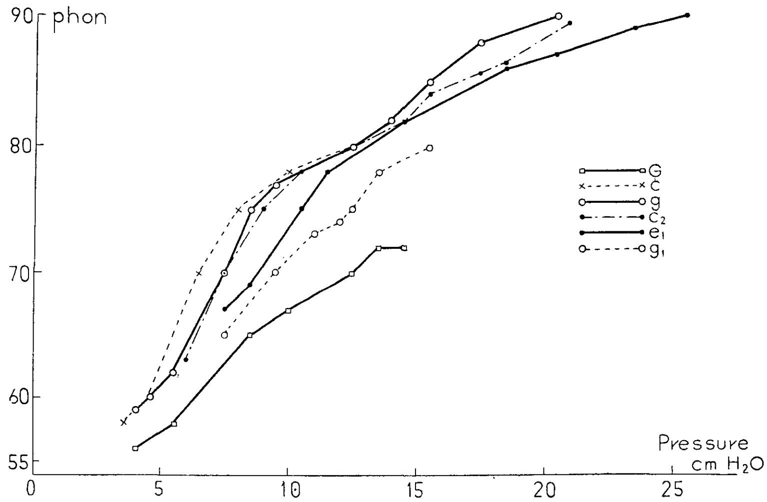


**Fig. 2** Relation of the subglottic pressure to the pitch and volume of voice. abscissa : subglottic pressure in cm water, ordinate : volume of voice in phon, vowel "ah" is sung. Microphone is placed 50 cm apart from the mouth.

## III) Results

### A) Relation between Subglottic Pressure and the Pitch and Volume of Voice

1) *Subglottic pressure and pitch of voice*

Fig. 2 illustrates that the increase in pitch is in general accompanied by increased subglottic pressure, if the volume of voice indicated in phon is kept constant. However, the pressure change corresponding to the change in pitch of one octave was not more than 5 cm water. It is of interest to note that the subglottic pressure on producing a too low pitch tone with difficulty was exceptionally higher than that of high tone of equal volume.

2) *Subglottic pressure and volume of voice*

Fig. 2 shows that,

1. The greater the volume, the higher the subglottic pressure when singing at fixed pitch.
2. Change in subglottic pressure due to the change in volume is more marked than that due to the change in pitch.
3. The increase of subglottic pressure corresponding to a certain increase in volume is almost equal at any pitch (indicated by each curve running nearly parallel in Fig. 2).
4. The increase of subglottic pressure required for a certain increase in volume when singing at loud voice is slightly greater than that required for the equal increase in volume when singing at feeble voice.

