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Objective measurement of mucosal wave parameters in diagnosing benign lesions of the vocal folds

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\textbf{ABSTRACT}

\textbf{Introduction:} The diagnostic procedure of phonation is dominated by subjective assessment tools. It seems reasonable to seek methods of quantitative glottal cycle assessment.

\textbf{Objective:} The aim of our study was the analysis of open quotients (OQ) of the glottis.

\textbf{Methods:} One hundred and twenty-four people were included in the study. Methodology was based on tools available in everyday phoniatrics practice – laryngovideostroboscopy (LVS) and electroglottography (EGG). There were statistically significant differences between control and studied group. Vocal fold polyps, nodules and edema influence glottal function in a different manner, what can be illustrated by objective glottal function parameters. Establishing Videostroboscopic Open Quotient values from three parts of glottis and Electroglottographic Quasi Open Quotient (QOQ) value, can help in dividing patients with benign lesions of vocal folds according to the type of disease.

\textbf{Results and conclusions:} Measurement of the open quotient from three parts of the glottis helps to differentially diagnose and localize glottal vocal fold lesions. Videostroboscopic Open Quotient and Electroglottographic QQ values can be used to quantify the glottal cycle. Videostroboscopic Open Quotient, Electroglottographic QQ and their ratio varies depending on the type of organic dysphonia.

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Dysphonia; electroglottography; open quotient; stroboscopy; videostroboscopy; vocal fold

\section*{Introduction}

The diagnosis of phonation disorders is dominated by subjective assessment tools. In this context, it seems desirable to seek methods that can assess the glottis quantitatively, especially from laryngovideostroboscopy (LVS), the most common examination tool (1, 2). Acoustic analysis of the voice is the most common way of measuring phonation objectively (3). Another simple and non-invasive method of parameterizing vibrations of the vocal folds is electroglottography (EGG) (4). Combined with modern computer software, LVS and EGG offer the opportunity of objectively analyzing glottal function. Such an approach could facilitate the diagnosis and monitoring of voice disorders, especially in patients with benign vocal fold lesions. The literature shows that of people seeking medical attention due to changes in their voice, 50% had benign lesions of the vocal folds (5). Here, we use Open Quotients (OQ) based on the two above-mentioned methods. OQ measured on the basis of kymograms extracted from LVS recordings, method also called videostrobobokymography (VSK) – OQ\textsubscript{VSK} (6). From EGG we measured Quasi Open Quotient (QOQ\textsubscript{EGG}) (7). Both measures were used to characterize glottis in benign lesions of the vocal folds (7, 8).

\section*{Methods}

The study group consisted of 62 people aged 24–60 (51 females, 11 males) with benign lesions of the vocal folds (22 with nodules, 23 with Reinke’s edema and 17 with polyps) who were treated at the Audiology and Phoniatrics Clinic. Excluded from the study were patients with large Reinke’s edema (third degree according to the Yonekawa classification) or with a vocal fold polyp larger than 4 mm. The patients with vocal fold polyps comprised 8 women and 9 men, those with Reinke’s edema included 21 women and 2 men, while there were 22 (women only) who had vocal fold nodules. Mean patient ages were 41.7 years for polyps, 40.8 years for vocal fold nodules and 50.9 years for Reinke’s edema. The control group included 62 healthy people with no voice disorders and a good quality voice. The groups were balanced for gender and age. Each patient underwent otolaryngologic and phoniatric examination. The study design was approved by the Bioethics Committee (KB/07/2013).

