Fundamental Study on Vocal Fold Vibration and Its Clinical Application

H. Fukuda

Department of Otolaryngology
School of Medicine, Keio University
35 Shinanomachi, Shinjuku-ku, Tokyo 160, Japan

INTRODUCTION

Nobody can deny that the phonosurgical technique plays an important role for normal restoration of voice in cases of laryngeal lesions. For an excellent goal of phonosurgery, new ideas of surgical technique and new instruments have been world-wide developed. It would be said that these developments are designed mainly based on basic studies, especially ones on physiological aspects of the vocal fold vibration.

In our department, basic studies on the mechanism of vocal fold vibration have been carried out with a painstaking effort using canine larynges and with an X-ray stroboscope.

Clarification of the mechanisms of vocal fold vibration is a problem which continues to hold significant fascination for every laryngologist. The traditional means of observing and recording the phonatory behaviour of the vocal folds have been laryngostroboscopy and ultra-high speed cinematography. These methods have indeed clarified the vibratory mechanism to some extent, but they have allowed us to observe vibration on the superior surface of the vocal fold only.

The creation and introduction of X-ray stroboscopy by our laboratory has made observation of vocal fold vibration in the frontal and sagittal planes possible.

METHOD

For data collection, an x-ray stroboscope developed in our laboratory was driven by a trigger from a laryngostroboscope. A block diagram of this system is shown in Figure 1. Basically the system radiated x-ray beams synchronously with the fundamental frequency of the sound produced and permitted us to get a frontal view of vocal fold motion.

Experiments were conducted with the use of resected canine larynges. As contrasting media, lead particles were inserted into the vocal fold itself. Therefore, the vibratory pattern of the upper and lower surfaces of the vocal fold, as well as the vibratory movements under the epithelium, could be simultaneously demonstrated on a videoscope while being photographed by a 16 mm fluorocinematographic system.

For further experiments, the vibratory pattern was observed and x-ray stroboscopically recorded while the laryngeal muscles were activated using live canines.

The bilateral vocal folds were forced to adduct to obtain glottal closure by suture of the posterior commissure using nylon thread. After this procedure, the RLNs were electronically stimulates to obtain muscle activity. The high frequency electrical stimulation just above the threshold for the RLNs is thought to mainly activate the thyroarytenoid muscles. A polyethylene tube was inserted into the cut-end trachea for introducing the air flow needed to obtain experimental sound.

RESULT

– X-ray stroboscopy –

The pellet inserted into the very superficial part of the so-called free edge (Fig. 2) vibrates well (Fig. 3). However, we could not obtain any regular movement in the pellet (Fig. 4) as shown in Figure 5.

Another representative case is demonstrated in the following figures. The pellet G was inserted into the membranous part of the so-called free edge, and others, H I J and K were inserted into the muscle layer (Fig. 6). The movements of those pellets along the X and Y axes were demonstrated in Fig. 7 and their Lissajous' figure in Fig. 8. As shown in these figures, the regular and phasic movement is obtained in only the pellet G.

Observation from the Tracheal Side

In the second experiment, we also tried to observe laryngeal vibration from the tracheal side, namely, the lower surface vibration. It is very difficult to observe the lower surface of the vocal fold of an excised larynx while it is vibrating, because the tube providing the airflow source obstructs direct observation. Consequently, we modified the air source by sucking the air from the supraglottic space, thereby obtaining airflow from the subglottis to the supraglottis. In this way, a completely free space at the subglottic side was available for photographing (Fig. 9).

In Fig. 10 one cycle of vibration at 100 Hz is shown. The tracings are the movements of the upper and the lower surfaces of the vocal folds. The center beam is the movement of the upper vocal fold.

It is very interesting that the peak of the wave of the lower surface movement is faster than that of the upper surface movement (Fig. 11), and that the closed phase of vibration is obtained only in a limited portion as shown in Fig. 12. The arrow indicates the border in which vibration on the supraglottal surface during the closed phase may be seen.

CLINICAL APPLICATION

– Development of laryngeal vibrator –

Nobody can deny that good vibration of the vocal folds in essential for good sound production, and that flexibility of the vocal fold membrane is essential for good vibration. When the flexibility of the fold is impaired, vibration will be affected. Therefore, it is reasonable to observe the vocal fold during vibration to assess the flexibility of the vocal fold membrane. If the vocal fold surface exhibits an abnormal region where good vibration cannot be observed, this area would be expected to show reduced flexibility. In fact, this phenomenon can be observed clinically in vocal fold cancer.

