

Assessment of Irregular Voices After Total and Laser Surgical Partial Laryngectomy

Arno Olthoff, MD; Sibylle Mrugalla, MD; Rainer Laskawi, MD; Matthias Fröhlich, PhD; Ingo Stuermer, PhD; Eberhard Kruse, MD; Petra Ambrosch, MD; Wolfgang Steiner, MD

Objectives: To assess the merits of computer-aided voice analysis procedures for very irregular voices of patients after total and laser surgical partial laryngectomy, and to characterize qualitative differences in speech and voice function between these 2 groups of patients.

Design: Cross-sectional study.

Setting: University hospital in Göttingen, Germany.

Patients: Twenty-nine patients with advanced laryngeal carcinomas (T3-T4; according to the Union Internationale Contre le Cancer, TNM staging system, stages III-IVa) were examined: 18 patients with tracheoesophageal speech (voice prosthesis) after total laryngectomy and 11 patients who underwent partial transoral resection of the larynx (by means of laser microsurgery without surgical voice rehabilitation).

Main Outcome Measures: Speech intelligibility was measured by a standardized and validated telephone test, and voice quality was determined by 2 computerized voice

analysis systems (multidimensional voice program and Göttingen hoarseness diagram).

Results: The telephone test demonstrated a significantly better speech performance of the patients who had undergone organ-preserving surgery. The voices of both patient groups were too irregular for a qualitative differentiation with the multidimensional voice program. The multidimensional voice program results also failed to show significant correlations to speech intelligibility. The Göttingen hoarseness diagram showed significantly more regular voices in patients with partial laryngectomy than total laryngectomy. These results were correlated with speech intelligibility.

Conclusions: The Göttingen hoarseness diagram is suitable for a qualitative assessment even of irregular voices. Voice prosthesis offers a voice quality that at best approaches that of patients with partial laryngectomy.

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From the Departments of Phoniatics and Pedaudiology (Drs Olthoff and Kruse) and Otorhinolaryngology (Drs Mrugalla, Laskawi, Ambrosch, and Steiner), Drittes Physikalisches Institut (Dr Fröhlich), and Sensory Developmental and Voice Research, Department of Phoniatics and Pedaudiology (Dr Stuermer), University of Göttingen, Göttingen, Germany. The authors have no relevant financial interest in this article.

IN ADVANCED laryngeal carcinomas (T3-T4; according to the Union Internationale Contre le Cancer, TNM staging system, stages III-IVa), every kind of surgical treatment has an impact on voice quality and speech intelligibility regardless of the approach followed. The best results in voice rehabilitation after total laryngectomy have been described for tracheoesophageal speech.¹ For this purpose, a low-resistance voice prosthesis such as the Provox (Atos Medical, Hörby, Sweden) prosthesis is suitable.² The alaryngeal voice is thereby generated in the pharyngoesophageal segment. After partial laryngectomy, the remaining intralaryngeal tissues are used for voice production. In both modalities, the exhaled pulmonary air leads to vibrations of the mucosa (caused by the Bernoulli effect) and consequently to sound generation. The

voice qualities achieved, however, differ from normal glottic voices.

Patients with advanced laryngeal cancers who undergo different treatments often show differences in the perceptual assessment of voice qualities. However, computerized analyses have failed to reflect these observations because of the high irregularity of signals.³⁻⁹

The aim of our study was to assess the value of different computer-aided analytical procedures for highly irregular voices of patients after partial and total laryngectomy. A voice analysis program called the Göttingen hoarseness diagram^{10,11} was used for the first time in the analysis of this category of patients. Additionally, we addressed the question of how these objective measures relate to the perceptual assessment of voice quality and speech intelligibility by listeners and patients (self-assessment).

Voice quality and speech intelligibility were investigated for the first time, to our knowledge, in a homogeneous group of patients with advanced laryngeal cancer (stages T3-T4) for which patients had undergone partial transoral resection of the larynx by means of laser microsurgery as an organ-preserving treatment. The results of these patients are compared with the outcome of patients using tracheoesophageal speech after total laryngectomy.

