Acoustic Changes in Chinese Patients With Cancer-Related Unilateral Vocal Fold Paralysis After Medialization Thyroplasty

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ABSTRACT: The present study investigated the change in the voice quality of patients with unilateral vocal fold paralysis (UVFP) of benign and malignant causes after medialization thyroplasty. Thirty-four native Cantonese adults who had been diagnosed with UVFP participated in the study. Acoustical parameters including the average voice fundamental frequency, percent jitter, relative average perturbation (RAP), percent shimmer, and noise-to-harmonic ratio (NHR) were measured from the sustained vowel /a/ that was recorded before and after the thyroplasty procedure. Maximum phonation time (MPT) was also obtained. Results indicated that, for both benign and malignant patients, all acoustical parameters except for NHR showed improvement after thyroplasty: Percent jitter, RAP, and percent shimmer values were significantly reduced, and MPT was significantly lengthened. Our findings support the notion that medialization thyroplasty is a useful palliative procedure to improve voice production in Cantonese-speaking UVFP patients. Despite the cancerous condition, it is still beneficial to malignant UVFP patients, and better voice quality can be achieved.

KEY WORDS: acoustic, thyroplasty, Cantonese, malignant, cancer
participants’ vocal folds after Teflon injection versus medialization thyroplasty. Based on stroboscopic examination of their 21 patients, Gardner and Parnes found that patients who underwent medialization thyroplasty exhibited better mucosal wave and better voice quality than did those who underwent Teflon injection. The better vocal quality in patients with thyroplasty was due to the minimal intrusion to the deep layers of the vocal folds during the surgery, and thus normal vocal fold vibratory behavior was preserved (Gardner & Parnes, 1991). Similar findings were observed by Leder and Sasaki (1994), and Rosingh and Dikkers (1995). Gray, Barkmeier, Jones, Titze, and Druker (1992) also reported better perceptual quality of the voice after medialization thyroplasty in the treatment of unilateral vocal fold paralysis (UVFP).

Although many of the studies were based on subjective and noninstrumental assessment of the voice, a few reported instrumental assessment of voice quality after medialization thyroplasty. Based on aerodynamic measurements, perceptual ratings, and stroboscopic examination, D’Antonio, Wigley, and Zimmerman (1995) reported favorable surgical outcomes and better postoperative voice quality after medialization thyroplasty in contrast to Teflon injection. The poorer voice quality in Teflon injection patients was believed to be due to the “violation of the true vocal fold cover, particularly increased true vocal fold mass and stiffness” (D’Antonio et al., p. 256). Maximum phonation time (MPT) changes after medialization thyroplasty were also found to be a reliable predictor of vocal outcome after medialization thyroplasty (Lundy, Casiano, & Xue, 2004).

Many studies have compared the difference in using various kinds of implant materials in medialization thyroplasty. However, cancer-related UVFP was seldom mentioned. Most studies simply examined the effect of medialization thyroplasty on UVFP patients without distinguishing between benign and malignant etiologies. However, it is possible that the preexisting cachexic condition and already impaired pulmonary status in malignant UVFP patients may confer worse acoustic outcomes from medialization surgery. To substantiate the use of medialization thyroplasty in malignant patients, it is thus essential to compare the acoustic outcome in malignant UVFP patients with that in patients with benign etiologies. In addition, reports available in the literature were mainly based on cases from the English-speaking population. The efficacy of medialization thyroplasty on Cantonese is yet unknown. We do not know if thyroplasty bears the same benefit on the voice quality of the Cantonese-speaking population. Cantonese is a tonal language in which the same phonetic segment carries different meanings if it is produced at different tones. In Cantonese, there are six contrasting tones: high level, high rising, mid level, low falling, low rising, and low level. For example, a syllable may mean mother if it is produced at a high-level tone, horse if produced at a low-rising tone, grandmother if produced at a low-falling tone, and so on.

The present study thus investigated the change in voice quality of Cantonese-speaking UVFP patients of benign and malignant causes. The possible differential effects of medialization thyroplasty on these two patient groups were determined. By using an array of acoustical parameters, objective assessments of the voice in both benign and malignant UVFP patients before and after medialization thyroplasty were evaluated.

