Imbalance of the Vocal Cords as a Factor for Dysphonia*

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Dysphonia without apparent organic lesion is usually referred to as functional voice disorder. This implies that the definition of "functional" would change with the development of diagnostic means. What appears normal on conventional indirect laryngoscopy may prove abnormal on further-advanced examination.

Indirect layngoscopy can reveal gross organic lesion of the vocal cords, but rheological changes of the vocal cord, for instance, would be rather difficult to find out by indirect laryngoscopy. Our clinical experience with the use of indirect laryngoscopy indicates that dysphonia is usually associated with imperfect closure of the glottis during phonation.

The factors contributory to hoarseness, other than the glottal gap, should be reevaluated under the experimental conditions representing each of the possible factors. The present paper particularly deals with tension and mass imbalance between the bilateral cords, and imbalance between glottal condition and expiratory air flow. The vibratory pattern of the vocal cords under varied artificial conditions was studied in dog through the use of a high speed camera.

Experimental Procedures

Twelve adult dogs and 96 rolls of high speed film were used for the experiment.

The dogs were anesthesized by Thiamylal Natrium 15 mg/kg intraperitoneously. Supraglottal laryngectomy was performed for better visualization. Voicing was elicited mostly by pain stimuli but on occasion when the above procedure failed to induce vocalization, Hering-Breuer's reflex was utilized: artificial blowing through the tracheostoma leads to the glottal closure and voicing.

1) Imbalance between the vocal cords.

The artificial conditions imposed on the vocal cords include tension or mass imbalance with or without glottal gap. Tension imbalance was produced either by section of the superior laryngeal nerve or by electronic stimulation of the unilateral cricothyroid muscle after section of the bilateral external branches of the superior nerve. The stimuli were 5 volt, 50 Hz and 5 msec in duration.

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In extirpated larynx, tension imbalance was directly created by pulling the unilateral arytenoid cartilage posteriorly. Mass imbalance was made by placing a tiny lead disc carefully upon the upper surface of the unilateral or bilateral vocal cord so as not to produce the glottal gap.

2) Imbalance between the glottis and expiratory air flow.

The conditions of too weak tension of the vocal cord versus too strong air flow was created by bilateral section of the external branch of the superior laryngeal nerve and artificial blowing through tracheostoma. A reverse relation was realized by electrical stimulation of the bilateral external branches or cricothyroid muscles during spontaneous phonation.

For analysis of the vibratory pattern of the vocal cord, a high speed motion film was taken during phonation (Hycam Model K 2001 by Read Lake Lab Inc., 4000–6000 frames/sec). Timing marks were plotted on one side of the film at 1 msec intervals. The films were analyzed frame by frame through the use of a film analyzer (Nac Motion Analyzer Model 16-S).

Results and Discussion

1. Tension imbalance between the two vocal cords.

The laryngeal picture and vibratory pattern of the vocal cords in case of unilateral section of the external branch of the superior laryngeal nerve were essentially identical with those in case of contralateral stimulation of the cricothyroid muscle after bilateral nerve section. Unilateral contraction of the cricothyroid muscle resulted in deviation of the posterior commissure of the glottis to the inactivated side and more elongation of the vocal cord on the active side than on the inactive side (Fig. 1). Under the above condition of imbalanced elongation of the vocal cords, the two vocal cords vibrated at the same frequency. (Fig. 2) The vocal cord on the side of active cricothyroid muscle, however, always preceded

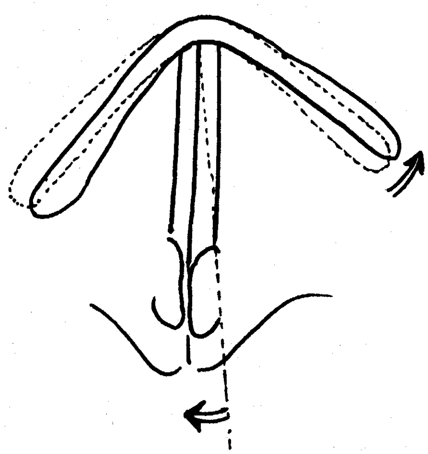

Figure 1. The glottal axis deviates toward the side of non-active cricothyroid muscle. Left nerve section or right stimulation.

