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Application of Reflectionless Acoustic Tube for Extraction of the Glottal Waveform

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ABSTRACT

A reflectionless acoustic tube described by Sondhi is utilized to obtain the glottal waveform. The rationale of this method is that the effect of vocal tract resonances on glottal waveform is considerably reduced by a reflectionless uniform tube connected with the mouth during phonation. Measurement of the transmission characteristic (frequency response) of the tube proved minimal attenuation caused by the tube.

The obtained glottal waveform for four normal subjects and for nine patients with laryngeal pathologies are reported herein and methods presently available for estimating the glottal waveform are also discussed.

The method to obtain the glottal waveform with the reflectionless acoustic tube proved to be simpler and more practical for clinical use than the other ones.

INTRODUCTION

Analysis of voice is one of methods most frequently used to understand the mechanisms of pathologic phonation and to diagnose laryngeal diseases.

Acoustic waveform at the mouth includes the glottal waveform characteristic and the transmission characteristic of the vocal tract.

At certain frequency, the amplitude of acoustic output at the mouth (P(f)) is given as the product of the amplitude of the glottal waveform (S(f)) and the transfer function of the vocal tract (T(f)).

$$P(f)=S(f)\cdot T(f)$$

in decibels,

$$20\log_{10}P(f)=20\log_{10}S(f)+20\log_{10}T(f)$$

Figure 1 illustrates the relationship of these functions (Fant[1] 1960).

The glottal waveform seems directly influenced by the glottal conditions. It is therefore desirable to obtain the glottal waveform without

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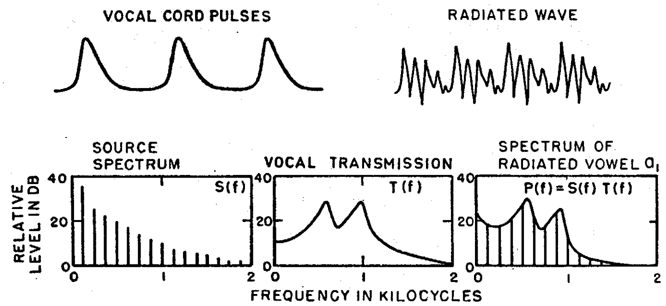

Figure 1: The transfer function of the vocal tract and frequency spectrums of the glottal waveform and the radiated sound (Fant, 1960).

distortion by vocal tract resonances in cases of voice problems.

It is the purpose of this work to apply a reflectionless acoustic tube designed by Sondhi[2] (1975) to obtain the glottal waveform.

METHOD AND MATERIALS

The rationale of Sondhi's method is that the effect of vocal tract resonances on glottal waveform is considerably reduced by phonating into a reflectionless uniform tube.

A reflectionless acoustic tube made following Sondhi's description is shown in Figure 2.

The tube is of brass, 1800mm long with an inner diameter of 26.5 mm. The reflectionless acoustic wedge is of fiberglass, 900mm long and approximately conical. A small hole with a diameter 2.2mm has been made in the wedge for releasing expiratory air during phonation.

A microphone (SONY ECM-51) is set in a small hole placed 300mm from the open end.

The transmission characteristic of the reflectionless acoustic tube was measured using a signal source on the open end and a microphone placed 300mm from the open end of the tube (Figure 3).

Figure 4 and 5 show the transmission characteristics of the tube with simple closed distal end and with open distal end respectively.
The transmission characteristic of the tube with the reflectionless acoustic wedge shown in Figure 6 proves minimal resonances in the tube.

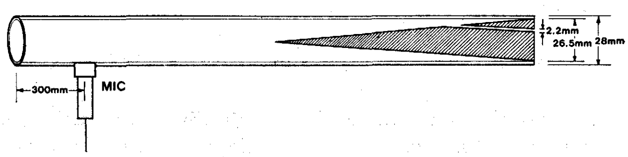

Figure 2: The reflectionless acoustic tube.