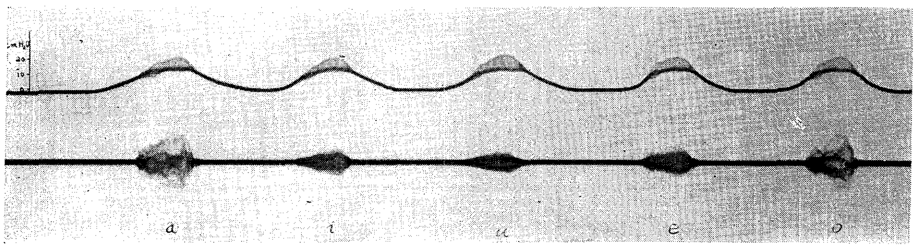

**Fig. 3** Subglottic pressure and voice. Oscillation of subglottic pressure corresponding to the vocal pitch is shown.

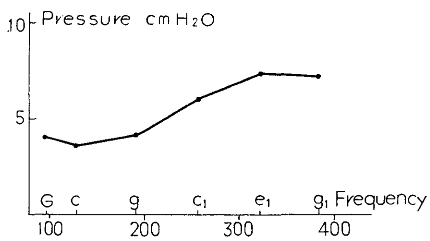


**Fig. 4** Minimal subglottic pressure required for phonation at given pitch. Vowel "ah" is sung, the subject male.

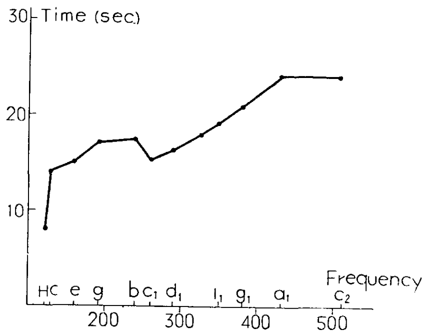


**Fig. 5** Duration of phonation at various pitches with subglottic pressure fixed (12 cm water). Vowel "ah" is sung, the subject male.

As shown in Fig. 3, oscillation of subglottic pressure in the tracheotomized subject on producing a voice was recorded. The amplitude of oscillation was considerably great as compared with the mean or minimal value of the subglottic pressure during phonation and was roughly proportional to the amplitude of voice so long as the voice produced is the same vowel at fixed pitch. There was a tendency that the oscillating amplitude of subglottic pressure is small at the onset and end of voice.

3) *Minimal subglottic pressure required for phonation*

This signifies the subglottic pressure for a voice as feeble as possible at given pitch. There seems no proper means to indicate a degree of resistance at the glottis to the air current, though it has been thought to be very important for voice control. An attempt was made in this study to apply this minimal subglottic pressure as an indicator for the resistance at the glottis. Fig. 4 suggests that the resistance increases with the increase in pitch. This value is naturally partly dependent on how trained the subject is in singing.

4) *Duration of phonation at various pitches with fixed subglottic pressure*

1. Object The changes of subglottic pressure can be caused chiefly by two factors…resistance at the glottis and the blowing condition. As a means to analyze these two factors, duration of phonation with fixed subglottic pressure was measured. Blowing condition may be represented approximately by the air volume expelled per second, which is almost equivalent to the vital capacity devided by phonatory duration. (Tab. 1).

**Tab. 1**

| | | | | |
|---|---|---|---|---|
| Closing degree of the glottis | + | ++ | + | ++ |
| Exhaling condition | + | + | ++ | ++ |
| Subglottic pressure | + | ++ | ++ | +++ |
| Voice | feeble, low pitch | feeble, high pitch | loud, low pitch | loud, high pitch |
| Duration of phonation | long | long | short | short |

2. Procedure Phonatory duration was measured when vowel "ah" was sung at various pitches with subglottic pressure kept at 12 cm water under the visual guidance of manometer.

3. Results (Fig. 5) The duration of phonation at high pitch was longer than that at low pitch, when the subglottic pressure was kept constant. These observations suggest that when singing at high pitch, resistance at the glottis would play more important role in the elevation of subglottic pressure than exhaling exertion, while on phonation at low pitch the latter would be more significant than the former. Exceptional short duration of phonation at "$c_1$" may be assumed as having some relation to the transition of register.

5) *Changes in voice caused by increased exhalation*

1. Object The effect of primarily increased blowing on the voice was investigated in men and dogs.

2. Procedure Increase of exhalation during phonation was attained by sudden press of the thorax. It was evidenced by electro-myography that no significant change in action potentials of the laryngeal muscles occurs at the moment of pressing the thorax.

3. Results Fig. 6 illustrates that when singing at low pitch, sudden increase of subglottic pressure gives rise to a marked increase in volume and slight elevation of pitch. This is not apparent at high pitches. When singing at transition from head register to falsetto, the pressure increase caused a contrary effect ··· the volume increased but the pitch decreased with some noise mixed in some cases, shown by sonagram of Fig. 7. Similar effect was rather common in the experiments on dogs where the voice was generally high in pitch. Vibrating part was observed on dogs to extend from the front margin of the glottis to the whole vocal cord when the pitch decreased suddenly following the press of the thorax.