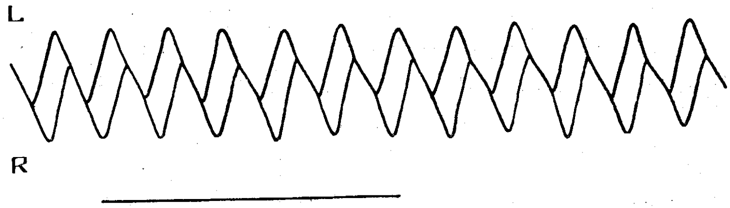

Figure 2. Vocal cord vibration after section of the external branch of the superior laryngeal nerve on the left. The frequency are equal on both sides. Note the phase shift between the two cords : more tense side (r) precedes the opposite member in opening and closing the glottis.

the mate in vibratory cycle. These findings were quite consistent among different materials. As to the amplitude of vibration, the findings were rather diverse. In 4 of 9 cases, no essential differences in amplitude were noted between the two cords. In the other 5 cases, the amplitude of vibration on the crico-thyroid active side was slightly greater than the non-active side.

On the extirpated larynx, where the cricothyroid distance was manually approximated on one side, the frequency of vibration was same on both sides and the tense cord preceded the opposite cord in vibratory cycle just as in the non-extirpated larynx.

When one vocal cord of the extirpated larynx was strongly stretched by direct pull of the arytenoid posteriorly, the tense cord vibrated with much less amplitude.

First, it should be noted that the effect of tension imbalance induced by unilateral contraction of the cricothyroid muscle is entirely different from that induced by direct stretching of one vocal cord. In other words, contraction of the unilateral cricothyroid muscle produces not only tension imbalance but also shift of the glottal axis, which in turn may cause imbalance in the air-pressure force exterted against each subglottal plane. Of clinical interest is the finding that the vocal cord on the side of the inactivated cricothyroid muscle is stretched remarkably, (2 mm for 12 cm vocal cord) by the contraction of the opposite cricothyroid muscle, though less than the active side (3 mm). Within the limitation of the experimental materials used, it should be emphasized that the effect of contraction of cricothyroid muscle on the vocal cord tension is not sharply separable between both sides.

The phase shift between the bilateral vocal cords, which was consistently found in case of unilateral action of the cricothyroid muscle, is difficult to explain at present. There is no knowing yet whether the phase shift is due to the slight difference in tension or due to the shift of glottal axis or both.

When the glottal gap was combined with tension imbalance, the vibratory pattern became irregular. The number of vibratory cycle were sometimes different and sometimes not, although counting the number of vibration itself was difficult.

2. Mass imbalance between the two vocal cords

In general, the weighted vocal cord vibrated with smaller amplitude but the frequency of vibration was identical on both sides. The voice was lowered in pitch but not hoarse. Increase in mass of the vocal cord resulted in increase of the glottal resistance, and stronger subglottal blowing was required for voice production. If the glottis was not completely closed at rest, the vibration of the both cords became irregular and unloaded vocal cord frequently corssed the mid-line in closed phase (Figure 3). In summary, our experimental results indicate that if there is no glottal gap, tension or mass imbalance of the two cords does not produce independent vibrations at different frequencies.

Smith and Moore, utilizing the Smith's vocal cord model, demonstrated that the weighted cord vibrates with less amplitude but at the same frequency as the opposite cord. As to the clinical cases, von Leden, Moore, and Timcke reported that no measurable difference in the fundamental frequencies of the two vocal cords was observed even in the presence of pronounced unilateral diseases.

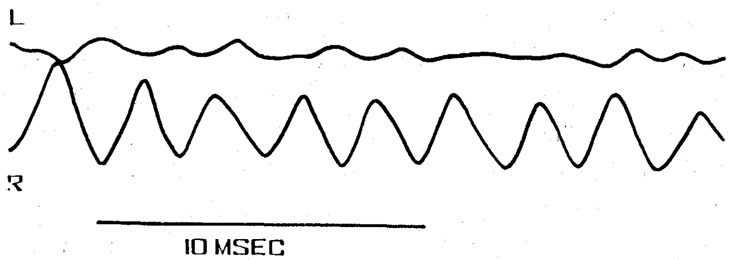

Figure 3. Weighting one vocal cord (l) and glottal gap. The vibration of the weighted cord is irregular and the unloaded cord frequently crosses the midline in closed phase.

