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## Rheological Characteristics of the Vocal Cord

—Measurement of the Damping Ratio—

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The mode of vibration of the vocal cord depends greatly on its rheological characteristics. When we simulate phonation with the use of computer model, it seems most important to select parameter values as close as possible to those of the live human larynx. The damping ratio of the vocal cord is one of such factors which determines the mode of vibration.

The damping ratios of the vocal cord were measured by utilizing human larynges extirpated at autopsy or at surgery. In the surgical cases, the measurements were done within a few hours of surgery. The vocal cords on the intact side were used for the experiment. The larynges of autopsy cases had been kept frozen by the time of experiment. The vibration was given to the vocal cord by releasing it from a displaced position. Vocal cord vibration was photographed (6,000 frames/sec) with a high-speed motion picture camera (Hycam Model K2001, Red Lake Lab. Inc.) and the damping of the oscillation was traced by frame-by-frame analysis of the film (Nac Motion Analyzer Model 16-S). Figure 1 shows an example of the damped oscillation traced in the manner described above. The damping ratio was calculated according to formula shown below (Ishizaka, K.)<sup>1)</sup>.

$$\begin{aligned} \text{logarithmic decrement} \quad d &= \log_e \frac{A_k}{A_{k+2}} \\ \frac{d}{2} &= \log_e \left| \frac{A_k}{A_{k+1}} \right| \\ \text{damping ratio} \quad & \frac{1}{\sqrt{1 + \left( \frac{2\pi}{d} \right)^2}} \end{aligned}$$

Some examples of damped oscillation and the damping ratio are shown in Figure 2-4. The damped oscillation and damping ratio in an autopsy case are shown in Figure 2.

Figure 3 and 4 represent the damped oscillation and the damping ratio of vocal cords surgically resected. The damping ratios of the vocal cord (0.320 and 0.344) in the surgical cases were generally a little higher than those in the autopsy case (0.237).

The high damping ratio of the vocal cord in the surgical cases may be explainable by vocal cord edema caused by ligatures of the blood vessels during operation.

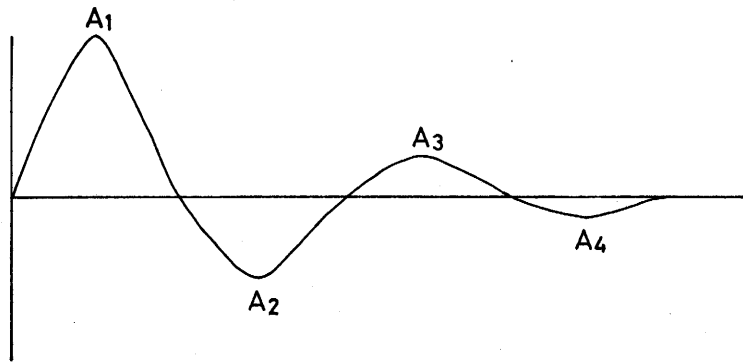


Fig. 1. An example of the damped oscillation. A1, A2 and A3 represent the values of successive peaks of the damped oscillation.

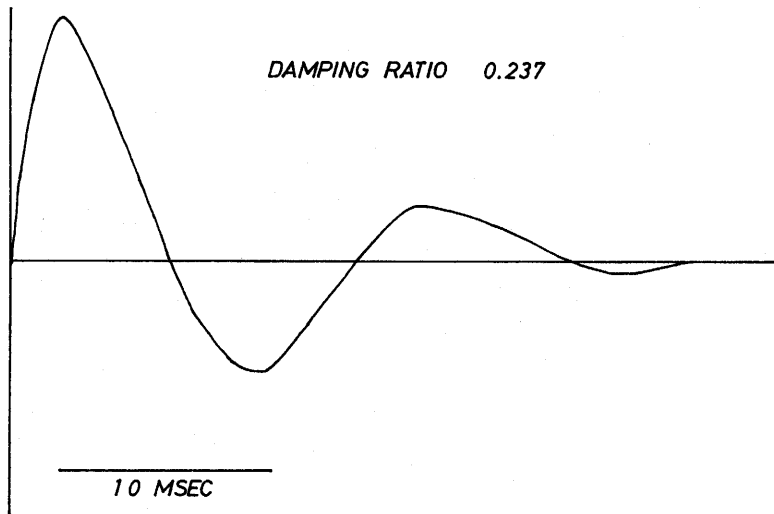


Fig. 2. Damped oscillation and damping ratio in an autopsy case.