Up to now, the high speed movement of the vocal fold during phonation has been observed perorally through use of high speed motion picture photography (Farnsworth, 1940) or laryngostroboscopy (Oertel, 1985: Timcke, 1956). However, this vibration can be obtained only when voice is produced. Laryngologists actually observe the vibratory pattern of the vocal fold while a patient phonates, for example during phonosurgery, but this kind of vibration cannot be observed when the patient is undergoing laryngomicrosurgery under general anesthesia. A method is needed to permit vibrations to be observed even when the patient is unconscious. Such a method would be an aid for performing laser surgery for vocal fold cancer under general anesthesia. The observed vibrations would help to determine which part of the fold should be vaporized by the laser.

We have designed a method to solve this problem. Instead of observing *phonatory* vibrations, we observe *forced* vibrations produced by applying a vibrator to the neck. In this paper, we report basic and clinical studies using the new method.

Figure 13 shows the vibrator, designed for clinical use by us with the collaboration of the Nagashima Medical Instrument Company. Vibration frequency is 100 Hz and vibratory amplitude is less than 5 mm. In clinical use, the externally induced vibration of the fold is observed under stroboscopic illumination. The stroboscope is controlled manually. Because the vibration frequency is fixed. apparent vibration frequency can be easily regulated with the stroboscope.

RESULT

– Observation in patients –

Figure 14 shows single frames from two representative patients. one with a vocal fold polyp and one with cancer (T_{1a}). In this figure, the black points represent the positions of targets that were used for frame by frame analysis.

The position of each of the points shown in Figure 14 was tracked in two dimensions. Results of this procedure are shown in Figure for the patient with a polyp and in Figure for the one with cancer.

Measures of distance between the pairs of points are shown for the patient with a polyp in Figure 15 and for the patient with cancer in Figure 16. It is evident and notable that the distance between the two points does not change in the case of vocal fold cancer, while the distance between the two points in the case of a vocal polyp changes regularly.

No change of the distance between the two points indicates the stiff change of the vocal fold, which means that there may be stiff vocal lesions like white mass including carcinoma. In fact. we have used this new method during laser surgery on a cencer-affected vocal fold. in order to know precisely what parts should be vaporized and what parts should not.

DISCUSSION

For phonosurgery or precise biopsy. Saito, Fukuda & Kitahara (1975) have employed a laryngostroboscope during the operation. However. for this method. the patient must phonate. Hence, this method can to be applied when an operation is carried out under general anesthesia using a tracheal tube or when the voice is too hoarse to drive a laryngostroboscope well.

The vibrator method permits the observation of wavelike motion of the vocal fold membrane stroboscopically, even without a patient's phonation. This method is especially useful for precise analysis of the physical properties of the vocal fold using ultrahigh speed cinematography. Moreover, the new method is clinically useful, especially when laryngomicrosurgery is carried out under general anesthesia. Using the new method, it is possible to determine whether there is wavelike motion on the surface of the vocal fold, even when the patient's phonation is too husky to drive a laryngostroboscope or when it is nonexistent.

From the basic studies on the wave motion viewed from multi-directions, it is now clear that the wave is observed mostly at the so-called free edge, and the wave starts near the free edge at the lower surface of the vocal fold. It is well known that the wave motion does not occure if the vocal fold membrane is stiffened. Hence, we should avoid an excessive and undesirable scar formation especially at the free edge after phonosurgical procedure. In order to avoid an undesirable scar formation, it is highly recommended that the vocal fold polyp or nodules, for example, should be removed with one action of forceps. The numbers of actions of surgical tools should be reduced as much as possible, expecting an excellent wound healing. An excellent wound healing will result in production of the healthy membrane which is exclusively necessary for the wave motion on the surface of the vocal fold.

Finally, it is emphasized that the key point of the phonosurgery is to maintain or restore the normal membrane especially at the free edge for production of the phasic wave motion, which will result in an excellent sound production.