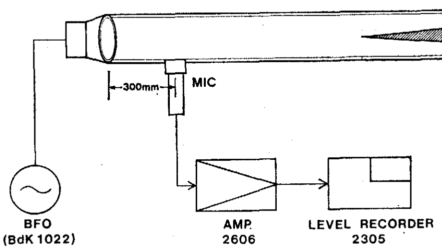

Figure 3: Measurement of the transmission characteristic of the tube.

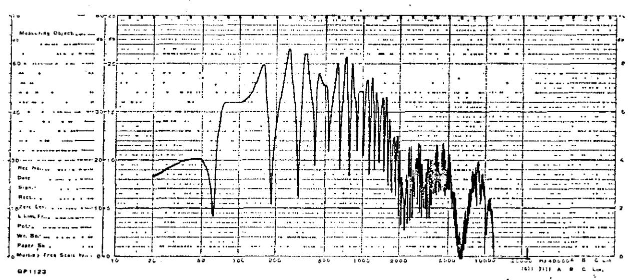

Figure 4: The transmission characteristic of the tube with simple closed end.

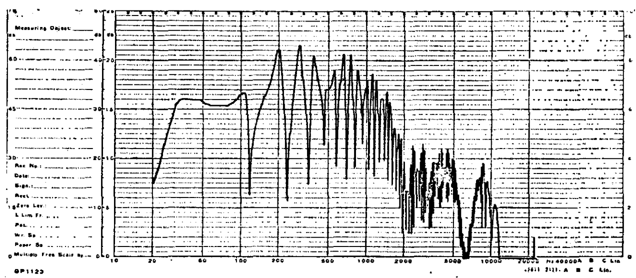

Figure 5: The transmission characteristic of the tube with open end.

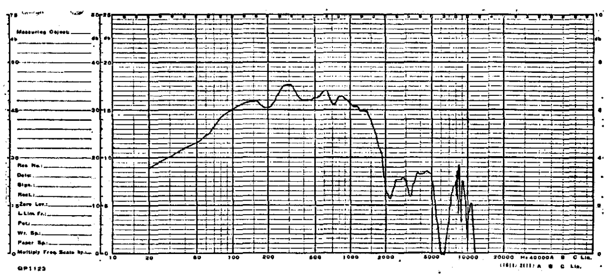

Figure 6: The transmission characteristic of the tube with a reflectionless acoustic wedge.

The glottal waveform in four normal subjects and in nine patients with laryngeal pathologies were measured in this study.

Each subject was instructed to insert the open end of reflectionless acoustic tube into mouth with special care to make smooth the connection between the vocal tract and the tube.

During phonation of the neutral vowel, the waveform via the microphone (SONY ECM-5) was recorded on a tape recorder (SONY TC 707MC) for precise analysis. The output of the microphone also fed into oscilloscope (TEXTRONIX 5103N) on line and the obtained waveform was photographed by a camera (C-5 OSCILLOSCOPE CAMERA).

RESULTS AND DISCUSSION

Figure 7 shows an example of acoustic output at the mouth and the extracted glottal waveform with the reflectionless acoustic tube. As recordings were not simultaneous, the phase of these two waveforms were not synchronous.

The glottal waveforms in three males and a female with no apparent voice defect was measured. Each was instructed to phonate the neutral vowel at various pitches.