Methodology was based on tools available in everyday phoniatrics practice – LVS and EGG, the latter being a simple, non-invasive examination. LVS and EGG were recorded using an EndoSTROB-DX-Xion device with DIVAS...
software. Individuals were recorded during prolonged, comfortable phonation of [e]. From LVS recordings, kymograms were made from the anterior, middle and posterior third of the membranous portion of the vocal folds. Figure 1 shows an LVS view (Figure 1(A)) and kymograms (Figure 1(B,C,D)) of a patient with Reinke’s edema. Figure 2 shows an LVS view (Figure 2(A)) and kymograms (Figure 2(B,C,D)) of a patient with vocal fold nodules. In the device, the examiner manually marks glottal cycle phases. The DIVAS software calculates automatically OQVSK from a selected cycle of the kymogram and displays the result. EGG cycle is automatically marked by the software after pointing on EGG wave. QOQ_{EGG} and sound pressure level (dB SPL) from each EGG cycle is also displayed. The values of QOQ_{EGG} and of dB SPL were averaged over 20 consecutive cycles from the middle of the EGG recording. EGG recordings were classified according to Titze’s classification (6).

Differences in OQVSK and QOQ_{EGG} mucosal wave parameters were sought between people with benign lesions of the vocal folds and healthy controls. We also tested whether OQVSK and QOQ_{EGG} varied with different organic voice disorders. The level of statistical significance was set at $p < .05$.

Results

Women comprised the majority of the study group, confirming what is reported in the literature (9). LVS testing of the study group showed that over 95% had abnormal parameters. Only three patients with lesions (one with a polyp and two with nodules) had normal amplitude, mucosal waves or glottal closure.

Among patients with polyps, disturbances in amplitude were found in nine cases: a reduction in amplitude in seven
cases and an increase in two cases. Decreased mucosal wave was observed in 11 patients. In 12 patients, the polyp caused incomplete glottal closure. One subject had an unreadable EGG recording (type 3 according to Titze’s classification). Three subjects had type 2 recordings (Figure 3 gives an example of a type 2 electroglottogram).

Among patients with vocal fold nodules, irregular vibrations of the vocal folds were observed in four patients. Amplitude reduction was observed in 13 cases and a reduction in the mucosal wave in 13 cases. In only two subjects with vocal fold nodules was glottal closure unaffected. In the entire group, all electroglottograms were legible, but in five
cases some of the EGG curves had an irregular shape (type 2 according to Titze’s classification).

Among patients with Reinke’s edema, disturbance of regularity was found in 5 cases, reduction of amplitude in 3 cases and amplitude increase in 17 cases. Decreased mucosal wave was observed in six patients. In 13 patients edema caused incomplete glottal closure. In the group as a whole, only one subject had an unreadable EGG. Type 2 recordings were found in two subjects.

Statistical analysis of LVS abnormalities did not separate patients with benign lesions of the vocal folds into subtypes. Mean values and medians of OQVSK and QOQEGG are shown in Tables 1 and 2. In the control group, the mean SPL was 78.0 dB. In patients with vocal fold lesions, the mean SPLs were 78.0 dB (with polyps, 78.8 dB; with nodules, 77.5 dB; with Reinke’s edema, 78.0 dB). The level of comfortable phonation in patients with benign lesions of the vocal folds was not significantly different to that of the control group.

Five patients were excluded from further analysis: three because of irregular vocal fold vibrations that made calculations of OQVSK impossible, and another two due to unreadable EGG recordings.

Results of statistical analysis are shown in Table 3. There were statistically significant differences between the control and study groups in OQVSK and QOQEGG. Average OQVSK and OQVSK measured from the middle of the vocal folds, precisely differentiated patients with benign lesions from healthy controls. Vocal fold polyps, nodules and edema affected glottal function differently, as indicated by objective glottal function parameters. Therefore, measuring OQVSK values from three parts of the glottis can be used to separate patients with benign lesions of the vocal folds into three types: those with polyps, nodules or Reinke’s edema. Patients with smaller average OQVSK values and smaller OQVSK from the middle part of glottis had vocal fold polyps. Patients with smaller OQVSK from the anterior and posterior part of glottis and higher values from the middle part of

