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Original Paper

Objective Quantitative Analysis of Laryngeal Glottal Gaps using High-Speed Video in Glottal Analysis Tools, a Case-Control Study

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Abstract

Quantitative voice analysis for clinical use has been focused upon for many years. The aim was to test if Glottal Analysis Tools (GAT) could be used, based on High-Speed Video (HSV) to quantify distances between the vocal folds at any place on the vocal folds. The software includes a reproduced computed film of the vocal fold movements online. 20 normal HSV and 30 with insufficient closure in the rear part of the vocal folds (rear glottal gap) were compared in a case-control study.

The distance of trajectories was chosen at 50% and 10% from the rear part of the glottis and maximum and minimum distances between the vocal folds were defined during phonation in the 2 groups. It was possible to calculate the absolute data of insufficiency of closure of the vocal folds compared to normal HSV with a statistical difference of p<0,0001. An interesting result was in this material also that functional closure was found in all images in the middle of the vocal folds.

In the future quantification of voice disorders should include specific parts of the Glottal Area Waveform (GAW) analyses based on HSV for better differentiation of function and pathology of the vocal folds.

Keywords

Vocal Folds, Glottal Gaps, High-Speed Video, Glottal Analysis Tools.

1. Introduction

In general laryngology documentation of exact voice measurement is focused upon but controlled trials have not documented their main clinical feasibility (Eysholdt et al., 2020). Stroboscopy shows an average picture of several movements of the vocal fold, whereby the evaluation has artifacts, High-Speed Videos (HSV) show the accurate movements of the vocal folds, which is a great step forward (Pedersen et al., 2015; Woo, 2021). Laryngopharyngeal reflux (LPR) is a frequent disorder where HSV often reveals an insufficient closure of the rear part of the vocal folds, leading to severe dysfunction of voices. The validity of the LPR diagnosis is discussed recently (Belafsky et al., 2008; Lechien et al., 2017; Lechien et al., 2019; Lechien et al., 2020; Pedersen et al., 2012; Woisard, 2020). Many studies attempt to make quantitative measurements of the Glottal Area Waveform (GAW) (George et al., 2008). Recent studies include an overview of the most important techniques to quantify the vibration behaviors of the GAW including glottal gaps (Andrade-Miranda et al., 2020). Essential are image studies based on severity, with analysis of image quantification (Kuo et al., 2020).

We focused on valid methods usable to measure the GAW generally as an option to describe the various insufficient closures of the vocal folds found routinely in the ear-nose-throat clinic.

There are few Randomized Controlled Trials (RCT) of hoarseness in the clinic (Pedersen et al., 2012). The American academy of otolaryngology has made clinical guidelines for hoarseness in part with evidence-based references (Stachler et al., 2018). We focused on the software: Glottal Analysis Tools (GAT) from Erlangen, Germany based on research for a long time by Eysholdt and Lohscheller (2008). In GAT there are possibilities for reproducible results usable in clinical diagnostics. An interesting part is the vocal fold movements films computerized online, where the insufficient parts of the glottis can easily be documented. GAT has been refined in 2020 so that there is an automatic method for identifying glottis on the HSV usable for clinical analysis (Gómez et al., 2020; Kist et al., 2021). In an earlier study, no significant change was measured of the 183 parameters in GAT on HSV before and after treatment of hoarse patients (Pedersen et al., 2016). Still, the part of GAT that focuses on the computed reproduction of GAW is of major interest. It is possible to use the GAW with a choice of closure between the vocal folds anywhere.

Many studies attempt to make quantitative measurements of the GAW in various connections, A study describes methods for quantifying distances between the vocal folds compared with standard questionnaires. In the clinic documentation of predicted glottal gaps can be made, e.g., documentation of voice therapy on glottal gaps was made using validation on stroboscopy (Nam et al., 2019; Santos et al., 2020).

The aim of this study was to show that it was possible to routinely quantify distances between the vocal folds in the rear part, based on automatic computerized film reproductions of HSV in GAT. In the future, the measurements can be made at any place between the vocal folds, and be combined with other parameters in GAT.

2. Method

Our clinical ear- nose- and throat database includes HSV since 2007. From the database, 30 videos with insufficient closure of the rear part of the vocal folds (rear glottal gap) were extracted randomly for analysis. 20 comparable normal HSV without glottal gaps were also extracted. The automatic fundamental frequency measurement (F0) of the HSV was comparable. We chose the rear part because we see so many in our daily work.