METHODS

PATIENTS

Between March 1, 1996, and October 31, 1998, a total of 61 previously untreated patients underwent surgery in our department for stage T3 and T4 (Union Internationale Contre le Cancer stages III-IVa) glottic carcinomas.¹² In 29 of these patients, total laryngectomy was performed. Voice prostheses (Provox) for voice rehabilitation were used in 22 patients, and 18 of them could be analyzed by the computerized analysis methods. Of the other 4 patients, one did not use the voice prosthesis, 2 patients could not perform the speech intelligibility test because their native language was not German, and 1 patient lived too far away for a follow-up study.

In the remaining 32 patients, partial transoral resection of the larynx was performed as an organ preservation method, with the use of laser microsurgery. None of the patients who underwent partial resection had undergone surgical procedures for reconstruction or voice rehabilitation. Wounds healed by spontaneous secondary intention. Oncologic safety was guaranteed by an appropriate surgical technique and by exact histologic evaluation of the intraoperative specimens.^{13,14} Many patients who arrived at our department desiring organ-preserving partial resection (n=32) came from a far distance, including other countries, so that only 11 of them could be followed up for the purpose of this study.

A total of 29 patients (11 with partial laryngectomies, 18 with total laryngectomies) took part in this study. One (total laryngectomy) was a woman, and 28 were men. The mean \pm SD age was 63 ± 12 years (range, 40-89 years) (Table 1). The operations had been performed at least 6 months previously. Except for one instance of chondrosarcoma, the histopathological findings all revealed squamous cell carcinomas.

Postoperative radiotherapy was performed in 11 patients (61%) after total laryngectomy and in 1 patient (9%) after partial laryngectomy. Voice training was provided for 12 patients (67%) after total laryngectomy and for 2 patients (18%) after partial laryngectomy (Table 1). The study was approved by the local ethics committee.

The 2 groups used different techniques of phonation. The patients who underwent total laryngectomy used their voice prostheses to generate tracheoesophageal voice. Because the glottic tissues were resected in all patients who underwent partial laryngectomy, they used their remaining intralaryngeal tissues (ventricular fold or aryepiglottic fold) for phonation. These supraglottic areas were used spontaneously or activated with special training ("functional voice training").¹⁵ Videostroboscopic controls were performed in the phoniatric department.

POSTLARYNGECTOMY TELEPHONE TEST

The postlaryngectomy telephone test (PLTT) was performed to obtain an objective measure of speech intelligibility. This test, developed for German-speaking countries, was initially designed to assess speech intelligibility after total laryngec-

Table 1. Demographic and Clinical Data*

Variable	Total Laryngectomy (n = 18)	Partial Laryngectomy (n = 11)
Sex, No. (%)		
M	17 (94)	11 (100)
F	1 (6)	0
Age, y		
Mean (SD)	64 (13)	62 (10)
Median	64	60
Range	40-89	47-77
UICC stage, No. (%)		
III	1 (6)	5 (45)
IVa	17 (94)	6 (55)
Radiotherapy, No. (%)	11 (61)	1 (9)
Speech therapy, No. (%)	12 (67)	2 (18)

Abbreviation: UICC, Union Internationale Contre le Cancer.

*Age distributions were not significantly different between patients with total or partial laryngectomy (Mann-Whitney test).

tomy but was later also used to compare and study patients with total and partial laryngectomy by the original authors of the test.¹⁶

As required by the PLTT, words and sentences were taken from the Freiburg (monosyllabic) test¹⁷ and from the Marburg (speech intelligibility) test¹⁸ without repetition. All patients (n=29) were seated in a soundproof booth (following German Institute for Standardization [DIN] 8253 standards) and spoke into the telephone 20 words from the Freiburg test and 5 sentences from the Marburg test. Words and sentences were selected randomly from the total vocabulary. The listeners sat in a separate booth with the same specifications and recorded in writing, without comments, the words and sentences spoken by the patients. All listeners were medical students with no previous experience of patients with total or partial laryngectomy. In all listeners, normal hearing level was confirmed on the basis of pure-tone audiogram (0.5-8 kHz). To exclude any effects of familiarization, each test person was paired with a different listener. Every word registered correctly represented one 20th (5%) of the total score and every sentence registered correctly, one fifth (20%). Performance was evaluated as a percentage according to a scheme laid down by the original authors of the PLTT.¹⁶ The signal-to-noise ratio of this setting was measured with a 2.5-cm microphone (BK2203/1613; Bruel & Kjaer, Naerum, Denmark) using an artificial ear (BK4152; Bruel & Kjaer). The signal-to-noise ratio values exceeded 42 dB in the range of 0.5 to 4 kHz.