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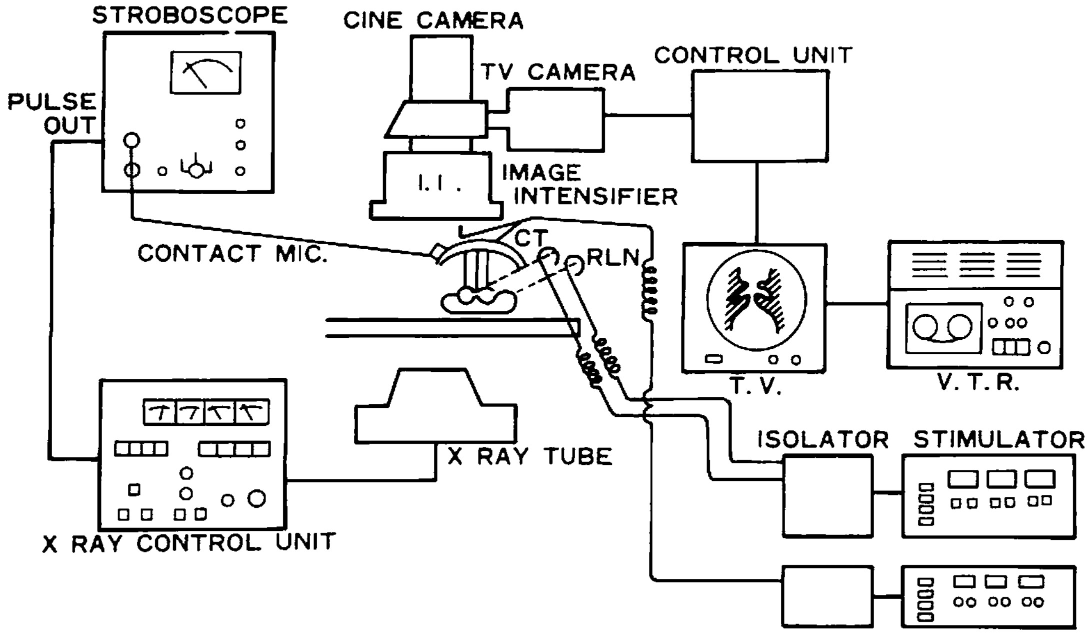

Fig.1 Block diagram of X-ray stroboscope.

Fig.2 A tiny pellet inserted into the free edge.
(An arrow indicated)

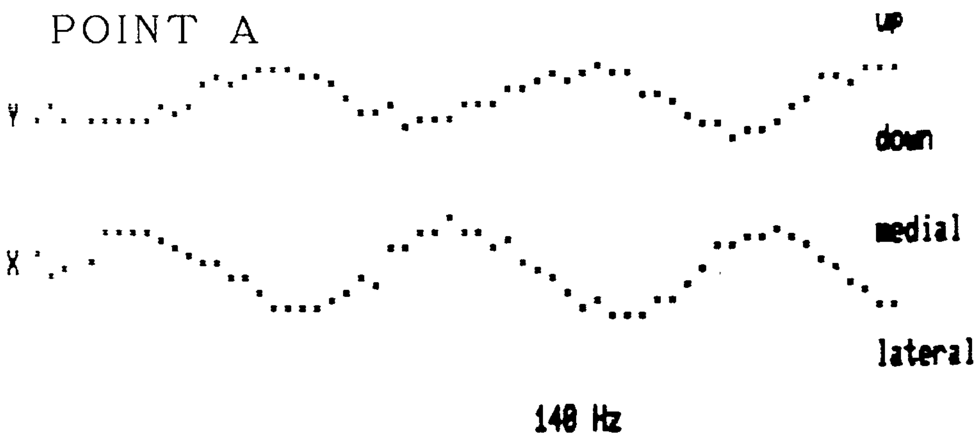

Fig.3 An analysis of movement of the pellet in the free edge along X and Y axes, showing phasic motion.

Fif.4 A tiny pellet inserted into the musle layer.
(An arrow indicated)

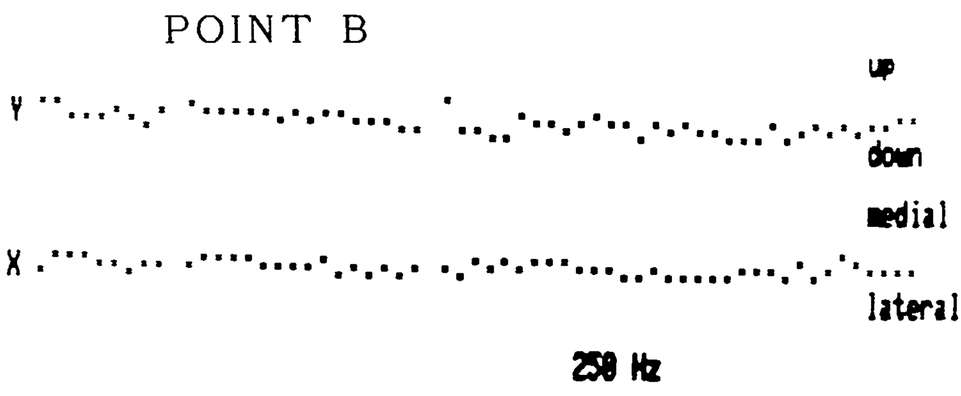

Fig.5 An analysis of movement of the pellet in the muscle layer along X and Y axes, showing no phasic motion.