HSV recording was performed with HRES Endocam 5562, Richard Wolf GmbH, Knittlingen Germany, 4,000 frames per second (fps) for a maximum of 2 seconds with a 90-degree rigid scope, on the intonation of /ah/.

GAT requires a license but is at this moment free of charge for the user. Trajectories in the GAW 10% and 50% from the rear part of the glottis were used. In this study trajectories are a transverse line on the glottis, defined in percentages starting with 0% in the rear and going to 100% in the front of the vocal folds, in which a place of interest can be chosen. The trajectories were calculated and computer reproduction of glottis with a marking of the trajectories of 10% and 50% were made in the GAT program.

2.1 Statistical Methods

The mean number of frames for analysis of the HSV of the two groups of 30 and 20 HSV was summarized. The GAT-derived parameters were analyzed in a t-test, comparing the two patient groups. The frame-by-frame analysis of the 10% and 50% trajectory distance between vocal folds were analyzed as repeated measurements: Data for the same film was considered dependent and an estimate of the difference between the 2 groups was conducted in a repeated measurements analysis or mixed model repeated measures (mmrm with SAS statistics).

The analyses of the vocal fold distance, of maximal open and closed phase at the 10% and 50% of the trajectory using distance measured both as pixels and percentage, were then conducted. The statistical model included groups (normal/rear glottal gap) as a fixed factor and number as a random factor. Measurements within films were assumed to be uniformly correlated corresponding to a compound symmetry covariance structure. The p-value and 95% confidence interval were calculated from the distribution of the fixed effects estimates and the corresponding variance using the Kenward and Roger (1990) method for calculating the degrees of freedom. The hypothesis was a difference between trajectories 10% of the 2 groups, but no difference between trajectories 50% of the 2 groups.

3. Result

In Table 1 descriptive data are presented of 30 films with insufficient closure of the rear part of the vocal folds, and 20 normal films with sufficient closure.

Table 1. Normal Films and Films with Rear Glottal Gap were Recorded with HSV and Analyzed with Glottal Analysis Tools (GAT)

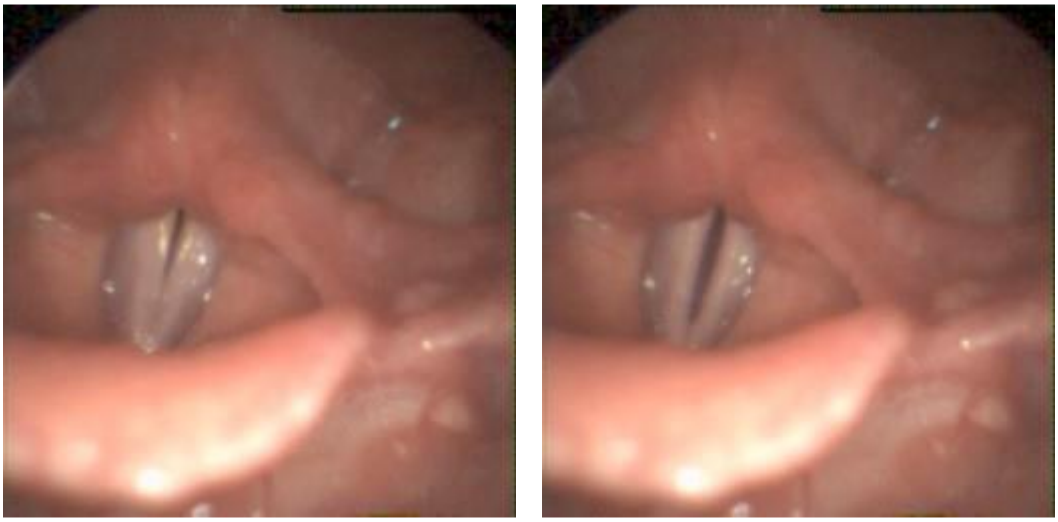
MEAN F0 (Hz)	Normal	217.2
	rear glottal gap	236.6
SD F0 (Hz)	Normal	85.0
	rear glottal gap	87.0
MEAN FRAMES	Normal	463.2
	rear glottal gap	548.0
SD FRAMES	Normal	230.5
	rear glottal gap	260.2

Table 1 descriptive data of 30 films with insufficient closure of the rear part of the vocal folds, and 20 normal films with sufficient closure. The F0 and number of frames are also presented.