ACOUSTIC VOICE ANALYSES

The acoustic voice analysis of sustained vowels was performed by 2 computerized analysis systems: the multidimensional voice program (MDVP) (Kay Elemetrics Corp, Pine Brook, NJ) and the Göttingen hoarseness diagram.^{10,11,15}

The sustained vowels were recorded in a soundproof room. Four patients with voice prostheses were unmotivated to perform this second task. Thus, 11 patients after partial laryngectomy and 14 patients after total laryngectomy were analyzed by the Göttingen hoarseness diagram.

For the MDVP evaluation, we recorded vowel phonations of the vowels /a/ and /o/ of 1.5 to 4 seconds' duration and always analyzed approximately the middle second. The signals analyzed by the MDVP were recorded directly on the hard disk of the computer by means of a microphone (MD 441 N; Sennheiser Electronic, Wedemark, Germany) mounted at a fixed

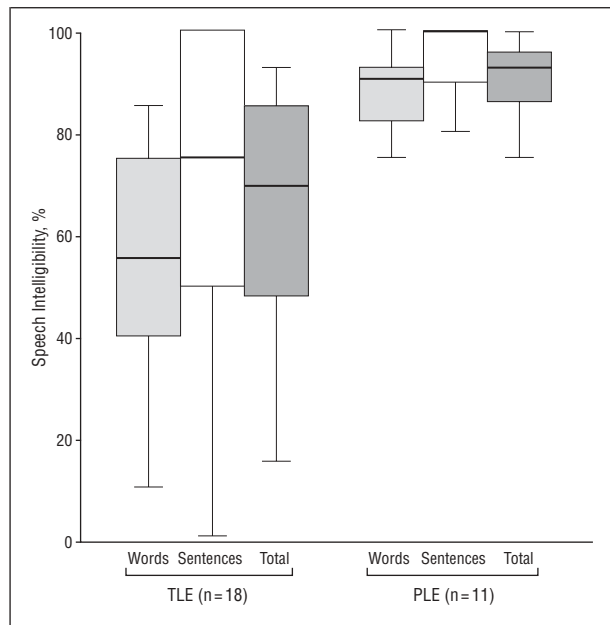


Figure 1. Results of the postlaryngectomy telephone test. In all 3 categories, speech intelligibility in patients with partial laryngectomy (PLE) was significantly higher (Mann-Whitney test). Box-plot graphs reflect minimum, 25th, 50th, and 75th percentiles, and maximum. TLE indicates total laryngectomy (including voice prosthesis insertion).

position of 50 cm and the analog-digital conversion hardware supplied by the MDVP setup. The sampling frequency was 50 kHz. The phonation task was repeated 4 times, and the mean value was used for further analyses.

For the Göttingen hoarseness diagram we used a headset microphone (Beyer Dynamics HEM 191) and a preamplifier (AXR Mic/Dat 2) together with a digital audiotape recorder (Pioneer D-07) operating at a sampling rate of 48 kHz. The recording protocol for the Göttingen hoarseness diagram comprised 4 series of the vowels /e/, /a/, /e/, /i/, /o/, /u/, /e/. Phonation time was 2 to 5 seconds for each vowel token. The computerized analysis was based on the stationary part of the signal (ie, the onset and offset of the phonation were excluded).¹⁰ As reference values, we used results obtained by the analysis of “normal” voices (n=116) and “aphonic” voices (n=60), which were taken from a previous study.¹⁰

Voices recorded on MDVP were evaluated with respect to fundamental frequency (f0) (in hertz), voice breaks, including inaudible breaks (percentage), harmonic-to-noise ratio (HNR) (quotient of spectral energies between the harmonic and unharmonic part), jitter (frequency modulation noise in the voice signal) (percentage), shimmer (amplitude modulation noise in the voice signal) (percentage), and maximum phonation time (seconds).

Features obtained by the analysis with the Göttingen hoarseness diagram were the irregularity component and the noise component.¹¹ To describe the additive noise content, the glottal-to-noise excitation ratio was used. This method has been presented and validated in earlier investigations.^{10,11}

QUESTIONNAIRE

The listeners were asked to rate their subjective impression of voice quality by means of a grading system where 1 indicated excellent and 5, very poor. The patients used a visual analog scale (0, very poor; 10, excellent) for self-evaluation. The patients were also questioned about which method of communication they practiced and what command they had

over their voice in everyday situations. The perceptual assessments by the listeners were compared with the self-assessments of the patients.

