Effects of Surgery on the Phonation Threshold Pressure in Patients With Vocal Fold Polyps

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Background/Purpose: There are few objective measurements to assess the results of surgery for vocal fold polyps. This study investigated the effects of surgery on the phonation threshold pressure (PTP) in patients with vocal fold polyps.

Methods: Prospectively, 32 consecutive patients with vocal fold polyps were enrolled. PTP was measured 1 day before and 6 weeks after laryngomicrosurgery, by means of an airflow interruption method. An accelerometer was used to detect the vocal fold vibration instead of using an acoustic signal.

Results: In all 32 patients, the average preoperative PTP was 0.51 ± 0.23 kPa, and 6 weeks after surgery, it was 0.28 ± 0.17 kPa; this difference was statistically significant (p < 0.001). Individually, PTP decreased in 31 patients after surgery. PTP increased after surgery in only one patient, from 0.74 to 0.75 kPa. Subjectively, all patients could phonate with less effort after surgery. Use of an accelerometer to sense vocal fold vibration was feasible and made it easier to identify the time point of cessation of vocal fold vibration, which is important for PTP measurement.

Conclusion: Laryngomicrosurgery can lower PTP in patients with vocal fold polyps and improve the ease of phonation. PTP is one of the objective measurements for assessing the effects of surgery in patients with vocal fold polyps. Use of an accelerometer to detect vocal fold vibration improved the measurement of PTP. [J Formos Med Assoc 2010;109(1):62–68]

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many methods have been designed that are direct or indirect, invasive or noninvasive, to measure the subglottal pressure. Currently, the most popular method is to approximate the intraoral pressure to the subglottal pressure during bilabial stop /p/ production. PTP is assessed from the measures of subglottal pressure by the subjects attempting to sustain a train of /pi/ syllables as softly as possible. It is difficult for a person to accomplish this process without specific training. If a subject is equipped with an airflow interruption system, another method can approximately measure the intraoral pressure to the subglottal pressure by means of blocking the airflow suddenly, using an airway valve during phonation. Jiang et al refined this system and designed a sophisticated method to isolate the PTP from the subglottal pressure. The subglottal pressure during phonation is composed of two portions, the PTP and the driving pressure. The acoustic signal is recorded together with the airflow interruption system. The cessation point of the acoustic signal is taken for the stop point of the vocal fold vibration, which is the separation point between the PTP and the driving pressure. In this way, PTP can be estimated from subglottal pressure measurement. This device substantially potentiates the clinical application of PTP in assessing the phonation function of the vocal folds.

Here, PTP was measured in 32 patients with vocal fold polyps before and after laryngomicrosurgery. We tried to use a mini-accelerometer instead of the acoustic signal to detect the vocal fold vibration during PTP measurement. We discuss the pre- and post-operative PTP in patients with vocal fold polyps, which was measured using a mini-accelerometer.

**Materials and Methods**

**Instrumentation in the airflow interruption system**

The PTP measurement setup used in this study is illustrated in Figure 1. The specially designed airflow interruption system started with an anesthetic face mask and ended at a membrane-type electronic control shutter valve (SS-168; Shin-Yu Electric, Taipei, Taiwan), which could completely block the airflow within 50 ms. The face mask was fitted to the face of the subject to be tested such that the seal was air-tight. The acoustic signal was detected with a precision microphone (ECM-672; Sony, Tokyo, Japan) placed 5 cm from the mask and connected to channel 1. The pressure inside the face mask, which reflected the intraoral pressure, was measured using a calibrated pressure sensor (MP-45-30-871; Validyne Inc., Northridge, CA, USA), and the signal was connected to channel 3. A heated-wire airflow meter (PS-77H; Nagashima Medical Instruments, Tokyo, Japan) was placed between the mask and the shutter valve for the airflow rate measurement, and the signal was connected to channel 4. For the detection of the vocal fold vibration, a 5.0 × 5.0 × 1.8 mm mini-sized accelerometer (KXM52-1050; Kiorix, Ithaca, NY, USA) was used. This accelerometer was coupled with a custom-designed tiny circuit board (Figure 2), which is 14.8 × 7.6 × 1.2 mm in size, and was attached to the neck skin just over the lamina of the thyroid cartilage (Figure 1). The accelerometer sensed the acceleration of the vocal fold tissues during vibration. The signal was connected to channel 2. All the signals were digitalized, collected, and calculated with a personal computer and data acquisition and analysis equipment (WinDaq; Dataq Instruments, Akron, OH, USA).
A total of 32 consecutive patients with vocal fold polyps, who received laryngomicrosurgery at the Department of Otolaryngology, National Taiwan University Hospital by the senior author (Dr T.Y. Hsiao) from July to November 2008, were enrolled in this study. All patients received videostrobolaryngoscopic examination (RLS-9100; Kay Elemetrics Corp., Lincoln Park, NJ, USA) to verify the diagnosis before surgery. PTP measurement was performed initially 1 day before surgery at the most comfortable pitch and volume for the patient. The fundamental frequency of phonation was calculated from the recorded acoustic signal. The loudness of phonation was 70–75 dB sound pressure level at a distance of 5 cm from the mask (Type 2235; Brüel & Kjær, Nærum, Denmark). The second videostrobolaryngoscopic examination and PTP measurement were taken 6 weeks postoperatively. The laryngomicrosurgery was performed under general anesthesia. Absolute voice rest was recommended strongly for 3 days postoperatively, followed by 10 days of voice conservation. In general, PTP was measured as described previously.9 The whole procedure was explained thoroughly to the patients, because it was crucial to make sure that they understood the examination procedure and were cooperative throughout the process. The face mask was fitted to the face of the patient with an air-tight seal, and the microphone and the accelerometer were in their proper places. The patient was then asked to utter a steady vowel /a/ for 5 seconds at the pitch and volume most comfortable for him/her. Once the patient could phonate without stress, the blocking shutter valve was shut down suddenly by the tester for about 1 second in the middle of the phonation. All the patients could perform the procedure well after practicing several times. It took an average of 15–20 minutes to complete a measurement for each patient. The signal from the accelerometer was used to detect the vibration of the vocal folds instead of using an acoustic signal, as was used previously.9 The time point at which the tissue acceleration signal ceased was used to separate the PTP from the driving pressure during measurement of subglottal pressure.