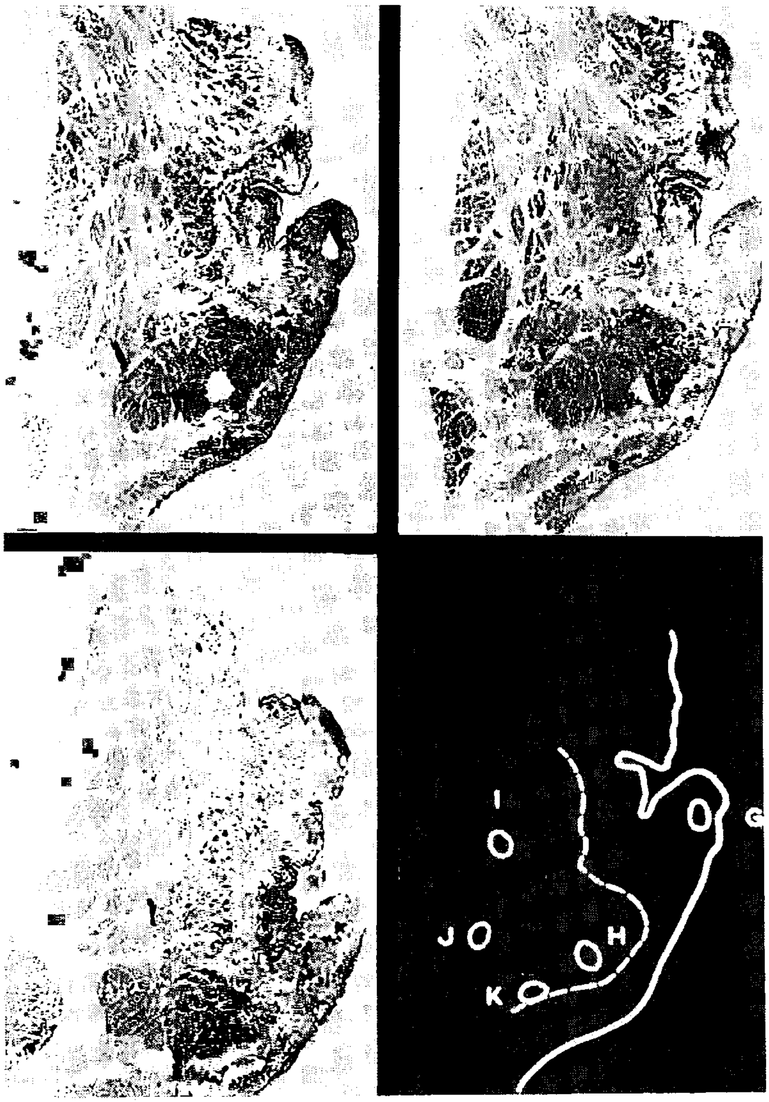

Fig.6 Another representative case.
Histlogical location of the inserted pellets.
Only the pellet G is inserted into the free edge.