| Table 1. Mean values and medians of OQVSK from control and studied group. |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | Anterior 1/3 | Middle 1/3 | Posterior 1/3 | Average |
| Polyps n = 17              |               |            |               |         |
| Mean values of OQVSK       | 0.4           | 0.386      | 0.568         | 0.451   |
| SD                         | 0.205         | 0.195      | 0.177         | 0.117   |
| Medians of OQVSK           | 0.495         | 0.405      | 0.605         | 0.476   |
| Min 0 Max 0.67             |               |            |               |         |
| Nodules n = 22             |               |            |               |         |
| Mean values of OQVSK       | 0.545         | 0.459      | 0.6           | 0.532   |
| SD                         | 0.11          | 0.1        | 0.06          | 0.06    |
| Medians of OQVSK           | 0.54          | 0.46       | 0.6           | 0.515   |
| Min 0.35 Max 0.76          |               |            |               |         |
| Reinke’s edema n = 23      |               |            |               |         |
| Mean values of OQVSK       | 0.45          | 0.497      | 0.526         | 0.492   |
| SD                         | 0.087         | 0.114      | 0.085         | 0.071   |
| Medians of OQVSK           | 0.46          | 0.485      | 0.52          | 0.485   |
| Min 0.31 Max 0.63          |               |            |               |         |
| All n = 62                 |               |            |               |         |
| Mean values of OQVSK       | 0.47          | 0.453      | 0.563         | 0.496   |
| SD                         | 0.148         | 0.141      | 0.11          | 0.08    |
| Medians of OQVSK           | 0.49          | 0.46       | 0.59          | 0.5     |
| Min 0 Max 0.74             |               |            |               |         |
| Control group n = 62       |               |            |               |         |
| Mean values of OQVSK       | 0.50          | 0.522      | 0.548         | 0.526   |
| SD                         | 0.04          | 0.044      | 0.061         | 0.038   |
| Medians of OQVSK           | 0.5           | 0.515      | 0.55          | 0.523   |
| Min 0.42 Max 0.6           |               |            |               |         |

| Table 2. Mean values and medians of QOQEGG from control and studied group. |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | Polyps n = 17 | Nodules n = 22 | Reinke’s edema n = 23 | All n = 62 | Control group n = 62 |
| QOQEGG mean values          | 0.558         | 0.577         | 0.558         | 0.565         | 0.547         |
| SD                          | 0.073         | 0.074         | 0.069         | 0.069         | 0.039         |
| QOQEGG median               | 0.526         | 0.574         | 0.53          | 0.541         | 0.544         |
| Min 0.48 Max 0.74           |               |               |               |               |               |
edema the lowest average values of OQVSK were recorded
of Reinke
found a relation between OQVSK values and the location of
effective in 42%
patients with normal voices, but the methods were not
tic and EGG). They found no difficulties in examining
(10) assessed three types of phonation analysis (LVS, acous-
tic irregularities were found in the control group. Hill et al.
problems with evaluation of 23 cases, problems were caused by excessively short, unsteady
phonation or signal irregularities in patients with aponia.

OQVSK decreased from posterior to anterior in the con-
trol group. This tendency was also observed by Lohscheller
et al. (11) using high-speed videolaryngoscopy. Parameters
acquired via EGG or VSK are not equivalent. Both methods
approximately describe the open phase of the glottal cycle,
and in this research we saw similarities in values of these
parameters. Hacki has described a correlation between OQ
measured from EGG, photoglottography and laryngostrobo-
scopy (12). In later work, he used QOQEGG to diagnose
functional dysphonia (13). No data were found in the litera-
ture regarding the use of QOQEGG to assess benign lesions
of the vocal folds or a combination of VSK and EGG.

