Shape and shift of the laryngeal ventricle during phonation

Kitzing, Peter; Sonesson, Björn

Published in:
Acta Oto-Laryngologica

1967

Acta oto-laryngologica 63, 479–488 (1967)

SHAPE AND SHIFT OF THE LARYNGEAL VENTRICLE DURING PHONATION

P. Kitzing and B. Sonesson
Lund, Sweden

From the Department of Anatomy (Head: Prof. C.-H. Hjortsjö) and the Department of Otolaryngology (Head: Prof. H. Koch), University of Lund

The shape and shift of the laryngeal ventricle during phonation was studied in profile roentgenographs of 41 young males with normal voice function. None of them was a trained singer.

From a mean of 14 mm at rest position of the vocal folds and during quiet respiration, the laryngeal ventricle was elongated by about 7 mm when the tone frequency was increased to 325 cps. The height of the laryngeal ventricle was increased from about 3 mm at rest position to about 5 mm at 225 cps. On further increase of the tone frequency the height diminished.

During respiration the laryngeal ventricle was generally located at the level of the lower border of the 5th cervical vertebra. During phonation at high pitch the laryngeal ventricle was generally elevated while at low pitch it moved downwards.

The elongation of the laryngeal ventricle was due mainly to a forward movement of the anterior border of the ventricle whereas the distance between the posterior border and the cervical column remained unchanged. It is confirmed that during phonation at increasing pitch the cricoid arch is rotated upwards about the transverse axis through the cricothyroid joints. The thyroid cartilage is moved forwards at the same time as the level of the laryngeal ventricle is raised.

INTRODUCTION

Proper evaluation of the significance of the shape of the laryngeal ventricle in phonation requires thorough knowledge of its functional anatomy. In the estimation of the acoustic significance of the laryngeal ventricle correct recording of the dimensions of the ventricle is important. According to van den Berg (1955) and Fant (1960) the laryngeal ventricle behaves as a low-pass filter setting a sharp upper frequency limited at about 4500 cps in the vowel spectrum and the spectrum of the tone frequencies appears to depend on the dimensions of the ventricle. Tomography (Husson, 1951; Luchsinger, 1953; van den Berg, 1955 and Shimizu, 1961) has shown the dimensions of the ventricle to vary during speech, and according to van den Berg (1955) this variation may be correlated with vowel as well as with the tone volume.

The present investigation was supported by grants from the Swedish Medical Research Council (Project No. 14X-122-01) and from the Faculty of Medicine, University of Lund.

Except for the paper by Curry (1937), who studied only one subject, no systematic analysis has hitherto been reported dealing with the possible relation between the dimensions of the ventricle and the pitch. In the subject studied by Curry the height of the laryngeal ventricle was at its minimum at lowest and highest pitches.

In planimetric studies of lateral roentgenograms of the ventricle during respiration Flach (1964) found that the average size of the ventricle was larger in singers with good voices than in subjects with voices of poor quality, indicating that the ventricle might have an acoustic influence upon the human voice.

Since the vocal fold forms the floor of the laryngeal ventricle, there is close correlation between the variation in length of the fold and of the ventricle. Several workers in this field have studied the relation between the frequency of tone and the length of the vocal folds and have shown that the increase in frequency is accompanied by a systematic lengthening of the vocal folds (Kirikae, 1943; Sonninen, 1954 and 1956; Hollien, 1960 and others). This correlation should of course, also apply to the laryngeal ventricle, but a perusal of the literature failed to reveal any systematic investigation to check this assumption. It would also be of interest to elucidate the effect of the upward tilting of the folds described by Hollien & Curtis (1962).

As to the level of the laryngeal ventricle during phonation the larynx is occasionally found to move cranially with increasing pitch (Parmenter, Trevino & Bevans, 1933; Faaborg-Andersen & Sonninen, 1959; Hollien & Curtis, 1962 and Keenan & Barrett, 1962), but in the well-trained singer it seems not to move appreciably (Frommhold & Hoppe, 1965). On the other hand, cinefluorographic observations have been reported indicating interindividual variations in the movement pattern of the larynx during phonation (Shelton, Bosma & Sheets, 1960).