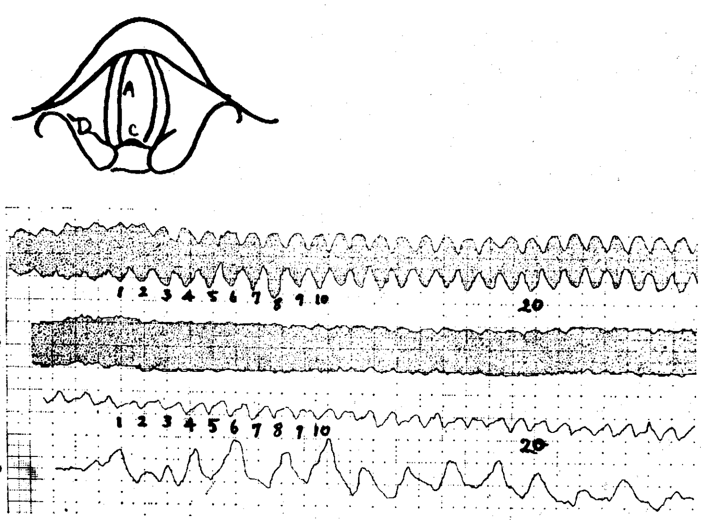

Figure 4. Glottal vibration during cough. The posterior wall of the glottis vibrates synchronously with the vocal cords.

Dunkel and Schlosshauer, and Jeschek reported on cases of recurrent laryngeal nerve paralysis in which the two cords vibrate at the same frequency.

Figure 4 illustrates the vibratory pattern of the vocal cord during cough. It is very interesting that the posterior wall (Marked C) vibrates synchronously with the vocal cords (Marked A). Under the condition of high velocity of air flow and consequent great Bernoulli effect at the glottis, the posterior wall of the glottis is assumed to be driven into vibration synchronously with the vocal cord.

The above example seems to indicate that any tissue on the same level at the glottis, regardless of slight difference in mass or tension, would vibrate at the same frequency, if the Bernoulli effect is great and the tissue is compliant. However the present experiment also indicates that when the glottis is not completely closed, the number of vibration of the imbalanced two cords may not coincide with each other.

Recent reports on the vibratory pattern of the vocal cords, however, show that the vocal cords could vibrate at different rate. Moore found that in case of small localized edema on one vocal cord the two cords vibrated at different rates. Ward, Sanders, Goldman and Moore reported on a very interesting case of physiological diplophonia where the two vocal cords vibrated at different frequencies. In our experiment, so far we have not been able to elicit periodic and independent vibration of the two vocal cords at different frequencies. The reported clinical cases of vibration of the two cords at different frequencies are rare condition worthy of special report. On the other hand, our experiment is now only at the qualitative stage, and quantitative and more systematic investigation is needed for explaining more varied type of vibration. Vocal cord vibration at different frequency for each side would take place only under very critical condition, if it is possible.

The effect of weighting one vocal cord is not so simple as may be expected. It also depends on the tension of the vocal cords. The next exemplifies the complexity of the relations between the factors. The voice was originally very high and weak due to great tension of the vocal cord. Loading one vocal cord with tiny lead disc facilitated voice production: louder and lower voice was produced. Loading the two cords with heavier disc completely ceased vocalization.

Vibratory features of the vocal cord is theoretically determined by three factors: stiffness (tension), mass of the vocal cord and subglottal air pressure. Therefore, more systematic and quantitative investigation as a function of the three parameters is required as the next step for understanding the mechanism of hoarseness.

3. Imbalance between the glottal condition and expiratory air flow.

When the bilateral external branches of the superior laryngeal nerve were cut, the voice became very low and rough although the glottis was completely

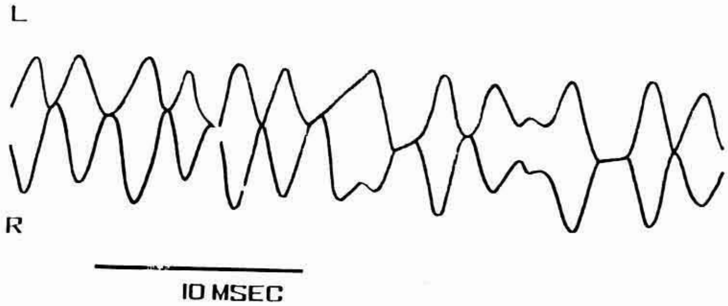

Figure 5. After bilateral section of the external branch of the superior laryngeal nerve.
Although the glottis closes completely at rest, too flaccid vocal cords give rise to aperiodic vibration.