## METHOD

### Participants

The present retrospective study included 34 (24 male and 10 female) consecutive Chinese patients who had undergone medialization thyroplasty for UVFP (11 benign and 23 malignant) at the Division of Otorhinolaryngology Head & Neck Surgery, Department of Surgery, University of Hong Kong Medical Centre, Queen Mary Hospital consecutively from September 2000 to January 2005 with complete recordings of pre- and postoperative speech samples. They were all native speakers of Cantonese.

Patients suffering from UVFP due to confirmed malignant causes, as a result of direct invasion of either the recurrent laryngeal nerve or the vagus nerve by advanced malignancy, and patients with UVFP secondary to cancer treatment, for example, intentional or inadvertent surgical sacrifice of the recurrent laryngeal nerve or the main vagal trunk and nerve palsy due to radiation neuritis, were categorized under the malignant group. The benign group could be due to traction neuropathy from pulmonary tuberculous scar, neck injury, or iatrogenic causes. Patients suffering from UVFP due to cancer-related causes, irreversible benign causes such as direct transection of the vagus nerve during surgery, or potentially reversible benign causes that failed spontaneous recovery after 6 months were treated by medialization thyroplasty with Silastic implants carved from a polymeric silicone block. The medialization procedure was carried out while the patient was conscious. During the procedure, a small window was surgically created on the thyroid lamina of the paralyzed side, and Silastic in the form of a gel-like ribbon was injected into the lateral aspect of the paralyzed fold. The vowel /a/ was continually produced by the patient in order to monitor the amount of medialization. The procedure was completed as soon as the patient was able to produce the vowel /a/ with a normal quality as judged by the operating otorhinolaryngologist.

The etiology pattern of the UVFP patients is shown in Table 1.

### Speech Materials

Each speaker performed two speech tasks in the study: (a) sustained vowel /a/ for at least 1 s and (b) the vowel /a/ for as long as he or she could. The participants were instructed to produce the speech materials at a comfortable loudness and pitch level. An array of acoustical parameters was obtained from the sustained vowel, and the MPT values were measured from the longest sustained phonation of the vowel /a/.
Speech Recordings

Recordings of patients’ speech were obtained 1–2 days before the surgery and approximately 1 month after the surgery. All recordings took place in a sound-treated booth that was located in the hospital. Before the actual recording, the participants were provided with a brief period of practice time to familiarize themselves with the recording format, speech materials, and recording environment.

During the experiment, the patients were asked to produce the speech materials at a comfortable loudness level. The order in which the speech samples were produced was randomized in order to minimize the order effect. Voice samples were recorded using a high-quality microphone (Shure, SM58) and were stored on audiotapes. To maintain a constant recording level, the microphone was placed at approximately 10 in. from the patient’s mouth during the recording. The recorded speech samples were digitized at a sampling rate of 20,000 Hz and were stored for later acoustic analyses.

Acoustic Analysis

Acoustical parameters were obtained by using the Multi-Dimensional Voice Profile (MDVP; KayPentax, Model 5105). To avoid initiation and termination errors, when performing the acoustic analysis, only the medial 90% of the entire speech sample was included. When measuring the MPT, however, the entire vowel sample was used. Actual measurements included the average fundamental frequency (F₀) values, percent jitter, relative average perturbation (RAP), percent shimmer, noise-to-harmonic ratio (NHR), and MPT values.

Statistical Analyses

Statistical analyses were carried out to test for significant changes to the voice quality after thyroplasty. Two-way (benign/malignancy × pre-/post-thyroplasty) repeated-measure analyses of variance (ANOVA) were used to determine if significant differences existed in percent jitter, RAP, percent shimmer, NHR, and MPT values between the recordings that were made before and after thyroplasty. When significant interactions were found, repeated-measure t tests were performed to test for significant differences in the main effects.