Since no anthropometric data are available on the laryngeal ventricle, it was thought legitimate to study the absolute dimensions with special reference to the changes which might occur during change in pitch and the present investigation is concerned with the dimensions found in the lateral roentgenogram.

MATERIAL AND METHOD

The material consisted of 41 apparently healthy male medical students, aged 20–22. None of them were amateur or professional singers.

(*a*) *X-ray technique*

A Siemens Heliophos-Tutomat was used for taking the roentgenograms.[1] The distance between the X-ray anode and the median plane of the head

[1] We thank Dr. Jan Gärtner for generous help with the collection of the material and in taking the roentgenograms.

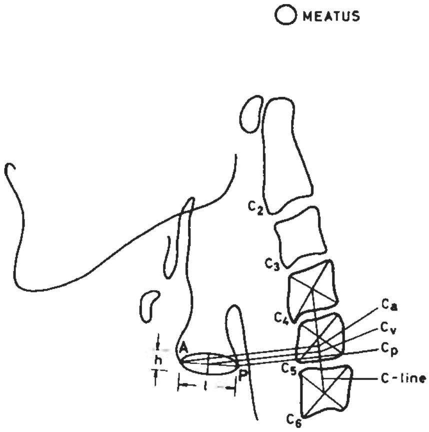

FIG. 1.

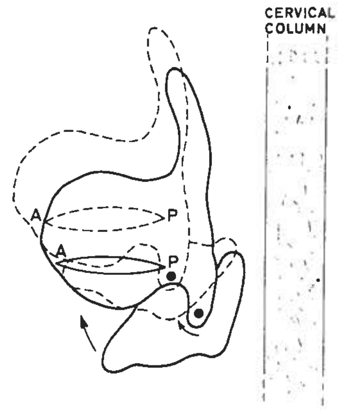

FIG. 2.

FIG. 1. Schematical drawing from the lateral roentgenogram of the neck and the laryngeal ventricle. A = the most anterior point of the ventricle; P = the most posterior point of the ventricle; l = the length of the ventricle; h = the height of the ventricle; *C*-line = *the Cervical line* connecting the central points of the cervical vertebral bodies. C_a = the projection point of the point A on the C-line; C_p = the projection point of the point P on the C-line; C_v = the projection point of the central point of the ventricle on the C-line.

FIG. 2. The shift of the laryngeal ventricle during increase in frequency of tone.

was 155 cm, and that between the median plane and the film plane was 9 cm. These distances, which gave an enlargement of approximately 6% of the image, were kept constant. The exposure time was 0.1 sec and the voltage 90 kV. This apparatus was fitted with a "head positioner". By means of a "pointer" the head was placed in the Frankfort plane and well-fixed so that it could not be moved in any direction. In this way it was always possible to place the head of a given subject in the same position from one occasion to another. This method proved just as good as the use of the best prevalent cephalometers available (for details see Hjortsjö *et al.*, 1954).

Lateral roentgenograms were taken of the region of the neck during *quiet respiration* at the end of the expiratory phase, and during phonation of the vowel "æ" at three different pitches. The subjects were given the different frequencies from a tone generator and were asked to phonate at medium intensity, corresponding to the intensity level of normal conversation. The subjects were divided into two groups, group A (28 subjects) phonating with the frequency of 100 and 300 cps, and group B (13 subjects) with the frequency of 125, 225 and 325 cps.

(*b*) *Measurements*

The contours of the laryngeal ventricle and the cervical vertebral bodies in the lateral roentgenograms were traced on paper, in which a line, called *the cervical line* (the C-line) was drawn, connecting the central points of the vertebral bodies. The C-line served as reference for measuring the movement of the laryngeal ventricle. The reference lines are given in Fig. 1.

On each drawing the following data were recorded:

1. Anterior-posterior length (*l*) and height (*h*) of the laryngeal ventricle.
2. Perpendicular distances from the most anterior and most posterior points of the laryngeal ventricle to the C-line (A-Ca and P-Cp), and the distance between the projection of these points on the C-line (Ca-Cp).
3. The perpendicular projection of the central point of the laryngeal ventricle on the C-line (Cv) was marked and the position of this point was defined during quiet respiration and at the different pitches recorded.