### Results

Between July and November 2008, 32 consecutive patients who received surgery for vocal fold polyps and pre- and post-operative PTP measurements were reviewed. There were five male patients with a mean age of 48.8 years (range, 42–57 years), and 27 female patients with a mean age of 34.9 years (range, 21–52 years). All patients tolerated the surgical procedure well. Follow-up PTP measurement was performed 6 weeks after surgery. At that time, all patients reported being able to phonate with less effort than before surgery.

PTP was calculated by using the signals from the accelerometer and pressure sensor. Data in these two channels were displayed at the same time, as shown in Figure 3. Once the shutter valve was blocked, the intraoral pressure measured inside the face mask rose and reached a plateau in about 200 ms. The pressure difference between the level before and after blocking the airflow and the plateau was approximately the same as that of the subglottal pressure during phonation.8,9 Meanwhile, as the shutter valve closed, the signal from the accelerometer that sensed the vocal fold vibration diminished in size and became completely silent. The cessation point of the
accelerometer signal represented the time at which the vocal fold vibration ceased. The value of the pressure difference between this point (point A in Figure 3) and the plateau was the PTP.9

The preoperative PTP in all 32 patients ranged from 0.20 to 0.96 kPa, with an average of 0.51 ± 0.23 kPa. The PTP measured 6 weeks after surgery ranged from 0.10 to 0.75 kPa, with an average of 0.28 ± 0.17 kPa. The difference between the values before and after surgery was statistically significant (p < 0.001, paired t test; Figure 4). The difference in the fundamental frequency of phonation between the pre- and post-operative comfort pitch level was less than two semitones. The pre- and post-operative PTP difference in each patient is shown in Figure 5. Thirty-one of the 32 patients had lower PTP values after surgery. There was only one patient whose PTP increased after surgery, from 0.74 to 0.75 kPa.

Discussion

The subglottal pressure provides the power to drive the glottal airflow that passes through the glottis. The glottal airflow propels the vocal folds to vibrate periodically to form the voice,2 which is a purely mechanical phenomenon.1 The subglottal pressure varies with the loudness of the voice in an exponential manner.10 To date, the subglottal pressure itself is seldom used for estimating the phonation function of the vocal folds. The PTP is the minimum subglottal pressure that is necessary to initiate and sustain the vocal fold vibration for a certain glottal configuration. The level of PTP is determined by the vocal fold thickness, vocal fold tissue viscosity, mucosal wave velocity during vocal fold vibration, and the prephonatory

Figure 3. Example of phonation threshold pressure calculations from the acceleration signal and pressure signal channels. A, the cessation point of vocal fold vibration; B, pressure level before shut-down of the blocking valve. The time interval between the mark M and the cursor line was 20 ms. AC = accelerometer signal; PS = pressure sensor signal; P = pressure level of the plateau; BP = subglottal pressure; AP = phonation threshold pressure.

Figure 4. Interquartile ranges of phonation threshold pressure in 32 patients before and after surgery.
glottal configuration. The PTP is the minimum subglottal pressure needed to overcome the energy dissipated in the vocal fold tissues. It can be predicted that PTP will become higher during phonation in patients with vocal fold diseases, in which the mechanical properties of the vocal folds change. The existence of organic vocal fold lesions, such as vocal fold polyps, has an impact on the mechanical attributes of the vocal folds, which will hinder the formation of vibration and increase PTP. Furthermore, PTP is the effort needed to overcome the energy loss during vocal fold vibration. Clinically, it can be considered as a measure of effort during phonation. In the present study, we tried to measure PTP as an objective measurement for assessing the effects of laryngomicrosurgery in patients with vocal fold polyps.