B) Vowel Phonation and the Subglottic Pressure

When five Japanese vowels were produced at fixed pitch with an intention to keep equal loudness, their subglottic pressure were almost equal one another (Fig. 8 A). (Subglottic pressure for "i" is slightly higher than others.) Regardless of giving the singer a sensation of approximately equal loudness, each of the vowels produced in this way had quite a different phon level indicated by sound level meter···a, o, e, u, i, in the order of decreasing phone level. On the other hand, when vowel production was controlled by seeing a sound level meter so as to keep equal phon level, the subglottic pressure was different according to the vowels···i, u, e, o, a, in the order of decreasing subglottic prsessure and of decreasing sensation of loudress the vowel gave to the hearers (Fig. 8 B). The width of the resonant

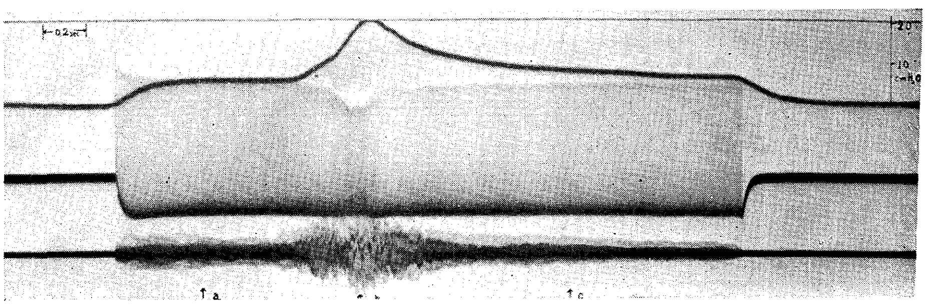

**Fig. 6** Effect of increased exhalalation on the pitch and volume of voice. Vocal pitch at "a" and "b" is 120 c/s and 170 c/s respectively. Recording of subglottic pressure delays about 0.1 sec because of the narrow caliber of needle inserted into the trachea.

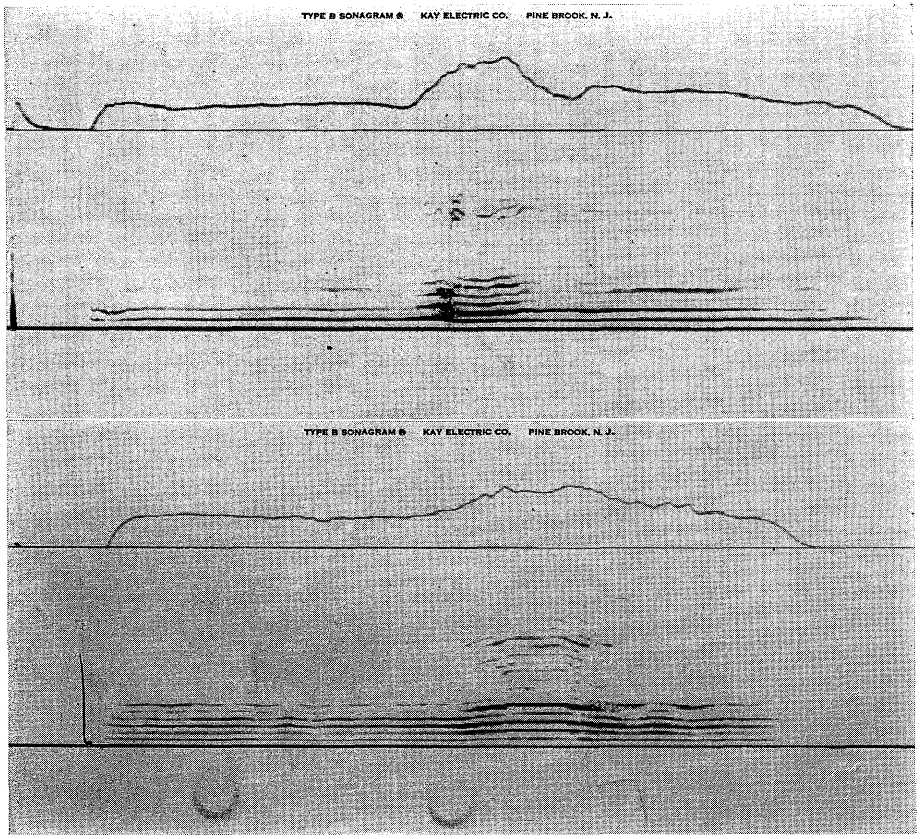


**Fig. 7** Sonagrams illustrating the effects of increased exhalatson on the pitch. upper : amplitude of voice, lower : frequency spectrum analysed by narrow hand pass filter