There are works describing the use of OQVSK in the diag-
nosis of organic lesions of the vocal folds (14–17): all these
found a relation between OQVSK values and the location of
glottal lesions. Szkiełkowska et al. (14) observed smaller
OQVSK values, measured at the location of the lesion, in
patients with vocal fold nodules (n = 14), polyps (n = 7) and
Reinke’s edema (n = 20) in comparison with a control group
(n = 13). The results were significantly different only in cases
of Reinke’s edema. In the work in patients with Reinke’s
edema the lowest average values of OQVSK were recorded
from the anterior part of the glottis. Values progressively
rose from the anterior to the posterior parts of the glottis:
0.297; 0.573; 0.604. The study group comprised patients with
different advancement of swelling (from first to third
according to the Yonekawa classification). In patients with
vocal fold polyps, again the lowest OQVSK values were mea-
sured at the middle of the vocal folds. Values from the ante-
tior to the posterior parts of the glottis: 0.620; 0.493; 0.654.
In our study group, all patients with vocal fold polyps were
included, without regard to lesion size. Bigger lesions
increase the distance between the vocal folds, and so it is
possible this might have caused the increase in OQVSK
measured from anterior and posterior parts of glottis. In
patients with vocal fold nodules, the lowest mean values of
OQVSK were measured in the anterior parts of the glottis.
Values from the anterior to the posterior parts of the glottis:
0.530; 0.569; 0.679.

Lee et al. (15) described similar observations of OQVSK
from 15 patients with Reinke’s edema, with values varying
depending on which part of the glottis was measured: edema
of the frontal parts of the vocal folds caused prolonged clos-
ure and a decreased open phase, but higher values of OQVSK
were measured at more posterior locations.

Kim et al. (16) published results of OQVSK from five peo-
dle [one with normal voice and four with benign lesions of
the vocal folds (nodules, polyp, cyst, Reinke’s edema)].
Kymograms from the place of the lesion showed prolonged
contact of the vocal folds. OQVSK measured before and
behind the lesion were higher. In Reinke’s edema, Kim
observed smaller values of OQVSK in the frontal parts of the
vocal folds, in accordance with the observations of Lee and
Szkiełkowska (14–16).

Lim et al. (18) used the EGG closed quotient (CQEGG) to
gauge the severity of Reinke’s edema. They saw an increase in
CQEGG values as the severity of the edema increased.
Furthermore, the average CQEGG value gave the best cor-
relation with improvement in voice quality after vocal fold
surgery.

In a previous study by Szkiełkowska et al. on the use of
VSK in patients with Reinke’s edema, the authors observed
statistically significant differences in OQVSK and CQVSK in
comparison with healthy controls (19). Furthermore, a rela-
tionship between the presence of edema and both OQVSK
and CQVSK was found. The relationship corresponded with
the degree of swelling according to the Yonekawa scale.

Kelly (20) published EGG results of women with vocal
fold nodules. The author observed a significantly lower pro-
portion of closed to opened time in the study group com-
pared to the control group.

The results of simultaneous measure of OQVSK and
QOQEGG have never been published before in benign vocal
fold lesions. In the study we show that different kinds of
lesions have different OQ characteristics. We think that it is
due to lesion location and influence that the lesion exerts on
the glottis during phonation. We show that different kinds
of lesions change distinct parts of glottis (expressed through
OQ). In our opinion OQVSK results should be presented at

| Table 3. Results of statistical analysis (p values of Mann–Whitney tests). |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | OQVSK from     | OQVSK from     | OQVSK from     | Averaged       |
|                 | anterior 1/3    | middle 1/3      | posterior 1/3   | OQVSK          | QOQEGG         |
| Polyp/control   | .185           | .000           | .055           | .011           | .167           |
| Polyp/other lesions | .175       | .024           | .173           | .072           | .184           |
| Nodules/control | .089           | .000           | .001           | .425           | .048           |
| Nodules/other lesions | .001       | .470           | .001           | .025           | .126           |
| Reinke’s edema/control | .004      | .106           | .060           | .022           | .353           |
| Reinke’s edema/other lesions | .055       | .030           | .001           | .268           | .373           |
| Benign lesion/control | .153       | .000           | .084           | .030           | .401           |
least from three parts of the vocal folds (anterior, middle, posterior third), not as an average.

Conclusions
The present publication has described a way of using videostrobokymography and EGG to obtain objective measures of glottal function in terms of OQ. The combination of EGG and VSK as used here provides a valuable method for making objective measurements of the voice. Such an approach has the potential to improve the diagnosis and monitoring of vocal fold diseases, and also provides a benchmark for comparing results between research centers.

Disclosure statement
The authors report no declaration of interest

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