The efficiency of voice production
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In Chapter 1, a short survey is given of the myoelastic-aerodynamic theory of voice production, briefly discussing the importance of airflow rate and subglottic pressure. By relating the power necessary for sound production to the produced sound intensity, the efficiency of the laryngeal generator can be ascertained. The purpose of our study was to establish to which degree the efficiency in various laryngeal disturbances will be influenced and to formulate criteria for predicting and evaluating the result on efficiency of therapeutic measures in our patients. Data obtained in normal subjects without vocal complaints have been used for comparison.

In Chapter 2, the methods employed for measuring sound intensity, airflow rate, and subglottic pressure at various pitches and sound intensities over the total vocal compass have been described. The sound intensity is measured by a microphone and the airflow rate by pneumotachography.

For measuring the subglottic pressure we used an indirect method. The subglottic pressure was ascertained from the changes in the oesophageal pressure during and/or after phonation. The pressure in the oesophagus also varies with varying lung volume, so we had to take this latter into account in the determination of subglottic pressure from measurements of the oesophageal pressure. The changing lung volume was ascertained by integration of the airflow signal from the pneumotachograph.

In the registration of volume curves, we had to correct for various differences in the physical properties of inspired and expired air. This is theoretically explained and illustrated by analytical experiments.

Generally, pressure changes due to the viscous resistance of the lungs and airways are low during phonation. By applying a second correction method, it was possible to compensate automatically the changes in the oesophageal pressure due to changes in the lung volume during the measuring series. Thus the subglottic pressure could be read directly from the corrected oesophageal pressure curve.

The indirect measurement of the
subglottic pressure was verified by simultaneous direct measurements in three patients.

In Chapter 3, the analysis of the curves and the accuracy of the measurements are discussed.

Reduction of the experimental data from single phonations took place by calculating regression lines through the measuring points. These regression lines apply to the relation between a) the intensity and b) respectively, the air flow rate, the subglottic pressure, or the efficiency.

The regression lines were used to obtain average values and characteristic values for each subject.

Chapter 4 gives the results obtained with normal subjects without vocal complaints. We started with 4267 phonations from 63 subjects in 93 measuring series. However, some phonations were assessed by trained listeners as acoustically deviant. The remaining data from 2736 well-sounding phonations, obtained in 72 measuring series in 24 males and 21 females, were used to establish reference values and reference areas for the evaluation of data from patients.

The pitch of the phonations appeared to have little influence on the course of the regression line. The data for all pitches in one measuring series therefore were converted into regression lines, the intensity being considered as independent variable.

The flow and pressure values and, therefore, also the efficiency values, showed a great inter-individual spread. Reproducibility measurements showed that the intra-individual differences are much smaller than the inter-individual differences and that a good reproducibility exists.

By statistical evaluation of the measurements in the same normal subject, reliability intervals were calculated, enabling us to establish the significance of therapeutic results in patients.

The averages of the regression coefficients of the regression lines of all normal subjects were used to ascertain reference regression lines for flow, pressure, and efficiency. By referring the measured efficiency to the reference efficiency line, a relative measure of efficiency was obtained, which enabled us to establish the efficiency of a given individual larynx.

The set of regression lines was used to obtain reference areas representing the distribution
spread of normal values. Later analysis of deviant sounding phonations proved that the aerodynamic data of these phonations lay for the greater part within the reference areas.

Intentionally produced hoarse phonations, from normal subjects appeared to deviate clearly from "normal" aerodynamic values of the same subject.

As the intra-individual differences are much smaller than the inter-individual differences, we concluded that a patient or a normal subject may serve as a standard for himself, to ascertain changes in the aerodynamic pattern, e.g. as the result of treatment.

The obtained measuring results were compared with data from the literature.

Chapter 5 gives the results obtained in 64 patients in 120 measuring series comprising 4983 phonations.

The patients showed a great variety of laryngeal disturbances. They were divided into three main groups: Group I, patients having organic disturbances of the vocal folds, Group II, patients having normal vocal folds and, in most cases, slight adduction disturbances, i.e. patients with "functional voice disorders", and Group III, patients having normal vocal folds, but with severe innervation disturbances of the laryngeal muscles.