A : Increased exhalation causes a marked increase in volume and slight decrease in pitch with some noise when singing at register boundary.

B : When singing at low pitch, the vocal pitch rises with increased exhalation.

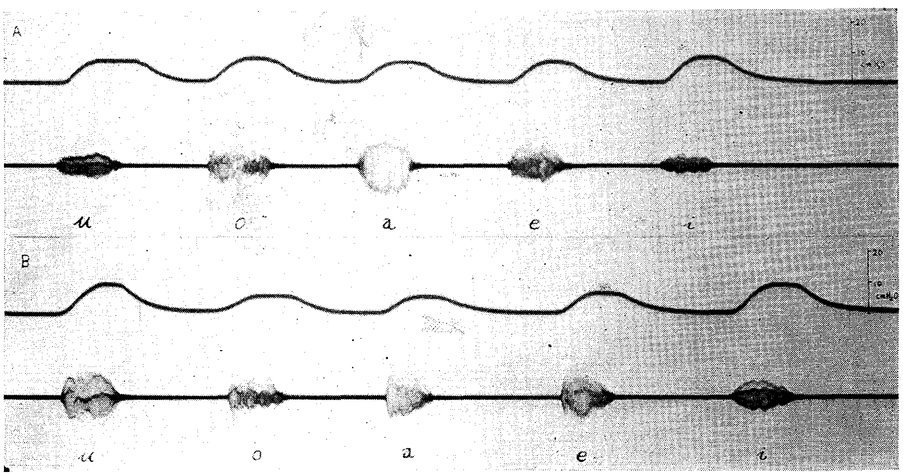


**Fig. 8** Subglottic pressure and vowel phonation

A : Five Japanese vowels are produced with an intention to phonate in equal loudness.

B : Vowel phonation is controlled by seeing a sound level meter so as to phonate in equal phon level.

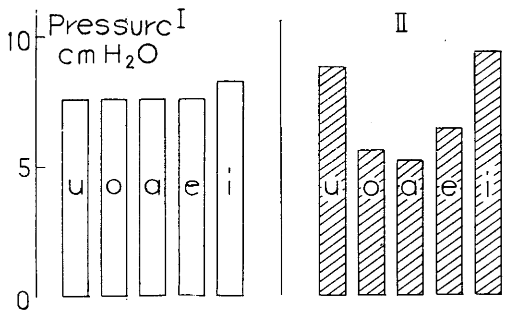


**Fig. 9** Subglottic pressure during phonation of five Japanese vowels is schematically shown.
Left (I) : phonated with intention to phonate in equal loudness
Right (II) : phonated in equal phon level

cavity above the glottis may also involved in the subglottic pressure as already suggested by Schilling.

## IV) DISCUSSION

Before discussing the relation between subglottic pressure and vocal pitch, it would be advisable to make a brief statement on determinant factors of the vocal pitch. It has been well established by Farnthworth, Pressman, and Sonninen that elongation of the vocal cord occurs with raising the vocal pitch. This fact is understood to signify that the vocal cords are elongated so as to increase their tension. Many experiments on artificial larynx have also shown that increased tension results in the elevation of vocal pitch. The other factor to determine the pitch directly than the vocal cord tension may be the vibrating mass, as is in any other vibrating system. To increase the tension of the vocal cord is, especially when it is in passive way (passive inner tension according to Sonninen), naturally accompanied by attenuation of the vocal cord. These two factors appear compatible and cooperating in pitch regulation under physiological condition. When the length or tension of the vocal cord reaches the maximum, the pitch of voice is mainly altered by changing the vibrating mass of the vocal cord, including the length (damping process according to Pressmann). This stage of adjustment appears to correspond approximately to the register of falsetto. It has been clearly demonstrated by many previous works (Luchsinger, Musehold, Husson, Satta, Kirikae) that with sliding the register from chest voice to head voice and from head voice to falsetto, vibrating part of the vocal cord shifts from the whole vocal cord to the margin of the cord and finally towards the front part.