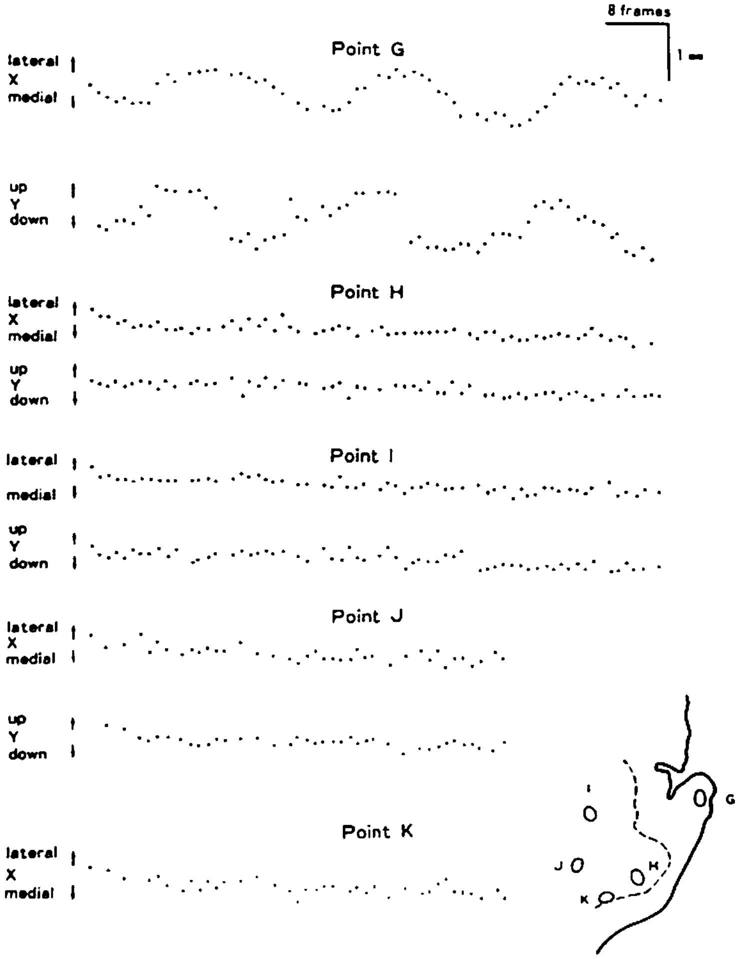

Fig.7 An analysis of those pellets movement along X and Y axes. A phasic motion is obtained in only yhe pellet G.

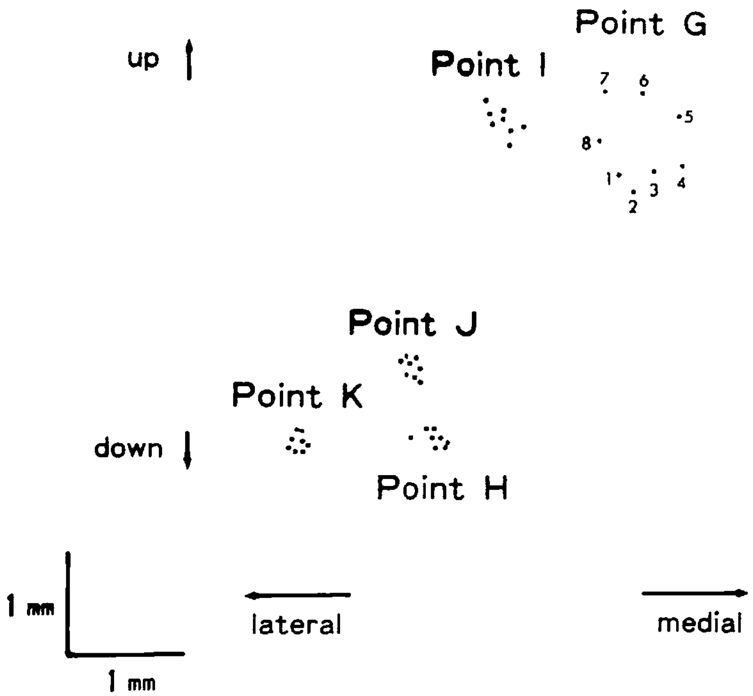

Fig.8 Lissajous figure of their movements.

