Variability of Electroglottographic Glottal Closed Quotients

Necessity of Standardization to Obtain Normative Values

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Objective: To demonstrate the variability of electroglottographic measurements of the glottal closed quotient (GCQ) in normal subjects by the calculation method used, fundamental frequency, and intensity.

Design: Prospective study.

Setting: Tertiary university-based referral center.

Subjects: Twenty healthy male volunteers without laryngeal disorder. Three successive sustained productions of the vowel /a/ were performed by each subject. Electroglottographic recordings of GCQ were obtained using the criterion level method, which defines an approximate duration of glottal closure and opening. Glottal closed quotient values were calculated based on criterion levels ranging from 10% to 40%.

Main Outcome Measures: The extent of correlation between GCQ variation and the mean fundamental frequency and intensity.

Results: As the criterion level increased, a decrease in the mean GCQ was recorded, which was significant with a 10% criterion level increase, up to a critical level of 25%. A significant positive correlation was found between GCQ and the variables of fundamental frequency and intensity.

Conclusions: This study demonstrated significant effects of the criterion level used, fundamental frequency, and intensity in the determination of normative values of GCQ. Normative values can only be assessed through the standardization of one criterion level reached by consensus.


During phonation, the vocal folds open and close as a result of several laryngeal and extralaryngeal activities. The phases of closure and opening of the vocal folds follow one another at a rate defined by the fundamental frequency (F0). The glottal closed quotient (GCQ) is the fraction of time the glottis is considered closed and has been thought to be a good indicator of voice quality. A noninvasive measurement of the GCQ is therefore of interest for theoretical and applied purposes.

Electroglottography (EGG) is a noninvasive method, based on Ohm law, of measuring the variation in electrical resistance between 2 electrodes placed on each side of the thyroid cartilage. When the vocal folds open and close during phonation, the electroglottographic wave changes in amplitude. The wave reflects variations of the vocal fold contact area (VFCA) and can be used to give a useful indication of the GCQ.

The definition of GCQ is illustrated in Figure 1 using the criterion level method. At the criterion level of 25%, distance A corresponds to an approximate duration of glottal closure, and distance B corresponds to an approximate duration of glottal opening. The ratio of A to A+B is an estimate of the portion of the cycle the glottis is closed and is called the GCQ.

The issue remains which criterion level should be used. Various levels ranging from 10% to 40% have been used in the literature. As the criterion level changes, the approximate durations of glottal opening and closure change. Therefore, the level that is arbitrarily chosen may significantly affect GCQ values. Therefore, GCQ normative values require investigation before clinical application.

The aim of this study was to test whether various criterion levels for GCQ calculation and some variables of voicing, such as F0 and intensity, may significantly affect normative values of GCQ.

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The simultaneously recorded EGG and acoustic signals were
directly digitized. The upper portion of the electroglottographic wave was considered and configured as the maximal
glottal closure and the lower portion of the electroglottographic wave as the maximal glottal opening.

CRITERIA OF EVALUATION

Normative Values

Mean normative values of GCQ were studied based on criterion levels ranging from 10% to 40%, with 5% increments.

Variables

The following variables were studied to determine their potential effects: (1) Fo and intensity of phonation and (2) day of recording (5 subjects each were recorded on 3 different occasions).

STATISTICAL ANALYSIS

Statistical analysis was performed using the StatView 4.5 program (Abacus Concepts Inc, Berkeley, Calif). Repeated analysis of variance was used to compare the means and distribution of different GCQs based on criterion levels and between smokers and nonsmokers. Correlations between GCQ and Fo and between GCQ and intensity were calculated using linear regression analysis, with a Pearson coefficient for each criterion level of the GCQ. Repeated analysis of variance for repeated measures was used to evaluate the effect of the day of recording on the GCQ. Statistical significance was set at P≤.05.

RESULTS

EFFECT OF CRITERION LEVEL ON NORMATIVE GCQ VALUES

Altogether, the mean±SD normative value of the GCQ was
0.52±0.10, ranging from 0.43 at criterion level 40% to 0.67
at criterion level 10% (Table 1). Figure 2 displays the mean values of GCQ based on each criterion level used for calculation of the GCQ. A decrease in the mean GCQ was recorded as the criterion level increased. There was no significant difference between mean GCQs when the criterion level differed by 5% (eg, between the 20%-25% criterion levels). When the criterion level differed by 10%, the 25% level was critical in that no significant difference was found above the 25% level, whereas a significant difference was noted below 25%. These results were not statistically different between smokers and nonsmokers.