Jiang et al designed a sophisticated method for measuring PTP. The subglottal pressure during normal phonation is divided into two components: PTP and driving pressure. During measurement of the subglottal pressure with an airflow interruption device, the time point of cessation of the acoustic signal, which is taken as the stop point of vocal fold vibration, is used to separate these two components. This method has made the measurement of PTP feasible in clinical applications. In this study, we custom-designed a tiny circuit board to couple with a commercially available mini-accelerometer to detect the vibration of the vocal folds. Once the vocal fold vibrated, the vocal fold tissues moved with changing velocity. The acceleration of the vocal fold tissues was sensed by the accelerometer. The flat surface of the circuit board was the appropriate shape and size to be attached well to the neck skin over the thyroid lamina, without interfering with the other recordings of the system. The accelerometer sensed the tissue acceleration directly during vocal fold vibration, thus, it avoided environmental noise interference. The amplitude of the accelerometer signal was related to the amplitude of vocal fold vibration. When the vocal folds stopped vibrating, the acceleration signal became silent. It was reasonable to take the cessation point of the accelerometer signal as the stop point of vocal fold vibration. In our experience, the cessation point of the acceleration signal is easier to identify than that of the acoustic signal, as shown in Figure 6. The application of a mini-accelerometer to detect vocal fold vibration improved PTP measurement.

The PTP measured 1 day before surgery in the series of 32 patients had an average value of $0.51 \pm 0.23 \text{kPa}$. This was compatible with data from a previous study and higher than that in normal subjects. Six weeks after surgery, the average PTP was $0.28 \pm 0.17 \text{kPa}$. It was obvious that PTP returned to the normal range after surgery, and the difference between the values before and after surgery was statistically significant ($p < 0.05$). Individually, PTP level was lower postoperatively in all patients except one. Subjectively, all the patients reported that they were able to phonate with less effort after surgery, which was in agreement with the average decrease in PTP after surgery. PTP level provides a basis for the measurement of ease of phonation. It has been studied in normal subjects under various hydration conditions and in subjects with different degrees of vocal fatigue. As shown in the present study, PTP can also be used as an objective measurement of the effects of laryngomicrosurgery in patients with vocal fold polyps. Vocal fold polyps alter the biomechanical characteristics of the vocal folds and render the formation of vocal fold vibration more difficult. Vocal fold...
Measurement of phonation threshold pressure

polyps also increase the viscosity of the vocal fold tissues. The high viscosity of the vocal fold tissues appears to change the mechanical properties of the tissue and hamper its vibration. The vocal fold mucosa and the Reinke’s space of the diseased vocal folds become stiffer, which accelerates the propagating mucosal wave velocity. Vocal fold polyps appear to separate the vocal folds and alter the glottal configuration for vibration. These changes in the mechanical properties of the vocal folds cause more energy dissipation in the vocal fold tissues, which means that more effort is required to propel the vocal fold vibration, thus increasing the PTP.4,12,16 It is evident that laryngomicrosurgery for vocal fold polyps improves the biomechanical characteristics of the vocal fold tissues for vibration and lowers PTP postoperatively.

Theoretically, PTP provides an excellent method for evaluating the effects of medical or surgical treatment of diseased vocal folds. However, there are still very few studies that have dealt with the clinical application of PTP. In our experience, it is important to explain the whole procedure to the patients before taking measurements, and the patients need to practice several times to avoid being startled at the sudden shut-down of the airflow shutter valve. In this study, the PTP was measured at the most comfortable volume and pitch for the patient. The volume of phonation was 70–75 dB sound pressure level. This voice intensity level has no significant effect on PTP,4,12,16 but higher pitch increases PTP.4,9,16–19 In the present 32 patients, the differences between the pre- and post-operative fundamental frequencies of the voices tested were all within two semitones. According to previous studies, the influence of this phonation frequency difference on PTP measurement is < 5%,17–19 and the error is negligible.

Figure 6. Comparison of the acoustic and acceleration signal in identifying the cessation point of the vocal fold vibration. The time interval between the mark M and the cursor line was 20 ms. Acoustic = channel of acoustic signal; AC = channel of accelerometer signal; PS = channel of pressure sensor signal.
In conclusion, PTP was measured using the airflow interruption method to evaluate the effect of laryngomicrosurgery in a series of 32 patients with vocal fold polyps. The vibration of vocal folds was detected by means of a mini-accelerometer instead of using an acoustic signal. Application of the mini-accelerometer seemed to improve PTP measurement, which could be a useful parameter for objectively evaluating the effects of treatment of vocal fold diseases in the future.

Acknowledgments

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References