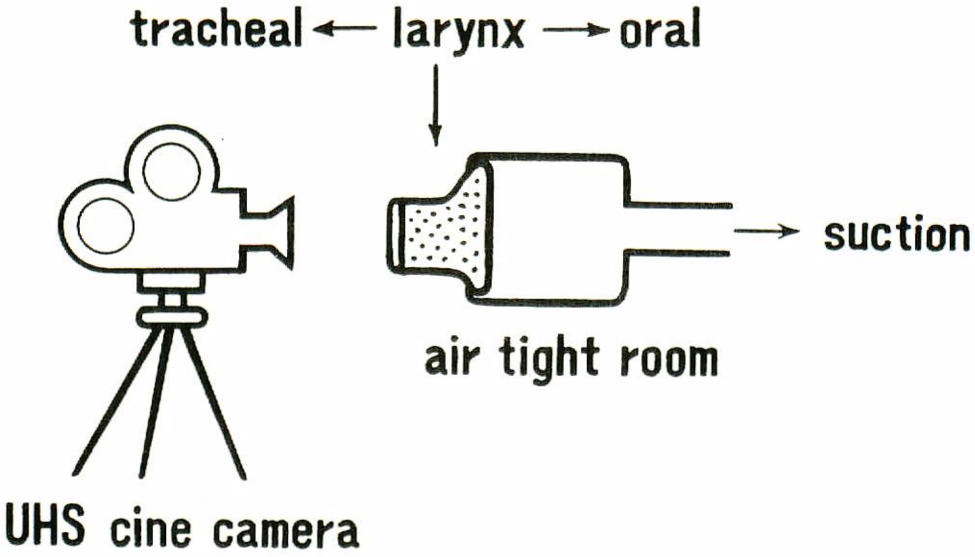

Fig.9 Block diagram of the system for photographing the vocal fold vibration from the lower surface.

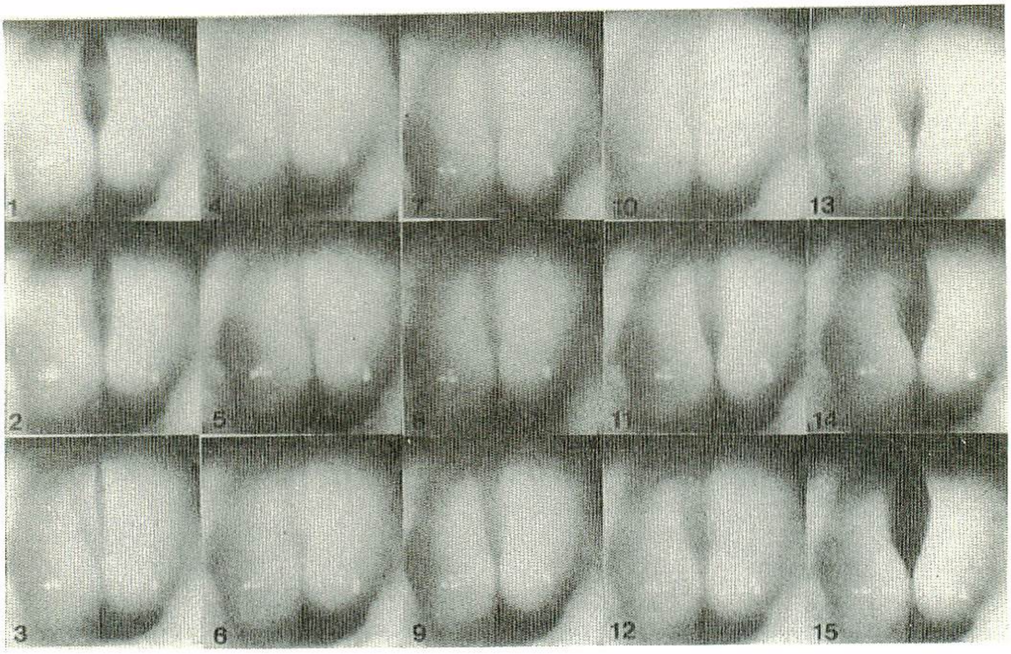

Fig.10 One cycle of vibration at 100 Hz.

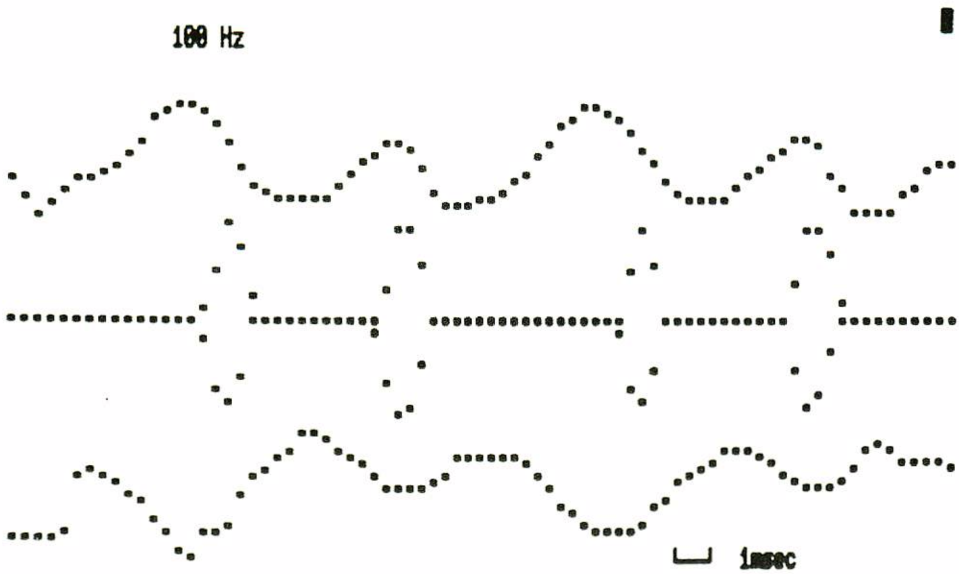

Fig.11 Trace of the movement.
Middle trace indicates the movement of the upper surface of the vocal fold.