Figures 8-11 show the obtained glottal waveforms with minimal distor-

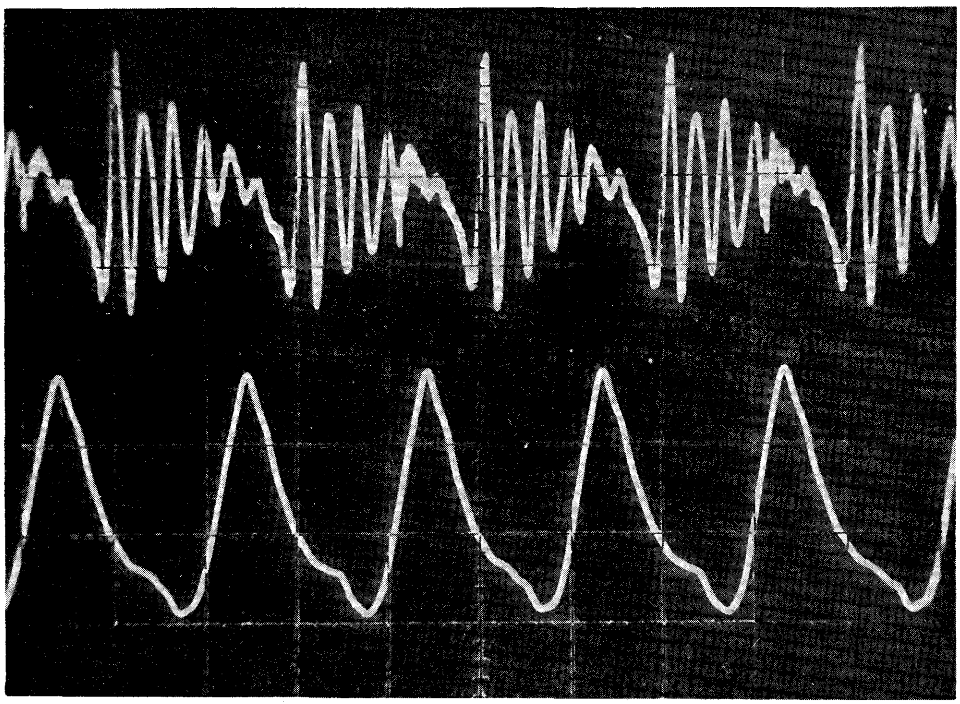

Figure 7: An example of obtained glottal waveform (bottom) and radiated sound wave (top).

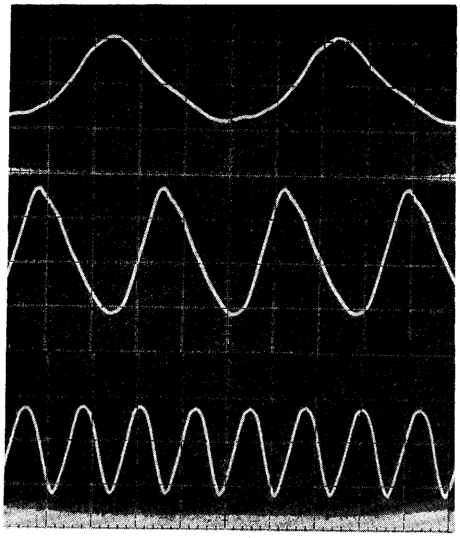

Figure 8: The obtained glottal waveform, normal subject, male, 2msec/ division.

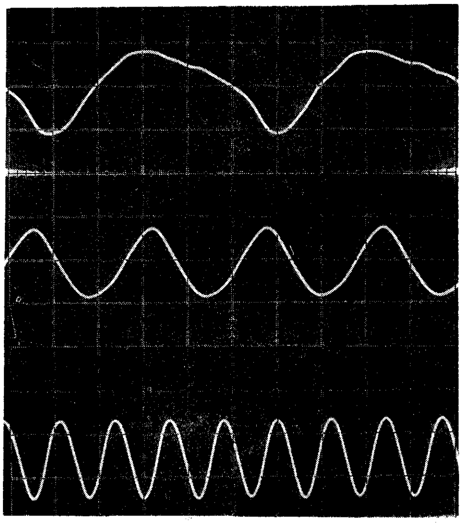

Figure 9: Normal subject, male, 2msec/ division.