In Figure 1 pictures are presented from a film of each group recorded with HSV and analyzed with GAT. Figure 1 a) presents two pictures from a HSV, with insufficient closure of the rear part of the vocal folds with the maximum opened and closed phase during phonation. Figure 1 b) presents two pictures from a HSV, with sufficient closure.

Figure 1.

a) HSV pictures with rear glottal gap during intonation with maximal and minimal closure.



b) HSV pictures without glottal gap (Normal) during intonation with maximal and minimal closure

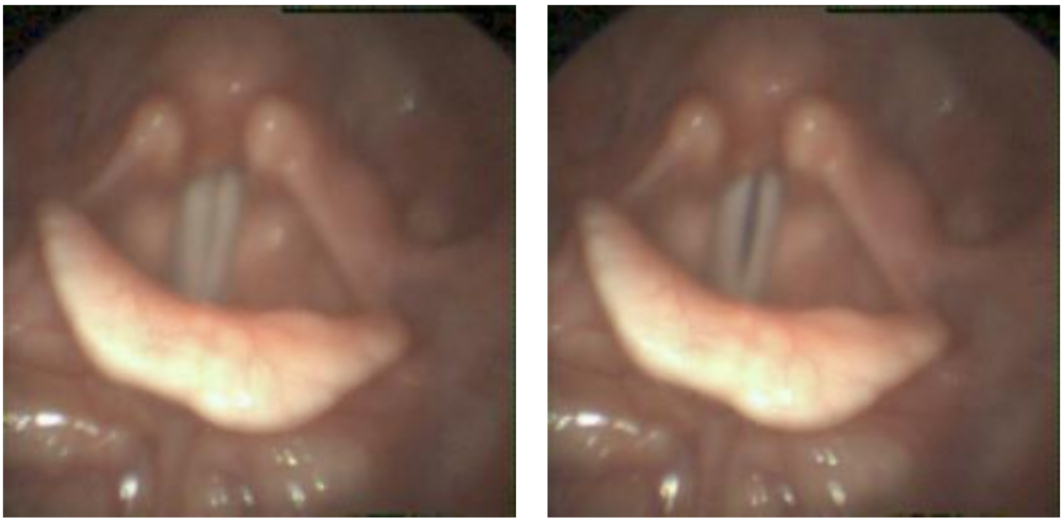


Figure 2 a-d) present the GAT trajectories data of the larynx with insufficient closure of the rear part of the vocal folds. a and b present the trajectories 10% from the rear glottal area waveform endpoint, the maximum open and closed phase during phonation. c and d present the trajectories 50% from the rear glottal area waveform endpoint, which means the middle area of the glottal area waveform during the maximum open and closed phase during phonation.

Figure 2 e-h) presents the GAT trajectories data of the larynx without insufficiency. e-f) presents the trajectories 10% from the rear glottal area waveform endpoint, the maximum open and closed phase during phonation. g-h) present the trajectories 50% from the rear glottal area waveform endpoint, which means the middle area of the glottal area waveform during the maximum open and closed phase during phonation. Only a-b) visually shows insufficient closure of the vocal folds of the trajectories.

Figure 2. Pictures from the Computed Films of Glottal Area Waveforms (GAW). The Given Trajectory of the Film is Marked on Each Picture

