Ann. Bull. RILP, No. 14, 73-78 (1980)

MEASUREMENT OF THE LARYNGEAL STRUCTURES DURING PHONATION BY USE OF A STEREOENDOSCOPE*

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ABSTRACT

A new system for stereoscopic observation of the laryngeal view has been devised by use of a modified oblique-angled endoscope which has two optical systems equipped with separate objective lenses located at a prescribed mutual distance at its tip.

The scope is inserted into the subject's pharynx through the oral cavity for appropriate visualization of the larynx.

The two images thus obtained are recorded in juxtaposition on each frame of 35mm film for subsequent computer processing of three-dimensional data.

The use of a specially designed stereoscopic fiberscope for insertion through the nasal passage of a subject during speech utterance (Sawashima and Miyazaki, 1974; Fujimura et al., 1976, 1979) has significantly contributed to the accuracy of measurement of quantitative information with respect to laryngeal gestures.

The difficulties to date, however, have involved the need to fix the two lenses relative to each other by means of a metal connector, and the insufficient image resolution owing to the use of fiberoptic bundles. Recently, to solve these problems, a specially designed stereoscopic endoscope was devised by our laboratory. A preliminary data collection session has been conducted and the device has been found satisfactorily effective and simple to use.

The stereoendoscope used was manufactured by Nagashima Medical Instrument Corporation according to our specifications. It consists of two independent rigid optical systems each of which is equipped with an objective lens housed in its tip, and two light guides and a joint structure accommodating an eyepiece to which the two optical systems are mounted.

The two image fields, as viewed through the two objective lenses, are recorded side-by-side on each frame of photographic film. Figure 1 shows an example of a pair of stereoscopic images of the larynx as recorded by use of the new stereoendoscope. It is demonstrated that finer images are obtained compared with those taken by a fiberscope. The finer images are advantageous for identifying the measurement points more accurately.

*This study was supported in part by the Grant in Aid for Scientific Research (No. 337040, No. 448322, No. 410207), Ministry of Education, Science and Culture.

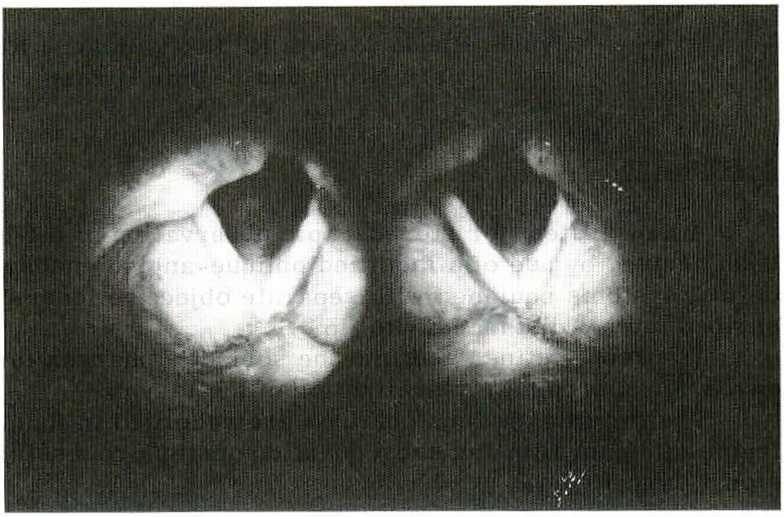
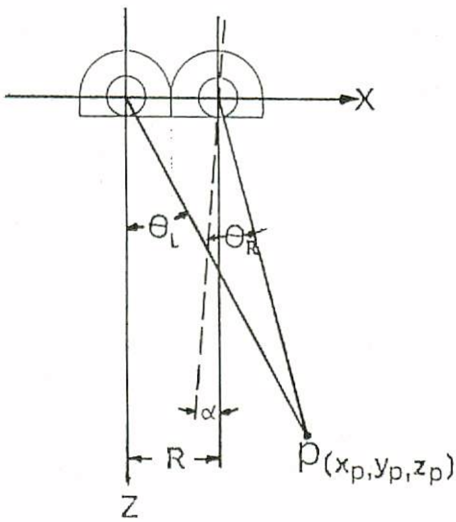


Figure 1. An example of a pair of stereoscopic images of the larynx recorded side by side.