As many previous reports described, it is apparent that the increased blowing results in the rise of pitch if the vocal cord tension is relatively slight or the voice is low in pitch. If the vocal cord is highly tensed, the increased blowing can produce a decrease in pitch, especially at register-boundary from head register to falsetto. These findings are somewhat similar to those of Wethlo's model experiments. He interprets the dual effect of blowing pressure on the pitch as due to which of the two is dominant in inducing the recoil of the vocal cord,··· the tension or suction, stating "Anzunehman ist, dass beide Arten der Rückstellkraft, die Tension sowohl wie die Suktion gleichzeitig und vereint auftreten können, dass aber jeweils die eine oder die andere vorherrschend sein kann. Ist das für die *Suktion* der Fall, so ist leicht einzusehen, dass ein stärkerer Anblasestrom das Auseinanderweichen wie auch den Rückschwung der Stimmlippen beschleunigen, den Ton also *erhöhen* muss. Ist aber die *Tension* vorherrschend, so ist ein stärkerer Winddruck der Rückstellwirkung entgegengesetzt. Es tritt nach stärkerem Ausschwingen eine Verzögerung des Rückschwunges und damit eine *Tonvertiefung* ein". However, observation of the vocal cord in the present experiment revealed that sudden fall of the pitch following the increased blowing is always accompanied by sudden marked increase of mass in vibration. There, the author considers that the sudden increase of vibrating mass would be more likely responsible for the decrease in pitch.

The influence of the increased subglottic pressure on the vibration is most evidently recognized at the register-boundary (transition). Here may lie the reason for difficulty in producing a swelling tone at register-boundary. One of the problems left unsolved is concerned with how the increased subglottic pressure causes a rise of pitch at chest register. At present, it is not fully known whether the subglottic pressure affect the vocal pitch directly just as the tension or vibrating mass does, or only indirectly by inducing the changes in tension or vibrating mass. However, it appears conceivable that this rise of pitch is due to the increased tension of vocal cord by increased subglottic pressure. The effect of subglottic pressure on vibrating mass has been partly ascertained by the present investigation. But the possibility of subglottic pressure affecting the vocal pitch directly, in such a way as "suction" expressed by Wethlo, must be another problem to be solved in connection with aerodynamic theory on voice production.

## V) Conclusion

In both healthy normal men and the tracheotomized, the subglottic pressure during phonation was recorded simultaneously with the voice.

The results may be summarized as follows. 1. Change in subglottic pressure according to the pitch is not so marked as that according to the volume of voice. 2. Gradual augmentation in oscillating amplitude of subglottic pressure at the onset of voice and gradual reduction at the termination are commonly observed. 3. Minimal subglottic pressure required for phonation increases with the rise of pitch, indicating that the resistance at the glottis to the air current increases with the rise of pitch. 4. On low pitch phonation, increased exhalation or blowing results

in the slightly increased pitch. At the register-boundary, increased exhalation lowers the pitch, that may be attributed to the consequent change in vibrating mass of the vocal cords. Vibrating mass of the vocal cords during phonation is mainly dependent on the tension and shape of the vocal cord, both of which are controlled by the internal and external laryngeal muscles, but to some extent is also affected by the subglottic pressure especially at the so-called register-boundary.
5. The vowels produced at fixed pitch with an intention to phonate in equal loudness have almost equal subglottic pressure, regardless of the different phon level according to the vowels.


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