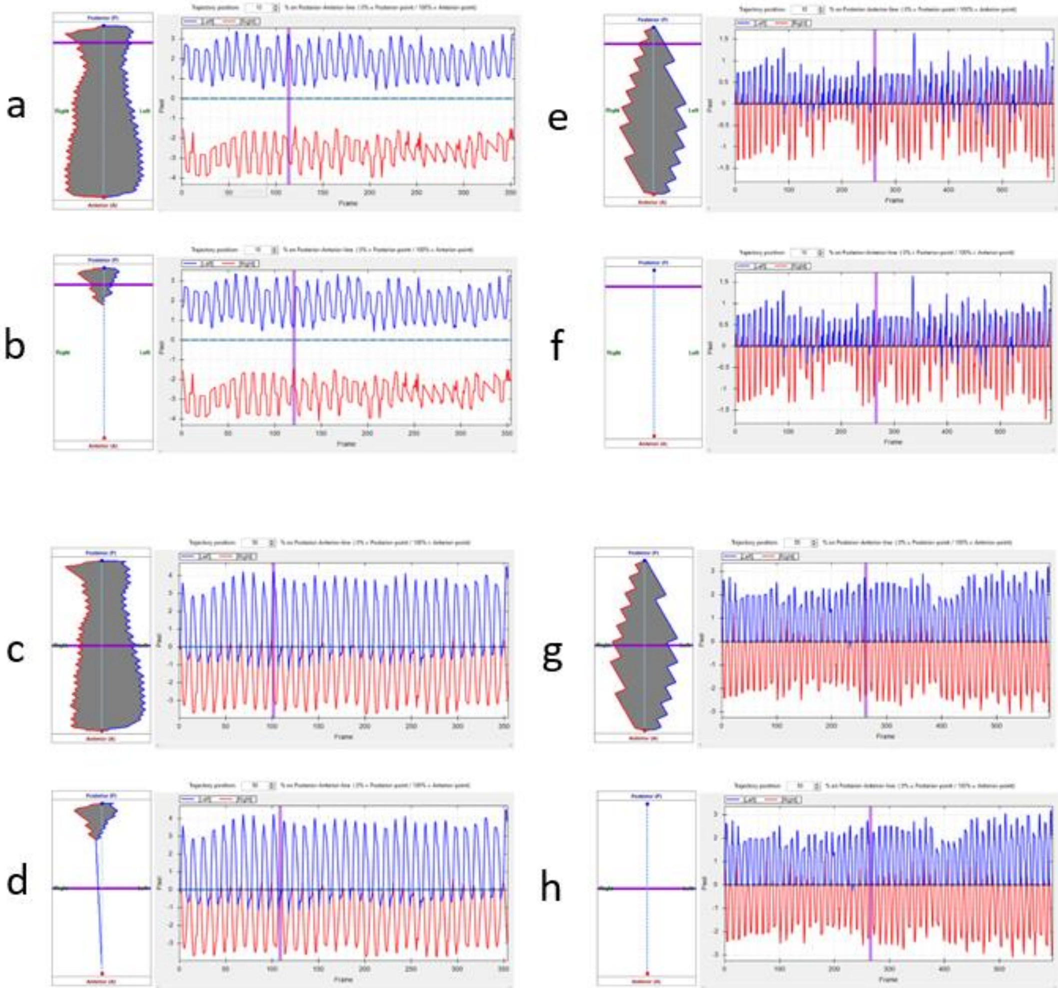


Table 2 shows the analysis of the vocal fold distance during phonation as shown in the 2 groups for trajectories 10% and 50% distance from the rear glottis.

Table 2. Statistical Analysis of Vocal Fold Distance on HSV at the 10% and 50% Trajectory from the Rear Glottis Using both Pixel and Percent Distance

	Parameter		N	n	LS Means	Standard error	95% confidence interval	p-value
a	TRAJ10PERCENT	Normal	20	9267	0.63	0.23		
		Rear glottal gap	30	15640	3.12	0.19		
		Diff (Rear glottal gap-Normal)			2.49	0.3	(1.90 – 3.09)	<0.0001
b	TRAJ10PIXEL	Normal	20	9267	1.61	0.37		
		Rear glottal gap	30	15640	4.87	0.3		
		Diff (Rear glottal gap-Normal)			3.26	0.48	(2.30 – 4.22)	<0.0001
c	TRAJ50PERCENT	Normal	20	9267	1.16	0.09		
		Rear glottal gap	30	15640	0.95	0.08		
		Diff (Rear glottal gap-Normal)			-0.21	0.12	(-0.46 – 0.03)	0.0848
d	TRAJ50PIXEL	Normal	20	9267	2.72	0.31		
		Rear glottal gap	30	15640	2.79	0.25		
		Diff (Rear glottal gap-Normal)			0.07	0.39	(-0.72 – 0.87)	0.8546

Data are analyzed in a Mixed model repeated measures (mmrm) - including patient group (rear glottal gap/normal) as fixed effect and film as random effect. N: Number of films, n: number of observations. The group difference between Rear glottal gap and Normal films is presented as Least Squares Means (LS Means) with a corresponding 95% confidence interval.