STATISTICAL ANALYSIS

To compare results between the patient groups, the Mann-Whitney test and the 2-dimensional Kolmogorov-Smirnov test were used for 1-dimensional and 2-dimensional tests, respectively. The Spearman rank correlation test was applied in the correlation analysis. Statistical significance was defined as $P < .05$.

RESULTS

POSTLARYNGECTOMY TELEPHONE TEST

The PLTT showed that the patients with organ-preserving operations achieved a significantly higher speech intelligibility ($P < .001$). In patients after partial laryngectomy, the mean overall speech intelligibility was $91\% \pm 2\%$, whereas in patients after total laryngectomy, it was $64\% \pm 6\%$. The results for words and sentences are shown in **Figure 1**.

Postoperative radiotherapy was performed in 11 patients after total laryngectomy and in 1 patient after partial laryngectomy. The 1 patient who received radiotherapy after partial laryngectomy showed inconspicuous results with regard to the other patients in the group. Results of statistical comparison of speech intelligibility after partial and total laryngectomy did not change after exclusion of this irradiated patient ($P = .001$).

Voice therapy was provided for 12 patients after total laryngectomy and for 2 patients with an organ-preserving treatment. There were no significant differences in speech intelligibility within both groups with respect to voice therapy. Age did not influence speech intelligibility significantly. The patients achieved a better speech intelligibility after partial resection of the larynx and at the same time received less speech therapy.

ACOUSTIC VOICE ANALYSIS

The results of the MDVP analysis procedure are given in **Table 2**. In patients after total laryngectomy (n=18) and in patients after partial laryngectomy (n=11), the voices were irregular in wide ranges without significant differences between the groups. For all patients, the MDVP features voice breaks, jitter, shimmer, HNR, and maximum phonation time were not significantly correlated with speech intelligibility measured on the PLTT (**Table 3**). The high irregularity of signals in both groups of patients prevented meaningful measurement of the fundamental frequency. Therefore, this feature was excluded from further analyses.

In the Göttingen hoarseness diagram, the pronounced irregularity of both voice classes (voice prosthesis and phonation after partial laryngectomy) was also recognizable. All patients had far from normal voices, but aphonia was not observed. The diagram indicates that patients with organ-preserving operations show more regular voices. The voice quality of the patients with voice

Table 2. Results of the Multidimensional Voice Program

Variable	TLE (n = 18)	PLE (n = 11)	P Value (Mann-Whitney Test)
Voice breaks, %			.64
Mean (SD)	14.4 (23.0)	16.0 (28.6)	
Median	0.0	0.0	
Jitter, %			.71
Mean (SD)	8.8 (5.4)	8.9 (6.9)	
Median	8.2	6.7	
Shimmer, %			.30
Mean (SD)	21.9 (11.3)	20.7 (12.3)	
Median	20.4	19.4	
HNR			.55
Mean (SD)	0.4 (0.3)	0.8 (1.5)	
Median	0.4	0.4	
Maximum phonation time, s			.55
Mean (SD)	8.6 (6.8)	8.3 (3.6)	
Median	6.5	7.0	

Abbreviations: HNR, harmonic-to-noise ratio; PLE, partial laryngectomy; TLE, total laryngectomy (including voice prosthesis insertion).

Table 3. Correlations Between PLTT Values and MDVP Measures*

MDVP Measure	Spearman Rank Correlation With PLTT Value
Voice breaks	-0.357
Jitter	-0.342
Shimmer	-0.336
HNR	-0.235
Maximum phonation time	-0.333

Abbreviations: HNR, harmonic-to-noise ratio; MDVP, multidimensional voice program; PLTT, postlaryngectomy telephone test.

*All correlations were not significant (n = 29).

prostheses at best approached that of the patients with partial laryngectomy (**Figure 2**).

The lowest values for the noise component were found in patients with a poor performance on the PLTT. In these cases we saw short phonation times together with perceptually pressed voices. The correlation between the noise component and speech intelligibility was not significant ($P = .11$), whereas the correlation between the irregularity component and speech intelligibility was significant ($P = .03$). Patients with a good speech intelligibility showed lower values in the irregularity component.