VARIABLES

Table 1 summarizes the linear correlations between Fo and GCQ for each criterion level ranging from 10% to 40%. No significant correlation was found between Fo and GCQ for criterion levels ranging from 10% to 25%. There was, however, a significant correlation for criterion levels higher than 25%. Figure 3 illustrates this effect. A significant positive correlation was found between GCQ and intensity for all criterion levels, except at the 10% criterion level (Table 1). A positive correlation existed between Fo and intensity, but this correla-

METHODS

SUBJECTS

Twenty healthy male volunteers were prospectively studied. All subjects gave informed consent to participate in this study and underwent a medical history and laryngeal examination. Inclusion criteria were native male French speakers, age between 25 and 45 years, no history of laryngeal or neurologic disease, no complaint of voice or speech deterioration, and normal results on laryngeal examination. Ages ranged from 26 to 39 years (mean±SD, 32.5±3.7 years). Thirteen subjects were nonsmokers, and 7 had tobacco intake of less than 1 pack of cigarettes per day. None were professional singers. All subjects were evaluated and recorded by one of us (R.E.K.).

INSTRUMENTATION

The EGG laryngograph (Laryngograph Ltd, London, England) measured the EGG signals that were displayed and analyzed by a computer data processor (SESANE, Aix-en-Provence, France). The EGG device recorded the electric impedance across the neck between 2 electrodes placed on either side of the thyroid cartilage and held in contact with the skin by an elastic collar. The output of the EGG device was processed by an electronic preamplifier (DIANA, SQLab) and then by a 16-bit analog to digital converter for acoustic recordings. A denser microphone (model C410; AKG Acoustics, Vienna, Austria) mounted on a headset was connected to the computer via a computer data processor (SESANE; SQLab, Aix-en-Provence, France). The EGG device recorded the electric impedance across the neck between 2 electrodes placed on either side of the thyroid cartilage and held in contact with the skin by an elastic collar. The output of the EGG device was processed by an electronic preamplifier (DIANA, SQLab) and then by a 16-bit analog to digital converter for acoustic recordings. A denser microphone (model C410; AKG Acoustics, Vienna, Austria) mounted on a headset was connected to the computer via the analog to digital converter for acoustic recordings.

PROCEDURE

The microphone was placed on the side of the mouth 8 cm from the labial commissure. The sound intensity was calibrated with a buzzer placed 22 cm in front of the microphone before each recording. The subjects were seated upright. Electrodes of the laryngograph were placed approximately 1.5 cm lateral to the anterior angle of the thyroid cartilage, with no conducting gel between the electrode and the skin. The subject was instructed to sustain the vowel /a/ at a comfortable pitch and intensity. Three successive phonations during approximately 3 seconds each were performed. This phonation task was then realized at low and high vocal intensity, the intensity levels being chosen arbitrarily by each subject.
tion was not statistically significant ($r = 0.25$, $P = 0.08$). There was no significant difference between smokers and non-smokers, nor was there a significant effect of the day of recording on the mean value of the GCQ.

**COMMENT**

Monitoring the degree of VFCA during phonation is useful for voice quality evaluation. Although EGG measurements reflect the VFCA, little effort has been made to quantify this function. Standardization is important for objective voice evaluation in clinical and research applications. Standardization is necessary to avoid problems of accuracy, relevance, and reliability of the measurements. The main objective of the present study was to demonstrate the problems existing in the determination of normative GCQ values using EGG.

The electroglottographic waveform can be considered as a function of the VFCA. The electroglottographic waveform can be used for monitoring the degree of VFCA, at least during normal phonation. However, the EGG has limitations as a transducer of the VFCA. Electroglottography only reflects the degree of VFCA, not the relative or absolute area of opening between the vocal folds. Once the vocal folds are open without any contact, the variable impedance does not reflect degrees of vocal fold opening. It cannot be calibrated to record the absolute magnitude of VFCA. It is not possible to determine the exact location of contact or the exact moment of opening or closure on the electroglottographic waveform. The variations of electrical impedance of the electroglottographic waveform do not represent a direct "photograph" of the 3-dimensional phenomenon of opening or closure of the vocal folds.