In order to investigate the effect of swelling of the vocal cord upon the damping ratio, 0.12 ml of physiological saline solution was injected into the vocal cord. The result is shown in the lower curve of Figure 5, the upper curve shows the control. Injection of physiological saline solution increased the damping ratio from 0.237 to 0.334.

Generally, the addition of mass to the vocal cord decreases the damping ratio. The relation between the damping ratio and the mass of the vocal cord is given by

$$\frac{\zeta'}{\zeta} = \sqrt{\frac{m}{m+m'}}$$

where  $\zeta$  is the damping ratio,  $\zeta'$  is the apparent damping ratio of the vocal cord with an additional mass,  $m$  is the vocal cord mass and  $m'$  is the mass added to the vocal cord.

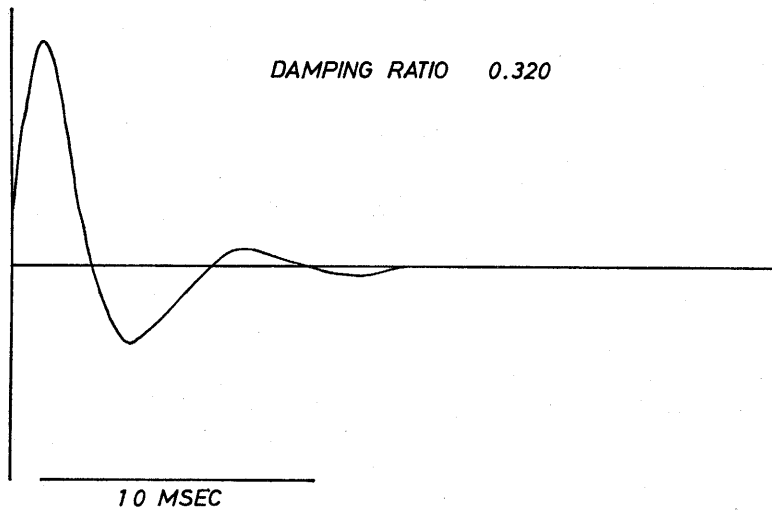


Fig. 3. Damped oscillation and damping ratio in a surgical case.

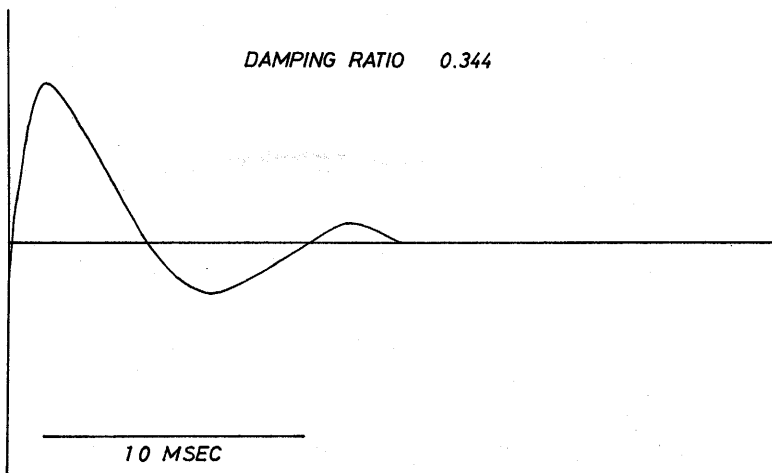


Fig. 4. Damped oscillation and damping ratio in a surgical case.

The damping ratio of the vocal cord should decrease if injection of physiological saline solution results in increase of mass without affecting other factors.

As shown in Figure 5, the damping ratio for the vocal cord with physiological saline solution injected was greater than that of the control. The result suggests that the effect of the rheological change of the vocal cord is greater than that of the saline solution-induced mass increase.