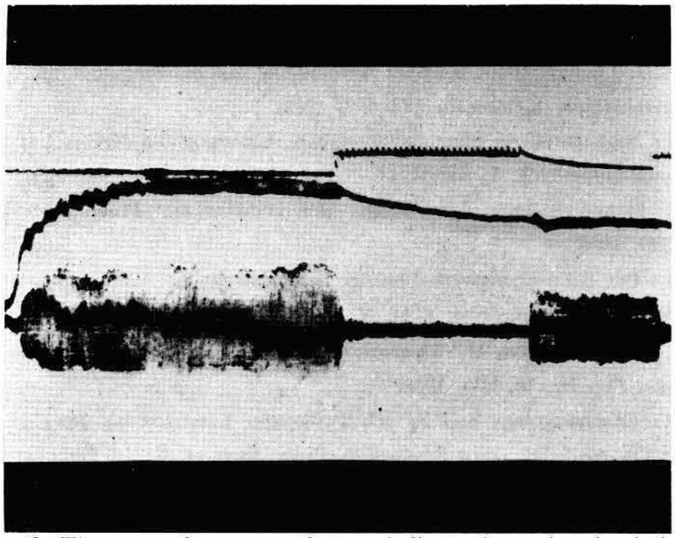

Figure 6. The curves from top to bottom indicate electronic stimulation to the cricothyroid muscle, subglottal pressure and voice. Voice ceases while the stimuli are given to the cricothyroid muscle.

closed at rest. High speed film demonstrated marked shift of the mucosa along the margin of the glottis indicating lax vocal cord and predominant Bernoulli effect at work. The vibration of the vocal cord is not very periodic, with the glottis sometimes closed and sometimes remaining open (Figure 5). As the expiratory air flow increases, the vibration of the vocal cords becomes more irregular. Briefly, too flaccid vocal cord can be responsible for dysphonia.

Too tense vocal cord can also be responsible for aphonia or dysphonia. Figure 6 demonstrates that voice can not be produced when the vocal cords are too tense: voice ceases while the electronic stimuli are given to the cricothyroid muscle.

Clinically, a case of hyperfunctional dysphonia was much improved in voice temporarily by 0.5% Xylocain injection into the cricothyroid muscle. These experimental and clinical findings suggest the importance of rheological characteristics (stiffness) or the vocal cord in so-called functional dysphonia.

Summary

The effect of various imbalance of the vocal cords was investigated in dog through the use of a high speed camera. Within the limit of our experimental procedure, the two vocal cords asymmetrical in mass or tension vibrated at the same frequency.

Experimental evidence and clinical experiences indicated that imbalance between the glottal condition and expiratory air flow could be an important factor in the etiology of functional dysphonia or aphonia.

References

1. Dunker, E. & Schlosshauer, B.: Klinische und experimentelle Studien über Stimmlippenschwingungen. Arch. Ohren- Nasen-Kehlkopfh. **172**: 363, 1958.
2. Dunker, E. and Schlosshauer, B.: Über Anspannung und Schwingungsform der Stimmlippen. Arch. Ohren- Nasen- Kehlkopfh. **173**: 492, 1958.
3. Döhne, E.: Beobachtungen über eine periphere Lähmung des Nerves Laryngeus Superior. Arch. Sprach-Stimmheilk. **5**, 157, 1941.
4. Hiroto, I.: Pathophysiology of the larynx as a vocal organ. Practica Otologica Kyoto 59 (suppl.), 229, 1966.
5. Jeschek, J.: Das Schwingungsverhalten der Stimmbänder bei Lähmung in Paramedian und Intermediärstellung. Zentralblatt f. H. N. O. Heilk. **64**, 239, 1959.
6. Moore, P. and von Leden, H.: Dynamic variations of the vibratory pattern in the normal larynx. Folia Phoniat. **10**, 205, 1958.
7. Moore, P.: Otolaryngology and Speech Pathology. Laryngoscope **78**: 1500, 1968.
8. Smith, S.: On Artificial Voice Production. Proceedings of the 4th International Congress of Phoniatric Sciences. Helsinki 1961.
9. Smith, S.: Remarks on the physiology of the vibrations of the vocal cords. Folia Phoniat. **6**, 166, 1954.
10. von Leden, H., Moore, P. and Timcke, R.: Laryngeal vibrations: measurement of the glottic wave. Part III. The pathologic larynx. Arch. Otolaryng. **71**: 16, 1960.
11. von Leden, H. and Moore, P.: Vibratory pattern of the vocal cords in unilateral laryngeal paralysis. Arch Otolaryng. **53**: 493, 1961.
12. Ward, P., Sanders, J., Goldman, R., and Moore, P.: Diplophonia. Annales of Otolog. **78**: 771, 1969.

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