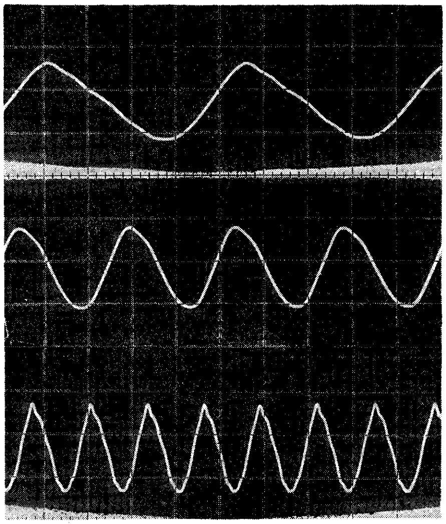

Figure 10: Normal subject, male, 2msec/ division.

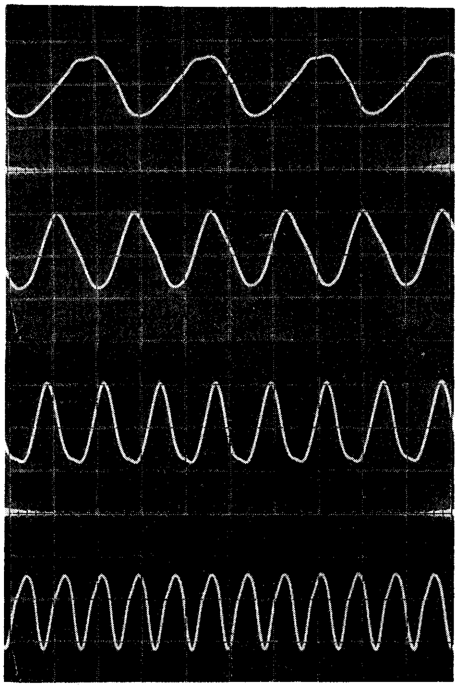

Figure 11: Normal subject, female, 2msec/ division.

tion by the vocal tract resonances.

The glottal waveforms obtained in nine patients with various laryngeal pathologies were shown in Figures 12-20.

Figures 12 and 13 show the glottal waveforms in cases of unilateral recurrent laryngeal nerve paralysis with narrow glottal chink.

The glottal waveforms obtained in two cases of unilateral recurrent laryngeal nerve paralysis with wide glottal chink are quite irregular as shown in Figures 14 and 15.

Figures 16 and 17 show the glottal waveforms of the patients with polypoid vocal cords.

Shown in Figures 18-20 are the glottal waveforms obtained in cases

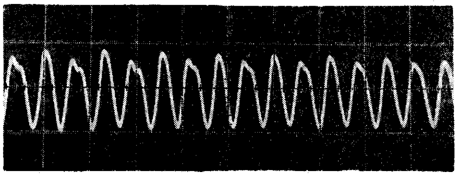

Figure 12: Unilateral recurrent laryngeal nerve paralysis (with narrow glottal chink), 5msec/division.

Figure 13: Unilateral recurrent laryngeal nerve paralysis (with narrow glottal chink), 5msec/division.

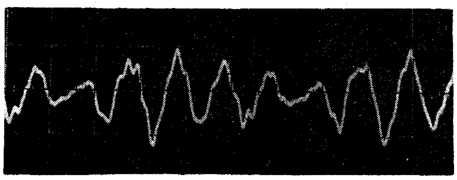

Figure 14: Unilateral recurrent laryngeal nerve paralysis (with wide glottal chink), 5msec/division.

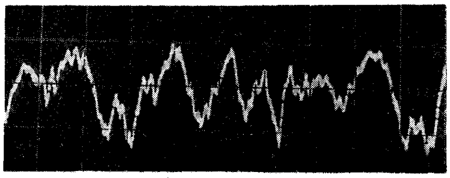

Figure 15: Unilateral recurrent laryngeal nerve paralysis (with wide glottal chink), 5msec/division.

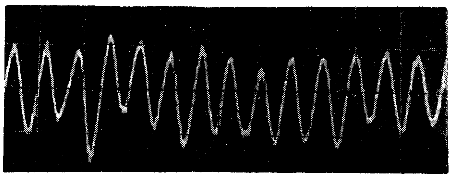

Figure 16: Polypoid vocal cords, 5msec/division.