The difference between patients with partial (n = 11) and total (n = 14) laryngectomy was significant in the 2-dimensional plane of the Göttingen hoarseness diagram with the use of the 2-dimensional Kolmogorov-Smirnov test ($P < .05$). The Mann-Whitney test showed a significant separation of both groups in regard to the noise component ($P = .03$). When the irregularity component was compared, the differences were not significant ($P = .24$).

QUESTIONNAIRE

The patients with partial laryngectomy as well as with total laryngectomy generally rated their voices as "good."

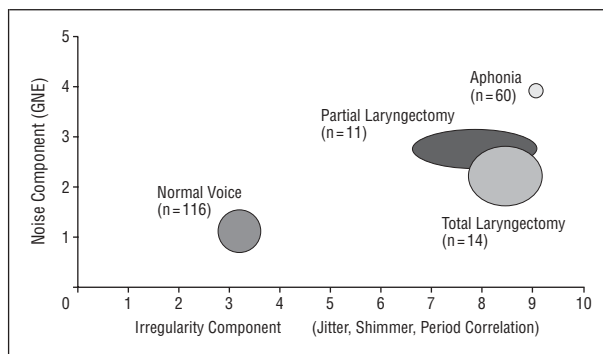


Figure 2. Göttingen hoarseness diagram. Ellipses reflect the distribution of the means of all patients (based on the analysis of 28 vowels for each subject) of each particular group, with ellipse centers reflecting the group mean and half axes the SDs. The noise component can be interpreted to reflect the quality of "glottal" closure and the irregularity component of the irregularity of voice generation. The difference between patients with partial and total laryngectomy was significant (Kolmogorov-Smirnov test). GNE indicates glottal-to-noise excitation ratio.

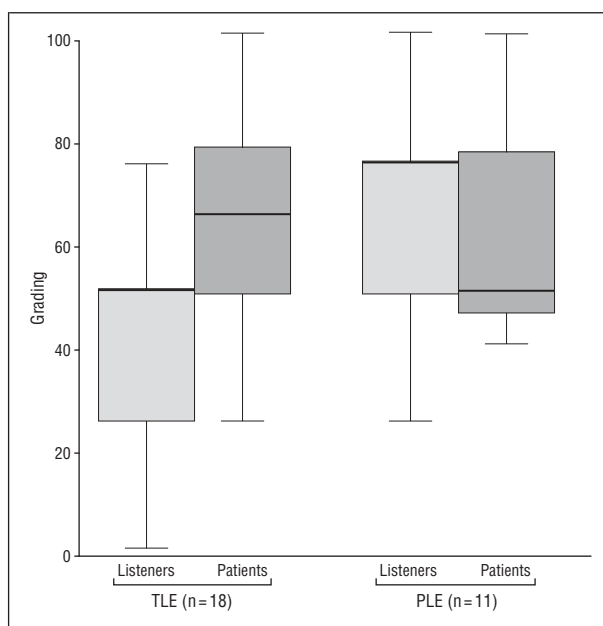


Figure 3. Perceptual assessment of voice quality, graded by listeners and by patients (self-assessment), where 0 indicates very poor and 100, excellent. There was no significant difference between the self-assessment of patients with total (TLE) and partial (PLE) laryngectomy (Mann-Whitney test). The listeners graded voice quality significantly lower after total laryngectomy. Box-plot graphs reflect minimum, 25th, 50th, and 75th percentiles, and maximum.

There was no significant difference between the 2 groups. However, the listeners agreed only with the patients with partial laryngectomy (**Figure 3**). Voice qualities of patients after total laryngectomy received significantly lower marks from the listeners than voice qualities of patients after partial laryngectomy.

All patients with total laryngectomy examined in this study used the voice prosthesis as their main means of communication. Alternative methods of communication in everyday situations were hand signaling, pseudo-whispering, and writing. Nine patients also learned to use esophageal speech, particularly for short messages and greetings. Three patients had been equipped with an elec-

Table 4. Questionnaire Results About Use of Alternative Speech and Communication Methods in Everyday Situations

Variable	Total Laryngectomy (n = 18)		Partial Laryngectomy (n = 11)	
	Yes	Never	Yes	Never
Esophageal speech	9	6	0	11
Electrolarynx	3	12	0	11
Pseudowhisper	7	8	0	11
Hand signal	15	0	2	9
Written message	5	10	0	11

trolarynx soon after total laryngectomy, when the quality of the voice prosthesis was still not good. Only 2 of the 11 patients with partial laryngectomy needed hand signaling as the only alternative method of communication (Table 4).