RESULTS

Group A

The mean length of the laryngeal ventricle at the end of the expiratory phase of respiration was 15 mm. At the frequency of 100 cps there was no significant change in the length of the ventricle. At the frequency of 300 cps the mean length of the ventricle increased to 21 mm. In two cases, however, the length remained unchanged compared with the length at respiration. *The mean height* of the laryngeal ventricle was 2 mm during respiration. At the frequency of 100 cps it increased to 3 and at 300 cps to 4 mm.

Group B

The mean length of the laryngeal ventricle at the end of the expiratory phase of respiration was 13 mm. At the frequency of 125 cps the mean length increased to 17 mm. In one case, however, the laryngeal ventricle became 2 mm shorter, and in one case the length remained unchanged. At 225 cps the mean length of the ventricle increased to 21 mm, and for all the subjects there was a more or less pronounced lengthening, varying

TABLE 1. *Mean length (l) and mean height (h) of the laryngeal ventricle at respiration and at different pitches (cf. Figs. 3 and 4).*

Experimental Group	Respiration	100 cps	125 cps	225 cps	300 cps	325 cps
Mean length, mm						
A	14.9	15.3	–	—	20.6	—
B	13.0	–	16.6	20.9	—	20.4
Mean height, mm						
A	2.3	3.3	—	—	3.6	—
B	2.6	—	4.4	5.1	—	3.8

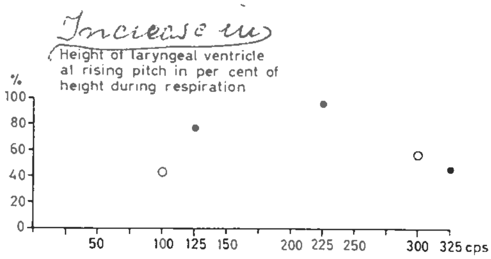

FIG. 3.

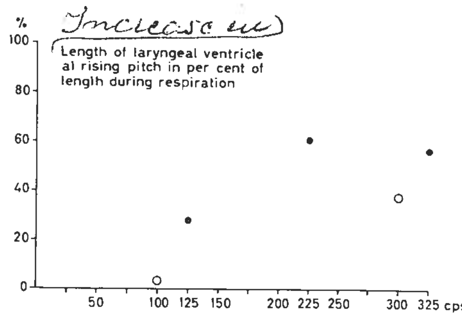

FIG. 4.

FIG. 3. The relation between the height of the laryngeal ventricle and the frequency of tone (cf. Table 1). ○ = group A; ● = group B.

FIG. 4. The relation between the length of the laryngeal ventricle and the frequency of tone (cf. Table 1). ○ = group A; ● = group B.

between 3 and 10 mm. At 325 cps no further increase was observed in the mean length of the ventricle (Table 1 and Fig. 4).

The mean height of the laryngeal ventricle, was 3 mm during respiration. At the frequency of 125 cps it increased to 4 mm and at 225 cps there was a further increase to 5 mm. At 325 cps, on the other hand, the height decreased, the mean value being 4 mm (Table 1 and Fig. 3).

The location of the laryngeal ventricle during respiration in group A and group B was generally on a horizontal level with the 5th cervical vertebra. In most of the subjects the position of the ventricle during respiration was the same as during phonation at frequencies of 100 and 125 cps. When changing from respiration to phonation at 225 cps (group B) the ventricle moved upwards in 6 cases, whereas in 4 cases it remained unchanged and in 3 cases it even moved downwards. When changing from respiration to phonation at the frequency of 300 cps the position of the

TABLE 2. *Vertical shift of the laryngeal ventricle (Cv) during phonation at different pitches as compared to the position during quiet respiration (cf. Fig. 1).*

c.p.s.	Upward movement	Downward movement	Unchanged position
100	2	16	10
125	3	7	3
225	6	3	4
300	8	2	18
325	8	—	5

TABLE 3. *Mean vertical shift (in mm) of the most anterior point (Ca) and the most posterior point (Cp) of the laryngeal ventricle during phonation at different pitches as compared to the position during quiet respiration (cf. Fig. 1).*