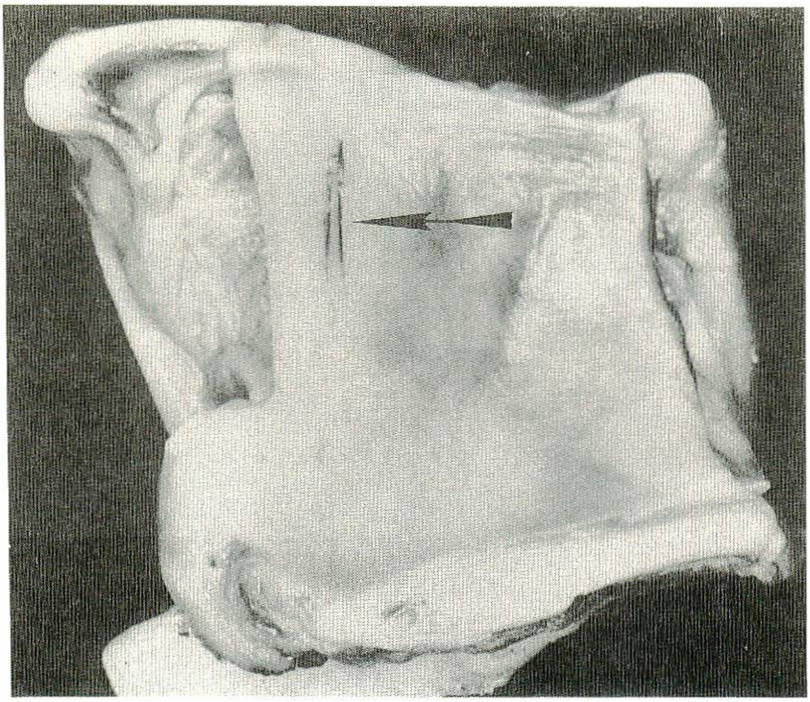

Fig.12 An arrow indicates the place of initiation of the vocal fold vibration.

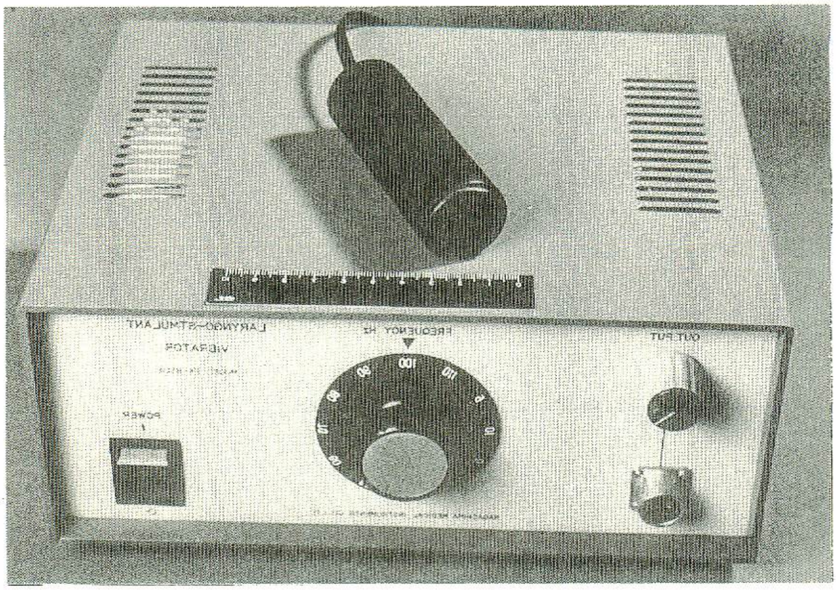

Fig.13 A newly designed laryngeal vibrator now on market.