Because of the problem of identifying the exact moment of initiation or loss of vocal fold contact, the concept of a relative GCQ emerged. A criterion level baseline crossing was suggested to define the EGG contact phase. The criterion level method has been used by various authors, with criterion levels varying between 10% and 40% ($r = -0.31$, $P = 0.83$). A significant positive correlation existed between GCQ and Fo at the 40% level ($r = 0.36$, $P = 0.007$).

**Table 1. Descriptive Statistics of Glottal Closed Quotient (GCQ) and Correlation With Fundamental Frequency and Intensity**

<table>
<thead>
<tr>
<th>Criterion Level, %</th>
<th>GCQ, Mean ± SD</th>
<th>Fundamental Frequency</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r$ Correlation</td>
<td>$P$ Value</td>
<td>$r$ Correlation</td>
</tr>
<tr>
<td>10</td>
<td>0.67 ± 0.08</td>
<td>-0.31</td>
<td>0.83</td>
</tr>
<tr>
<td>15</td>
<td>0.59 ± 0.08</td>
<td>0.33</td>
<td>0.82</td>
</tr>
<tr>
<td>20</td>
<td>0.53 ± 0.08</td>
<td>0.13</td>
<td>0.35</td>
</tr>
<tr>
<td>25</td>
<td>0.50 ± 0.08</td>
<td>0.23</td>
<td>0.10</td>
</tr>
<tr>
<td>30</td>
<td>0.47 ± 0.08</td>
<td>0.30</td>
<td>0.03*</td>
</tr>
<tr>
<td>35</td>
<td>0.45 ± 0.08</td>
<td>0.34</td>
<td>0.01*</td>
</tr>
<tr>
<td>40</td>
<td>0.43 ± 0.07</td>
<td>0.36</td>
<td>0.007*</td>
</tr>
</tbody>
</table>

*Significant positive correlation.
not depend on the period of the wave or, for voice, on Fo. A significant correlation between GCQ and Fo and between GCQ and intensity was found for criterion levels above 25%, demonstrating the effects of Fo and intensity on normative values of GCQ. Our results are in accord with significant effects of Fo that were reported on photoglottographic measurements of open quotient and significant effects of intensity on closed quotient. It is necessary to state the intensity at which the results were obtained when reporting data. Moreover, spontaneous vs Fo- or intensity-targeted phonations revealed significant differences in open quotient. The variability of GCQ with Fo and intensity contributes to reliability and standardization problems with GCQ as a measure of glottic closure.

Other investigations of the VFCA can be performed using the electroglossographic waveform. The closing duration or closing slope is another feature for estimating the VFCA. Other studies on opening phase measurements have been performed, but measurements of a duty cycle are probably more accurate than measurements of closing or opening duration.

Electroglossography has some limitations in providing reliable, valid, and accurate measurements of VFCA. The GCQ provides an approximation of variations in the VFCA. According to Rothenberg and Mahshie, GCQ is best used to display intrasubject variation, because the measure is a relative one, and it is less useful for intersubject comparisons. Electroglossography can also be useful with other methods of analyzing vocal fold vibration (photoglottography, inverse filtering, and videokymography), which provide other clues to the glottic cycle and vocal fold abduction and adduction.

In conclusion, this study showed significant variations in electroglossographic measurements of GCQ in normal subjects. The significant effects of the criterion level used, Fo, and intensity in the determination of normative values of GCQ were demonstrated. Electroglossography is limited in its capacity to provide reliable, valid, and accurate measurements of GCQ. Normative values of electroglossographic GCQs can only be obtained by adopting a standardized criterion level for future GCQ studies. The clinical relevance of GCQ electroglossographic measurements can be improved by standardization of the definition of GCQ and testing conditions.

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Table 2. Criterion Levels Reported for Calculation of Glottal Closed Quotient

<table>
<thead>
<tr>
<th>Source</th>
<th>Criterion Level, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marasek, 1995</td>
<td>10</td>
</tr>
<tr>
<td>Scherer et al, 1993</td>
<td>25</td>
</tr>
<tr>
<td>Orlikoff, 1991</td>
<td>25</td>
</tr>
<tr>
<td>Fourcin, 2000</td>
<td>30</td>
</tr>
<tr>
<td>Rothenberg and Mahshie, 1988</td>
<td>35</td>
</tr>
<tr>
<td>Higgins and Saxman, 1993</td>
<td>40</td>
</tr>
</tbody>
</table>

*Adrian J. Fourcin, PhD, oral communication, March 2000.

REFERENCES