	Anterior point (Ca)		Posterior point (Cp)	
c.p.s.	Upward movement (mm)	Downward movement (mm)	Upward movement (mm)	Downward movement (mm)
100	—	5.6	—	5.8
125	—	3.7	—	4.9
225	2.2	—	2.5	—
300	5.9	—	6.0	—
325	6.2	—	6.6	—

laryngeal ventricle remained unchanged in 18 subjects, but moved cranially in 8 subjects. Only in 2 cases did it move downwards and then only slightly (Table 2). At the tone frequency of 325 cps the level of the ventricle rose in 8 subjects (group B) and remained unchanged in 5 compared with the level during respiration.

In most of the cases the cervical lordosis was found to be more or less straightened at higher frequencies of tone.

The following observations were made on the projections of the most anterior and the most posterior points of the laryngeal ventricle on the C-line (Ca and Cp): At low frequencies both the anterior and the posterior points shifted in caudal direction, and the lower the frequency the greater the shift (at 125 cps 3.7 and 4.9; at 100 cps 5.6 and 5.8, respectively). Increasing frequency was accompanied by an elevation of the anterior as well as of the posterior point, so that at the highest frequency studied in

TABLE 4. *Mean horizontal shift (in mm) of the most anterior point (A) and the most posterior point (P) of the laryngeal ventricle during phonation at different pitches as compared to the position during quiet respiration (cf. Fig. 1).*

	Anterior point (A)		Posterior point (P)	
c.p.s.	Ventral movement (mm)	Dorsal movement (mm)	Ventral movement (mm)	Dorsal movement (mm)
100	—	0.8	—	1.1
125	1.7	—	—	1.7
225	5.7	—	—	1.7
300	5.2	—	—	1.1
325	7.0	—	—	0.3

the present material, 325 cps, the level rose 6.2 and 6.6 mm, respectively, from the location at respiration (Table 3).

The lengthening of the laryngeal ventricle with increasing frequency was reflected in a ventral shift of the anterior point while the distance from the posterior point to the C-line, remained almost unchanged (Fig. 2 and Table 4).

DISCUSSION

The present investigation confirmed the observation by Shelton, Bosma & Sheets (1960) that the variation in the position of the larynx during phonation varies from one individual to another. The increase in length of the vocal folds with increasing frequency of tone as described by Sonninen (1956), Hollien (1960), Hollien & Curtis (1962) and others was found to hold also for the laryngeal ventricle.

In the present study the mean length of the laryngeal ventricle during respiration was 14 mm, whereas the length of the relaxed membranous portion of the glottis is reported to be 15.5 mm (Schaeffer, 1953). This difference may be explained by the fact that when the vocal fold is in the abducted position the posterior part of the fold is at the same time elevated (Sonesson, 1959; von Leden & Moore, 1961) and thus masks the most posterior part of the ventricle, being not visualized in the roentgenogram. Therefore in respiration the laryngeal ventricle might be shorter than the vocal fold. During phonation, however, the vocal fold is adducted and at the same time depressed, and the most posterior part of the laryngeal ventricle is opened. This may explain the relatively great increase in length of the laryngeal ventricle when changing from respiration to phonation at 125 cps compared with the further increase in length with increasing pitch.

In our material the length of the laryngeal ventricle was increased maximally 60%, and Sonninen (1956) found a maximal increase of 25% in the length of the vocal folds. This difference may be explained by the suggestion that during respiration the laryngeal ventricle is shorter than the vocal folds, whereas during phonation both have the same length. This means that the laryngeal ventricle will increase its length relatively more than the vocal fold.

As a rule, the ventricle shifted cranially with increasing frequency. This confirms the findings by Faaborg-Andersen & Sonninen (1959), Hollien & Curtis (1962) and others. Like Sonninen (1956) we found that the cervical spine straightens out so that its cranial part sometimes bends forward at higher tone frequencies. It appears reasonable to assume that the suprahyoidal and infrahyoidal muscles partake in this movement and on contraction contribute to the elevation of the larynx, as suggested by Sonninen (1956).