Clinically, increase of the damping ratio of the vocal cord means increased difficulty of vocal cord vibration. Specifically, a high damping ratio of the vocal cord requires greater subglottal pressure to initiate the vibration of the vocal cords. An increase of the damping ratio results in a decrease in the amplitude of vibration and an elongation of the closed phase. A low damping ratio of the vocal cord

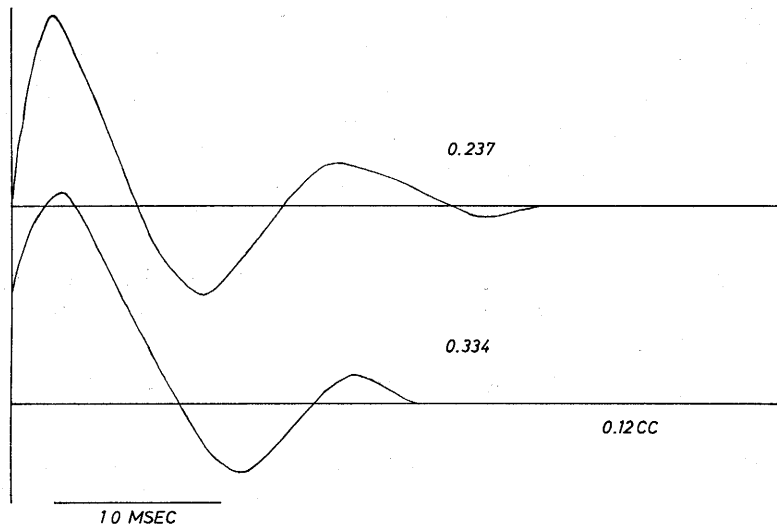


Fig. 5. The injection of physiological saline solution increases the damping ratio. The upper curve is a control and the lower curve is for physiological saline solution injection.

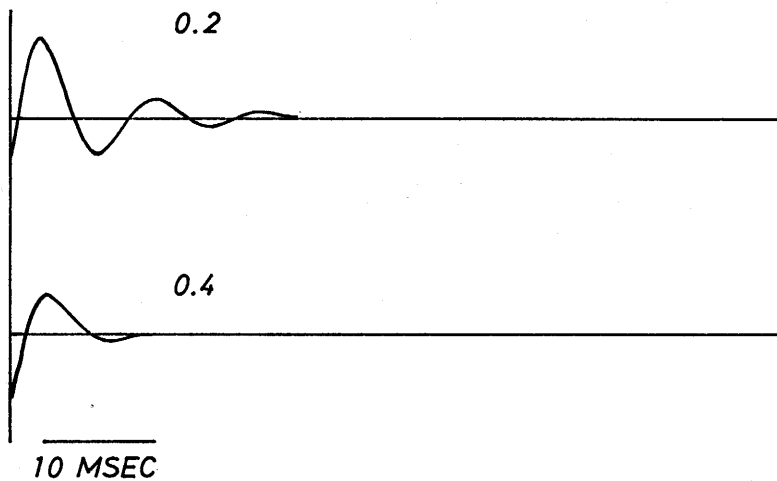


Fig. 6. Damped oscillation with a given damping ratio obtained by computer simulation.

usually facilitates the vibration. However, with a damping ratio of as low as 0.1, the effect of asymmetrical tension of the vocal cords becomes greater and the vibration becomes more irregular. Too low a damping ratio may also be disadvantageous for abrupt change of the vocal pitch.

The damping ratio of the vocal cords in the excised larynges in this study ranges around 0.3.

Figure 6 shows examples of damped oscillation with given damping ratios, obtained by computer simulation<sup>1)</sup>. The upper curve is a trace of damped oscil-

lation for damping ratio 0.2, the lower curve is for 0.4. The result of computer simulation also suggests the damping ratio of the vocal cord may range from 0.2 to 0.4.

The damping ratio of the vocal cord reported by Kaneko et al. (1974)<sup>2)</sup> is slightly lower than that measured in this study. The difference may be attributable to the different method employed in their experiments.

#### SUMMARY

The damping ratio of the vocal cord was measured in human larynges extirpated at autopsy or at surgery. The damped oscillation was produced by releasing the vocal cord from a displaced position.

The damping ratio of the vocal cord in the autopsy case was 0.237 and in the surgical cases 0.320 and 0.344.

Damped oscillation with a given damping ratio was simulated by use of computer.

#### REFERENCES

- 1) Ishizaka, K.: personal communication
- 2) Kaneko, T. et al.: Biomechanics of the vocal cord—damping ratio—(Japanese). J. Japan Broncho-Esophagol. Soc. 25: 133-138, 1974

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