Figure 2. Geometric quantities defined for computation of three-dimensional dimensions. The figure shows a projection onto the x-z plane. The angles θ_L and θ_R are defined within the plane.



Procedure and calibration of measurement

Measurements and the procedure of calculation are similar to those reported by Fujimura et al. (1979). Namely, the measurements are made by first projecting the filmed images onto the surface of a semitransparent digitizing tablet from the back and visually identifying the same landmark in both images.

By indicating the positions of these landmarks using a stylus associated with the digitizing tablet, the experimenter inputs their coodinates into a laboratory computer.

The computer then performs the calculations to locate these landmarks in three dimensions with respect to the endoscope tips. The description of a three-dimensional image is built up by measuring several points.

The geometrical considerations for the measurement theory are indicated in Figure 2. The two endoscope tips are assumed coplanar, and are mutually inclined to each other by a small angle α. The distance between the optical axis at the tips is R. A rectangular coordinate system is defined with the origin at the tip of the left endoscope. The Z-axis is along the optical axis of the left endoscope. The X-axis passes through the two endoscope tips, and the Y-axis is perpendicular (out of the page).

Vectors to the object point (x_p, y_p, z_p) form angles θ_L and θ_R with the left and right optical axes, respectively.

These angles are related to x_p and z_p by the equations

$$\tan\theta_L = X_P / Z_P \qquad \text{........(1)}$$

$$\tan(\theta_R - \alpha) = (X_P - R) / Z_P \qquad \text{......(2)}$$

Therefore,

$$Z_P = \frac{R}{\tan\theta_L - \tan(\theta_R - \alpha)} \qquad \text{........(3)}$$

For small α, this can be simplified to

$$Z_P = \frac{R}{\tan\theta_L - \tan\theta_R + \tan\alpha} \qquad \text{......(4)}$$

However, $\tan\theta_L$ and $\tan\theta_R$ are proportional to the distance D_L and D_R of the images of the point from the centers of the left and right optical fields, respectively.

Therefore, the equation can be further rewritten

$$Z_P = \frac{1}{K_1(D_L - D_R) + K_2} \quad \text{.......(5)}$$

Where D_L and D_R are measured on the projection of the image. The constants K_1 and K_2 depend on the endoscope tip geometry and the magnification of the projection system. Similarly, X_p is obtained from the relation

$$X_P = Z_P K_3 D_L \; , \; Y_P = Z_P K_3 D_P \quad \text{.......(6)}$$

The same multiplicative constant K_3 is also used to determine Y_p from measured distance in the Y direction on the images.

The calibration constants K_1, K_2, K_3 are empirically determined by photographing a grid at known distances.

Figure 3 shows the results of a calibration run consisting of several independent measurements at 9 known distances.

From the results of the calibration run, we can consider that the measurement errors would be smallest when the calibrations to fix the constants K_1, K_2, K_3 are held at the approximated measurement distances. Accordingly, the overall measurement error can be estimated at most within 3%.

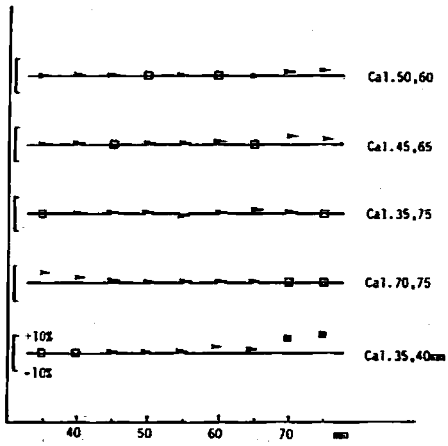


Figure 3

The ordinate shows the errors of measurement in percentages for each calibration run, and the abscissa is the actual vertical distances. A pair of □'s represent the distances used for calibration to fix K_1, K_2 and K_3.