During the lengthening of the laryngeal ventricle the posterior point remained largely the same distance from the cervical line, while its anterior point moved in ventral direction. If any downward rotation had occurred around the transverse axis of the cricothyroid joint with lowering of the anterior border of the thyroid cartilage, as described by Jeschek (1953) and Berendes (1956), the anterior point of the ventricle would have assumed a more caudal position than its posterior point and the ventricle would have declined to an oblique position. But no such tilting was observed; the ventricle remained largely in the horizontal plane even at high frequencies and our findings support the opinion presented by Mayet & Mündnich (1958), Zenker & Zenker (1960), Arnold (1961) and others, that the rotation in the cricothyroid joint during lengthening of the vocal folds is an upward movement of the cricoid arch with a backward tilting of the cricoid lamina and the two arytenoid cartilages. The thyroid cartilage, however, seemed to remain in the horizontal position (Fig. 2).

The increase in height of the laryngeal ventricle when changing from respiration to phonation can be explained by the oblique axis of rotation in the cricoarytenoid joint, described by Sonesson (1959), Frable (1961) and von Leden & Moore (1961). When the vocal fold is adducted the arytenoid cartilage rotates about the oblique axis, moving the vocal process not only medially but also downwards. This implies that vocal folds moves away from the ventricular fold increasing the height of the laryngeal ventricle. The muscle fibres in the ventricular fold might also elevate this fold, contributing to the increase in the height of the ventricle.

At the frequencies above 225 cps, however, there was a reduction in the height of the laryngeal ventricle, and this finding supports the observation by Hollien & Curtis (1962) that the vocal folds are tilting upwards with increasing frequency of tone.

ZUSAMMENFASSUNG

Die Gestalt- und Lageveränderungen des Ventriculus laryngis während der Stimmgebung wurden an Hand seitlicher Röntgenaufnahmen bei 41 jungen Männern mit normaler, jedoch ungeschulter Stimme studiert.

In Ruhestellung der Stimmlippen und bei ruhiger Atmung betrug die Länge des Ventriculus laryngis im Durchschnitt 14 mm, während bei der Tonfrequenz von 325 Hz eine Verlängerung von durchschnittlich 7 mm auftrat. Die Breite des Ventriculus laryngis stieg von einem Ruhewert von 3 mm auf 5 mm bei 225 Hz an. Eine weitere Erhöhung der Tonfrequenz führte zu einer Verschmälerung des Ventriculus laryngis.

Während ruhiger Atmung lag der Ventriculus laryngis gewöhnlich in einer Höhe übereinstimmend mit der unteren Kante des 5. Halswirbels. Während der Stimmgebung in höheren Tonlagen erhöhte sich der Ventriculus laryngis gewöhnlich, während er bei tieferen Tonlagen abwärts sank.

Die Verlängerung des Ventriculus laryngis kam hauptsächlich durch eine Vorwärtsbewegung seiner vorderen Kante zustande, wohingegen der Abstand zwischen der hinteren Kante und der Halswirbelsäule unverändert blieb. Es

konnte festgestellt werden, dass sich bei Stimmgebung in steigenden Tonfrequenzen der Bogen des Ringknorpels um die horizontelle Achse durch die beiden Cricothyreoidgelenke aufwärts dreht. Der Schildknorpel bewegt sich hierbei vorwärts gleichzeitig mit einer Erhöhung des ganzen Ventriculus laryngis.

REFERENCES

Arnold, G., 1961: Physiology and pathology of the cricothyroid muscle. *Laryngoscope, 71*, 687.

Bérendes, J., 1956: Neuere Ergebnisse über Bewegungsstörungen des Kehlkopfes. *Arch. Ohr. Nas. Kehlkopfheilk., 169*, 1.

van den Berg, Jw., 1955: On the role of the laryngeal ventricle in voice production. *Folia Phoniat.* (Basel), 7, 57.

Curry, R., 1937: The mechanism of pitch change in the voice. *J. Physiol., 91*, 254.

Faaborg-Andersen, K., and Sonninen, A., 1959: The function of the extrinsic laryngeal muscles at different pitch. *Acta Otolaryng.* (Stockh.), *51*, 89.