COMMENT

The very good acceptance and successful use of the voice prostheses by the patients as their main means of communication has been described in the literature.^{2,19} In the self-assessment of voice quality, we found no differences between the groups of patients with partial and total laryngectomy. Both groups rated their voice quality as being good. The listeners, however, registered poorer voice quality in patients with total laryngectomy.

The positive attitude of the patients corresponds to a number of studies on life quality after laryngectomy. List et al²⁰ and Morton²¹ found no correlation between functional deficits (speech, food ingestion) and the measured quality of life. We suggest that the patients became accustomed to their altered life situation and functional deficits regardless of the surgical treatment, so that the questionnaire on voice quality did not elicit any differences.

Investigation of speech intelligibility by the PLTT, however, demonstrated a distinct advantage for the patients with organ-preserving operations. This may be interpreted as indicating that these patients possess more favorable conditions for voice generation in everyday communication situations. This observation is in line with the results of our questionnaire about the main means of communication. Only 2 patients after partial laryngectomy used alternative communication means such as hand signaling, compared with all 15 patients after total laryngectomy. These findings indicate that patients after partial laryngectomy achieved a better speech intelligibility with less effort, such as the need for speech therapy.

Because of the very pronounced irregularity of the voices studied, the fundamental frequency could not be detected meaningfully in either voice analysis procedure. This corresponds to findings by Debruyne et al,¹ who detected a fundamental frequency combined with a long phonation time only in "good" tracheoesophageal speech. They used this feature to describe voice quality of tracheoesophageal vs esophageal speech.¹

With the use of the MDVP, a qualitative differentiation of patients after total or partial laryngectomy was not possible. Equally, for the variable HNR, a qualitative assessment was not possible because the voice irregularities were too large. A similar restriction concerning examination and comparison of irregular voices (voice prosthesis vs esophageal speech) with MDVP was also found by Bertino et al³ and Crevier-Buchman et al.⁵ The HNR is a useful predictor of breathy and rough glottic voices but could not be determined in a meaningful way in these unglottic voices.²² The HNR is influenced by jitter and shimmer, which are factors limiting the descriptive power of the variables for irregular voice signals.^{23,24} No significant differences appeared for the feature maximum phonation time, because the patients in both groups were able to use their full lung capacity for voice production. Also for voice breaks, jitter, and shimmer, no significant differences were detectable. All speakers possessed very irregular voices, and the measured voice quality did not correlate with their speech intelligibility evaluated on the PLTT.

The Göttingen hoarseness diagram offers an inexpensive and quick acoustic analysis procedure that allows the quantitative assessment even of irregular voice signals. In regard to the noise component, the separation between patients with partial and total laryngectomy was statistically significant ($P=.03$). Regarding the irregularity component, all 25 patients presented highly irregular voices with no significant differences ($P=.24$). However, the correlation of the irregularity component with speech intelligibility was significant ($P=.03$). A high irregularity in the Göttingen hoarseness diagram was seen in patients with a poor speech intelligibility on the PLTT.

In these highly pathological and irregular voices, the meaning of breathiness differs from that of glottic phonations. The low noise component of the patients with total laryngectomy who had poor speech intelligibility might be explained by a pressed voice that was observed together with a very short phonation time. These 2 factors are probably responsible for the low noise component values measured (Figure 2).

In conclusion, the Göttingen hoarseness diagram is suitable for a quantitative assessment even of irregular voices. The voice quality evaluated with this procedure correlates with the speech intelligibility measured by the PLTT. Best results in speech intelligibility and voice quality were obtained in patients after organ-preserving treatment. In the most favorable cases, the speech intelligibility of the patients who received voice prostheses approached the values of the patients with partial laryngectomy.

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Corresponding author: Arno Olthoff, MD, Department of Phoniatics and Pedaudiology, University of Göttingen, Robert-Koch-Str 40, D-37075 Göttingen, Germany (e-mail: olthoff@uni.de).

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