RESULTS

Average F₀ Values

Due to the intrinsic F₀ difference between adult males and females, no attempt was made to collapse data from male and female patients, and no inferential statistic tests were performed. Results from the present study showed that male benign and malignant UVFP patients exhibited an average F₀ value of 251.6 Hz before the procedure and 161.6 Hz after the procedure, and 203.1 Hz before the procedure and 165.7 Hz after the procedure, respectively. Female benign and malignant UVFP patients exhibited an average F₀ value of 257.7 Hz before the procedure and 250.9 Hz after the procedure, and 255.8 Hz before the procedure and 290.7 Hz after the procedure, respectively. All average F₀ values are shown in Figures 1 and 2.

Acoustical Parameters for Voice Quality

The acoustical parameters obtained from benign and malignant patients before and after medialization thyroplasty are summarized in Table 2. Two-way (benign/malignancy × pre-/post-thyroplasty) repeated-measure ANOVAs were used to determine if significant differences were present in percent jitter, RAP, percent shimmer, NHR, and MPT before and after the thyroplasty between benign and malignant UVFP patients. All ANOVA tests failed to reveal significant interaction at the 0.01 probability level between the two independent variables: the UVFP is of a benign or malignant etiology (malignancy), and data obtained before or after the surgery (pre-/post-thyroplasty): percent jitter, \( F(1, 32) = 1.561, p > 0.01 \); RAP, \( F(1, 32) = \).
1.359, \( p > 0.01 \); percent shimmer, \( F(1, 32) = 2.226, p > 0.01 \); NHR, \( F(1, 32) = 0.174, p > 0.01 \); and MPT, \( F(1, 32) = 1.029, p > 0.01 \). The effect of pre-/post-thyroplasty was found for percent jitter, RAP, and MPT, but not for shimmer and NHR values (see below).

### Percent Jitter

Percent jitter values are depicted in Figure 3. The mean percent jitter value for patients with benign etiology and malignant etiology was 6.28% and 7.18%, respectively, before surgery, and 4.38% and 3.25%, respectively, after surgery. Significant difference in percent jitter was found between the measurement obtained before and after surgery: \( F(1, 32) = 12.759, p < 0.01 \). However, no significant difference was observed between benign and malignant etiologies: \( F(1, 32) = 0.016, p > 0.01 \).

### RAP

Average RAP values are presented in Figure 4. The average RAP value was 3.74 for benign patients and 4.20 for malignant patients before surgery, and 2.58 for benign patients and 1.94 for malignant patients after surgery. Significant difference was found between the measurement obtained before and after surgery: \( F(1, 32) = 13.264, p < 0.01 \). No significant main effect was found for malignancy: \( F(1, 32) = 0.029, p > 0.01 \).

### Percent Shimmer

Average percent shimmer values are shown in Figure 5. The average percent shimmer value was 9.92% before surgery and 9.61% after surgery for UVFP patients with benign causes, and 12.15% before surgery and 7.36% after surgery for UVFP patients with malignant causes. No significant differences for both main effects (pre-/post-thyroplasty and malignancy) were found: pre-/post-thyroplasty, \( F(1, 32) = 2.226, p > 0.01 \); malignancy, \( F(1, 32) = 0.000, p > 0.01 \).

### NHR

Average NHR values are depicted in Figure 6. For patients with benign causes, the average NHR value was 0.343 before surgery and 0.271 after surgery. For patients with malignant causes, the average NHR value was 0.320 before surgery and 0.336 after surgery. Effects of pre-/post-thyroplasty and malignancy were not significant: pre-/post-thyroplasty, \( F(1, 32) = 0.174, p > 0.01 \); malignancy, \( F(1, 32) = 0.042, p > 0.01 \).

**Table 2. Summary of acoustical parameters measured before and after medialization thyroplasty.**

<table>
<thead>
<tr>
<th>Benign</th>
<th>Malignant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
</tr>
<tr>
<td></td>
<td>M</td>
</tr>
<tr>
<td>RAP (%)</td>
<td>3.740</td>
</tr>
<tr>
<td>NHR</td>
<td>0.343</td>
</tr>
<tr>
<td>MPT (s)</td>
<td>5.970</td>
</tr>
</tbody>
</table>

**Note.** RAP = relative average perturbation, NHR = noise-to-harmonic ratio, MPT = maximum phonation time.
Figure 4. Changes in relative average perturbation (RAP) before and after surgery for benign ($n = 11$) and malignant ($n = 23$) etiologies.