Fant, G., 1960: *Acoustic theory of speech production* ('s-Gravenhage).

Flach, M., 1964: Über die unterschiedliche Grösse der Morgagnischen Ventrikel bei Sängern. *Folia Phoniat.* (Basel), *16*, 67.

Frable, A., 1961: Computation of motion at the cricoarytenoid joint. *Arch. Otolaryng.* (Chic.), *73*, 551.

Frommhold, W., and Hoppe, G., 1965: Tomographische Studien zur Funktion des menschlichen Kehlkopfes. *Folia Phoniat.* (Basel), *17*, 83.

Hjortsjö, C.-H., Persson, P.-I., Sonesson, A., and Sonesson, B., 1954: A tomographic study of the rotation movements in the temporomandibular joint during lowering and forward movement of the mandible. *Odont. Rev., 5*, 81.

Hollien, H., 1960: Vocal pitch variation related to changes in vocal fold length. *J. Speech Hearing Res., 3*, 150.

Hollien, H., and Curtis, J. F., 1962: Elevation and tilting of vocal fold as a function of vocal pitch. *Folia Phoniat.* (Basel), *14*, 23.

Husson, R., 1951: Etude tomographique des modalités de l'accolement des cordes vocales et du role des ventricules de Morgagni dans la différenciation des voyelles chantées. *C. R. Acad. Sci.* (Par.), *232*, 348.

Jeschek, J., 1953: Theorie und Klinik der Stimmbandlähmung. Arch. Ohr. Nas. Kehlkopfheilk., *162*, 269.

Keenan, J. S., and Barrett, G. C., 1962: Intralaryngeal relationships during pitch and intensity changes. *J. Speech Hearing Res., 5*, 173.

Kirikae, I., 1943: Über den Bewegungsvorgang an den Stimmlippen und die Öffnungs- und Verschlusszeit der Stimmritze während der Phonation. *Z. Otorhinolaryng.* (Tokyo), *49*, 236.

von Leden, H., and Moore, P., 1961: The mechanics of the cricoarytenoid joint. *Arch. Otolaryng.* (Chic.), *73*, 541.

Luchsinger, R., 1953: Physiologie der Stimme. *Folia Phoniat.* (Basel), *5*, 58.

Mayet, A., and Mündnich, K., 1958: Beitrag zur Anatomie und zur Funktion des M. cricothyreoideus und der Cricothyreoidgelenke. *Acta Anat.* (Basel), *33*, 273.

Parmenter, C. E., Trevino, S. N., and Bevans, C. A., 1933: The influence of a change in pitch on the articulation of a vowel. *J. Ling. Soc. Amer., 9*, 72.

Schaeffer, J. P., 1953: in *Morris' Human Anatomy*, 11th edition. The Blackston Co., Philadelphia.

Shelton, R. L., Bosma, J. F., and Sheets, B. V., 1960: Tongue, hyoid and larynx displacement in swallow and phonation. *J. Appl. Physiol., 15*, 283.

Shimizu, K., 1961: On the motions of the vocal cords in phonation studied by means of the high voltage radiograph movies. *Z. Hals. Nas. Ohrenheilk., 70*, 95.

SONESSON, B., 1959: Die funktionelle Anatomie des Crico-arytaenoidgelenkes. *Z. Anat. Entwicklungsgesch.*, *121*, 292.

SONNINEN, A., 1954: Is the length of the vocal cords the same at all different levels of singing? *Acta Otolaryng.* (Stockh.), Suppl. *118*.

— 1956: The role of the external laryngeal muscles in length-adjustment of the vocal cords in singing. *Acta Otolaryng.* (Stockh.), Suppl. *130*.

TRUFFERT, P., 1957: In *Larynx et phonation*. Bibliothèque des centres d'études supérieures speciales. Presses universitaires de France.

ZENKER, W., and ZENKER, A., 1960: Über die Regelung der Stimmlippenspannung durch von aussen eingreifende Mechanismen. *Folia Phoniat.* (Basel), *12*, 1.

Dept. of Anatomy, University of Lund,
Lund, Sweden

Received August 19, 1966