From each group, the cases of some interesting patients are discussed in detail.

The data of the first measuring series were used to ascertain the diagnostic value of the aerodynamic data: flow and subglottic pressure, alone or in combination (efficiency).

The great inter-individual dispersion in patients with seemingly the same laryngeal disturbance, depreciates the value of single data. It appears that a specific aerodynamic pattern for a certain laryngeal disturbance does not exist. This also means that a single measurement can hardly establish the diagnosis of a vocal disturbance. However, since it yields a rough impression about the functioning of the larynx it may reveal a hyperfunctional use, as we see from the fact that the subglottic pressure regression lines from all patients were found to lie higher than the pressure reference line and in 59% of the cases to lie outside the reference area.

In Group I (organic disturbances),
in about 30% of the patients no aerodynamic disturbances were diagnosed. This was the case with patients with slight vocal fold affections like hyperaemia or oedema, or some patients with the clinical diagnosis of nodules. In more severe disturbances, obviously deviating aerodynamic values were measured.

The subglottic pressure values lay in general too high, the flow values were much dispersed. The efficiency was about 1 to 6 dB lower than the reference value, with one highly deviating value of -13.5 dB.

It was remarkable that it made little difference in the efficiency whether the vocal fold affection consisted of local disturbances like nodules, polyps, cysts, or papillomas, or of more extensive disturbances of the surface of the folds. The possibility of (dynamic) glottis closure appeared to be of great importance.

In Group II (functional disturbances), in nearly all patients an incomplete closure of the glottis was ascertained. Despite these incomplete glottis closures, the flow values appeared to be deviant in only two cases, whereas the subglottic pressures in most cases appeared to be too high. The efficiency lay roughly about 4 dB lower than the reference value. Most patients in this group received voice training.

With respect to the patients of Group III (severe innervation disturbances) a survey has been given of the clinical aspects of unilateral or bilateral laryngeal paralysis. In three patients with a bilateral paralysis surgical widening of the glottis was necessary because of respiratory difficulties. The effect of the operation on the efficiency and on possibilities of communication is discussed.

In this group the efficiency in patients in whom no static closure of the glottis was effectuated, was about 8 dB lower than the reference value. The subglottic pressure in this group appeared to be, despite the paralysis, remarkably high.

In 47 patients, a second measuring series was performed, after some form of medical (surgical) therapy and/or voice training had been given.

A number of these patients were examined several times, in a total of 56 measuring series after therapy, 2434 phonations were obtained.
The efficacy of therapeutic measures, derived from the difference of the relative efficiency values, appeared to be favourable in most patients, though the relative efficiency values nearly always remained negative.

In the patients in whom even after treatment complete (dynamic) glottis closure was still impossible, e.g. by a persisting chink, an improvement of the efficiency appeared to be related to a more relaxed phonatory pattern. In aerodynamic terms, this was related to the decrease of the subglottic pressure. To what extent the flow values were changed depended mainly on the possibility of a dynamic closure of the glottis.

In Chapter 6, we discuss the results of investigations with five trained singing voices. The efficiency was compared with that of non-trained voices. We concluded that the singers produced the sound in such a way that the efficiency was of secondary importance to the aesthetic demands.

These qualitative demands, especially in the tenor singers led to the appearance of very high subglottic pressures at high sound intensities. The influence of these very high subglottic pressures on the blood circulation is indicated and demonstrated by photoplethysmography. Some qualitative aspects like vibrato and the presence of the singing formant were studied.

The acoustic coupling of the vocal tract to the larynx is discussed with respect to the occurrence of a particular resonance phenomenon.

The chapter closes with a discussion of aerodynamic aspects of some variants of the singing voice production, based on various pedagogic techniques. The efficiency appeared to differ little in these variants, though difficulties with respect to flow and pressure values could be demonstrated. Our conclusion was that in these variants of the singing voice production the subjective and singing pedagogic aspects are of greater importance than the aerodynamic ones.