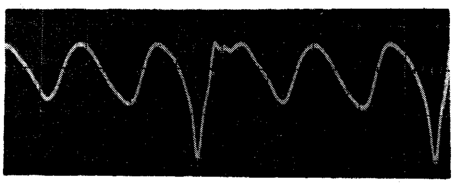

Figure 17: Polypoid vocal cords, 5msec/division.

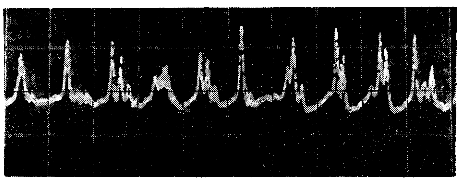

Figure 18: Glottic cancer, 5msec/division.

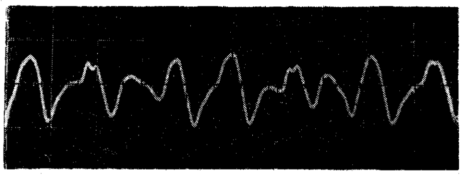

Figure 19: Androphonia, 5msec/division.

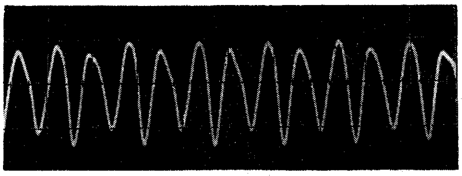

Figure 20: Laryngeal trauma, 5msec/division.

of glottic cancer, androphonia and laryngeal trauma, respectively.

Approximate glottal waveforms with simple shape are obtained in all those cases.

Although, it is ideal to measure directly the glottal waveform to diagnose laryngeal pathologies, a direct measurement is yet technically difficult. Various indirect methods or approximation methods are used to obtain the glottal waveform at the moment.

The other methods presently available are discussed briefly in comparison with the method used in this study.

(1) High speed motion pictures of the larynx may be processed to yield several thousand samples per second of the area Ag(t) of the glottis. This technique can at best give an accurate estimate of Ag(t). The airflow must be estimated from this.

(2) The photoelectrical method (Sonesson[3], 1960) give the pattern of variations in the transmitted light through the glottis. Ag(t) must be estimated from this.

(3) Ag(t) can also be estimated by measuring the variable electrical capacity of the vibrating vocal cords (electrical glottogram; Fabre[4], 1958).

In comparison with (1), although (2) and (3) give a less reliable estimate Ag(t), measurements are simpler and more practical technically.

(4) The vibration of the pretracheal wall has been used as an aid to extract the vocal pitches especially in a medical field (Sugimoto and Hiki[5], 1960). The extracted waveform has a resemblance to the glottal waveform in our experience. However, the frequency response of the pretracheal wall can not be easily calibrated.

(5) Other techniques designed to obtain the glottal waveform, for example, the use of ultrasonic waves (Bordone-Sacerdote and Sacerdote[6], 1965) and the direct measurement of subglottal air pressure (Hiki et al[7], 1970) are yet impractical.

(6) Recently, inverse filtering technique is often employed to estimate glottal waveform (Mathews et al[8], 1961; Rothenberg[9], 1973). The basic idea of this method is to measure the glottal waveform directly from the recorded acoustic out-put at the mouth by using the filter which is the inverse of the estimate transfer function of the vocal tract. However,

it is rather difficult to set up an adequate filter, and the technique can not be applied to subjects on line.

The crucial difference between the inverse filtering and Sondhi's method applied in this study is that instead of removal of the influence of the vocal tract resonances from the radiated sound waveform, the condition is set up so that the vocal tract transmit the glottal waveform with minimal distortion.

As the results in this study show, measurement of the glottal waveform (approximate glottal waveform, in the strict sense) with the reflectionless acoustic tube is simpler and more practical than the other methods available.

This method can be a useful means to understand the mechanisms of hoarse voice production and to diagnose laryngeal pathologies.

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