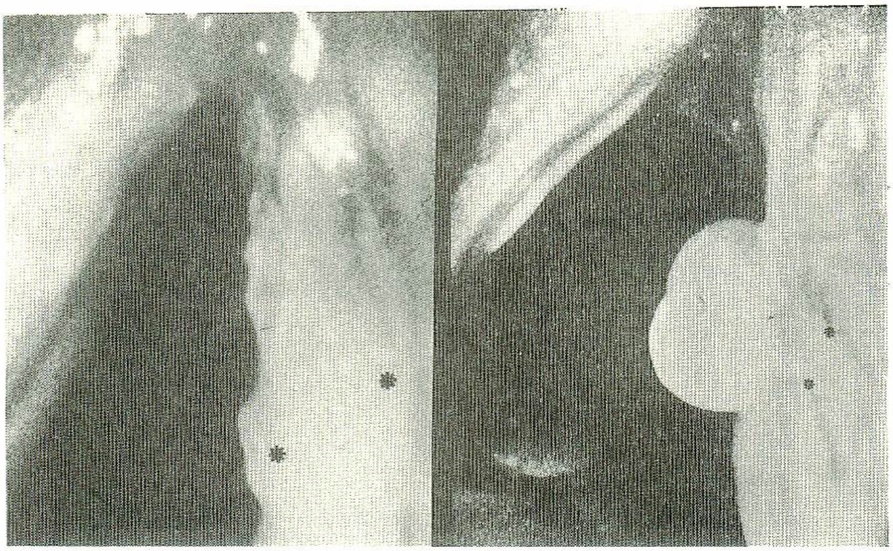

Fig.14 A clinical application of the laryngeal vibrator. The left figure is the vocal fold carcinoma. The right figure is the vocal fold polyp. The black points are selected for analyzing the wave motion induced by the laryngeal vibrator.

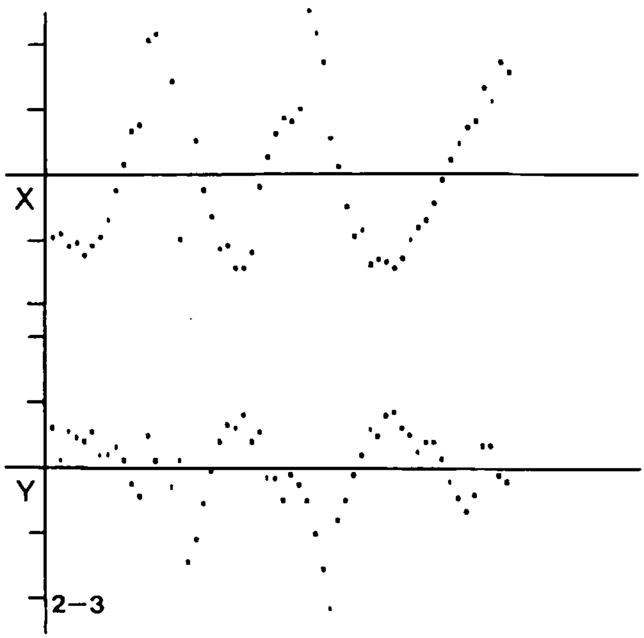

Fig.15 Phasic change of distance between two points in case of polyp.

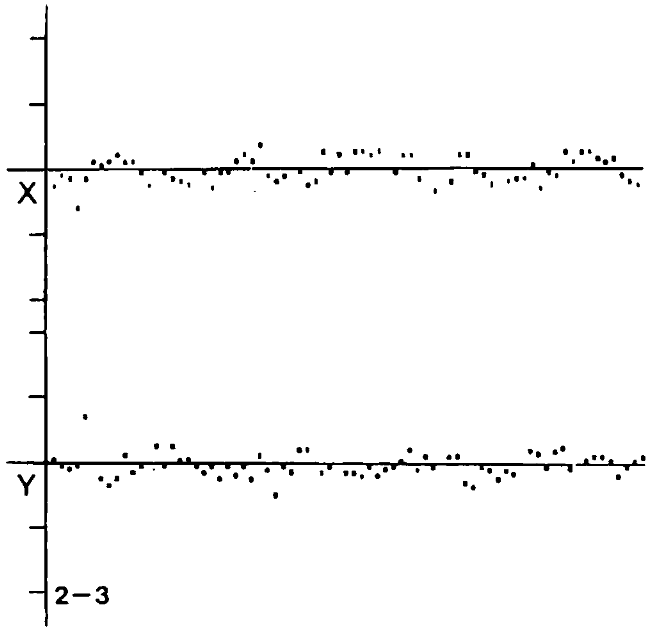

Fig.16 No phasic change of distance between two points in case of cancer.