Each ► shows the error of measured distances. ■ indicates a result having an error greater than 10%.

Measurement of the larynx

1) Figure 4 shows the result of the stereoscopic measurement on the vocal fold length and the distance between the two false vocal folds during sustained phonation in chest register where the tongue of the subject is pulled out of the mouth, in respect of pitch dependency.

In the figure, the ordinate indicates the distance (1mm for each division), and the abscissa the fundamental frequency (F_0) in logscale.

In the upper plot of the graph, the vocal fold length, i. e. the distance in a straight line between the anterior end and posterior end of the glottis slit, is shown by ■.

It can be observed that the vocal fold length is proportional to the logarithm of fundamental frequency in the scope of chest register. In the lower part of the graph, the distance between the two false vocal folds is plotted by ✱.

It is revealed that the distance between the two false vocal folds is almost stational regardless of the F_0 change.

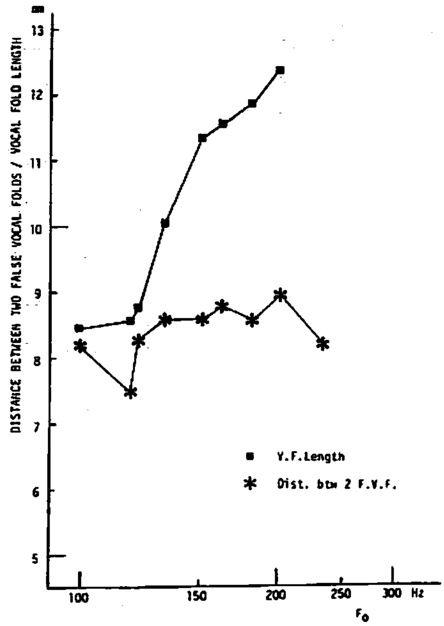


Figure 4

2) Figure 5 shows the result of stereoscopic measurement on the vocal fold length in relation to the change of the glottal width.

In the figure, the ordinate indicates the vocal fold length, and the abscissa the glottal width. As for the measurement of the vocal fold length during respiration, we measured the distance between the anterior commissure and the vocal process in a straight line, and the distance between both right and left vocal processes was measured as the glottal width.

It is revealed that the vocal fold length increases in relation to the opening of the glottis.

It is also observed that the lengths of right and left vocal folds are the same at both maximum and minimum opening of the glottis, while they differ from each other in the intermediate position of opening.

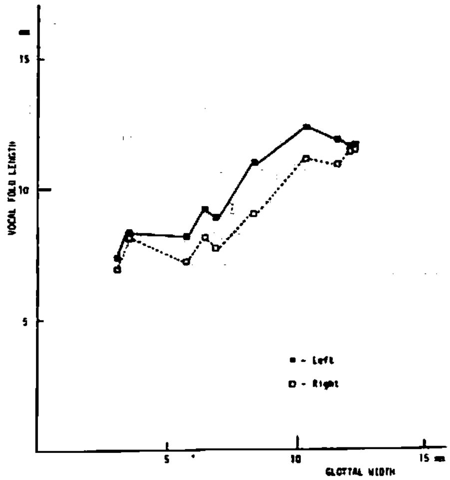


Figure 5

Further possibilities of stereoscopic measurement

The following table summarizes the possibilities inherent with stereoscopic measurement.

Measurement Items:	a. Vocal fold length b. Distance between both false vocal folds c. Inclination and height of the glottis* d. Glottal width e. Analysis of vibration of the vocal folds
Measurement Conditions:	1. Respiration and phonation 2. Fundamental frequency 3. Singing voice 4. Age

*A monitoring device is required for determining the position of the stereoendoscope.

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