3.1 Statistical Results

In Table 1, we showed that the 2 groups are comparable by calculating the mean and standard deviation for fundamental frequency (F0) measured in Hz in the HSV program, and the number of frames during phonation for each video.

In Table 2 the statistical analyses of the vocal fold distance during phonation closure in GAT are shown in the 2 groups for trajectories 10% and 50% distance from the rear glottal gap:

the 10% and 50% of the trajectories are using distance measured both as pixel and percentage, conducted mixed model repeated measures (mmrm analysis with SAS statistics). The results were based on normal/rear glottal gap findings used as fixed factor and films as random factor.

Table 2 a. The trajectories 10% in percent shows the difference between the groups was 2.49%, p <0.0001.

Table 2 b. The trajectories 10% in pixel shows the difference between the groups was 3.26 pixel, $p < 0.0001$.

Table 2 c. The trajectories 50% in percent shows the difference between the groups was -0.21%, p 0.0848.

Table 2 d. The trajectories 50% in pixel shows the difference between the groups was 0.07%, p 0.8546.

The p values and 95% confidence intervals presented were calculated from the fixed estimate and corresponding variance.

Based on the results of this evidence-based case-controlled analysis the computed GAT trajectories in the GAW are clinically usable for quantitative measures of distances between the vocal folds eventually compared to other parameters in the GAT software program.

4. Discussion

As for the background of the study, GAT software is interesting because it is possible to specify a place on the vocal folds to measure insufficient closure in a computer-reproduced film of the GAW. The results can without further be compared to other voice parameters in the GAT software program. It was earlier necessary to define the glottis area on each HSV manually, on Endocam 5262 equipment, and on GAT as well, but with the development of GAT 2020, this part has been automated with deep learning (Kist et al., 2021). Another problem has been the minimal use of GAT in the ear nose throat clinics which is now attempted (Gómez et al., 2020). We have earlier made a comparison of GAT before and after treatment of hoarse patients. None of the 183 parameters that GAT measures, showed any evidence of change. But in all our studies GAW was of interest, due to the computed visualization of the glottis (Pedersen et al., 2016).

The rationale was to use the possibility of quantification of the GAW included in GAT based on HSV. There is here a further possibility for use of deep learning (Fehling et al., 2020), where software can be fully developed not only to measure the variation of the total glottal gap but also of chosen parts hereof. Deep learning is also focused upon in LPR (Wang et al., 2021). The aspect is to use these measures in connected speech (Yousef et al., 2021).

The findings are as expected from the many daily experiences of HSV in the clinic. The evidence-based case-control study showed that it is possible to quantify the distances between the vocal folds during adduction/abduction in phonation at a defined place (Table 2). The findings are based on HSV frames reproduced in GAT. The study by Fehling et al. (2020), also based on HSV Endocam 5562, showed that the GAW can be measured with deep learning for the variation in pixel or percent.

In LPR we mostly on HSV note that there is better closure of the GAW at trajectories 50% in opposition to the 10% trajectories, which was the case in this study – documented quantitatively. The study was made with 30 films together with 20 normal controls and enough frames from an HSV database. It was tried to plug the data randomized from the database. The selection method of the 2 groups can be discussed, but it seems difficult to find an optimal solution for the HSV choice. Since we used the automatic software for defining the glottis in the films the limitation of glottis picture variability is reduced, but the limitation of variable pictures is still present. It has not been focused upon in this study.

The implication of the setup in this study opens for better functional understanding and documentation of the GAW at a specified well-defined place in the glottis with the perspective of an automatic deep learning model in the future. Future routine use in the clinic is possible.

5. Conclusion

The statistical results of the Glottal Area Waveform (GAW) during phonation are of interest in comparing trajectories. In this study trajectories are perpendicular transverse lines on the vocal folds in Glottis Analysis Tools (GAT), defined in percentages starting with 0% in the rear going to 100% in the front of the vocal folds, in which any place of interest on High-Speed Video (HSV) can be chosen. We now have a new tool used to document voice disorders before and after treatment. The distance between the vocal folds has been described quantitatively in an evidence-based case-control study at a specified location in the glottis, here 10% compared with 50% from the rear glottis. The distance is given in pixels but was also converted to a percentage for comparison with other parameters. This study shows that it is possible to routinely quantify insufficient closure of the vocal folds at a given place in the glottis clinically.

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