Figure 5. Changes in percent shimmer values before and after surgery for benign ($n = 11$) and malignant ($n = 23$) etiologies.

Figure 6. Changes in noise-to-harmonic ratio (NHR) values before and after surgery for benign ($n = 11$) and malignant ($n = 23$) etiologies.

Figure 7. Changes in maximum phonation time (MPT) before and after surgery for benign ($n = 11$) and malignant ($n = 23$) etiologies.

MPT

Average MPT values are shown in Figure 7. The mean MPT values for benign patients was $5.97$ s before surgery and $8.30$ s after surgery, and that for malignant patients was $2.99$ s before surgery and $6.87$ s after surgery. The effect of pre-/post-thyroplasty was found to be significant: $F(1, 32) = 1.029, p < 0.01$. However, no significant difference was found between benign and malignant causes at the 0.01 level: $F(1, 32) = 5.397, p > 0.01$.

DISCUSSION

$F_0$

The average $F_0$ values associated with benign and malignant UVFP for male and female patients are depicted in Figures 1 and 2. It is apparent that, regardless of malignancy, UVFP patients generally showed higher average $F_0$ than normal speakers before thyroplasty. This was more pronounced in male UVFP patients (an average $F_0$ of 219.3 Hz compared to approximately 100 Hz to 120 Hz for normal adult males). Physiologically, a higher $F_0$ corresponds to faster vibration of vocal folds, possibly as a result of higher laryngeal tension. Perhaps the increased tension is more obvious in male UVFP patients as their habitual $F_0$ is lower than that of female patients. The fact that both male and female UVFP patients exhibited higher $F_0$ before the surgery suggests a higher laryngeal and supralaryngeal tension as a result of compensatory behavior. To compensate for their inability to achieve a complete glottal closure, UVFP patients may overadduct the nonparalyzed fold. Endoscopic laryngeal examination often reveals the arytenoid cartilage of the nonparalyzed fold crossing the midline and ending up anteriorly on the other side of the glottis. This concomitantly increases the tension in the surrounding structures. In fact, tensing of the strap muscles accompanied by laryngeal elevation is not uncommon in these patients.

Substantial reduction in $F_0$ was found in the male UVFP patients regardless of malignancy, but not in the female patients (see Figures 1 and 2). $F_0$ appeared to decrease...
drastically in male patients after medialization thyroplasty, implying a reduction of laryngeal tension and relaxation of neck structures after surgery. \( F_0 \) value can be a good indicator of how much tension the patients were imposing on their larynges (Colton & Casper, 1996). It is believed that, after the medialization procedure, the paralyzed fold is situated in a more medialized position. The glottal gap becomes smaller and the overadduction of the non-paralyzed fold is reduced. This process is probably unconscious, and the patients were not aware of the compensatory behavior. As a consequence, laryngeal tension is reduced and \( F_0 \) is lowered.

However, this was not found in female malignant UVFP patients. In fact, medialization thyroplasty appeared to increase the \( F_0 \) of female UVFP patients of malignant etiology. The difference in the findings between males and females may be related to the difference in the respiratory support between males and females. \( F_0 \) is a result of the interaction between the respiratory and altered phonatory systems. The different respiratory contribution to \( F_0 \) in female speakers may yield different changes in the \( F_0 \) when compared to males. More information is needed to confirm this notion. It should be noted that, due to the intrinsic gender difference in \( F_0 \) and the small sample size in each sex group, no inferential statistical testing was performed. Future research should perhaps provide more quantitative comparison of \( F_0 \) between male and female UVFP patients.

**Acoustical Parameters for Voice Quality Perturbation Measurements**

Our data indicated that percent jitter and RAP were significantly reduced after the medialization thyroplasty, with no significant difference between benign and malignant patients (see Figures 3 and 4). The reduced perturbation measures indicate that, after the paralyzed vocal fold was medialized, vibration of vocal folds had become more steady and regular, and better voice was achieved. The improvement of vocal fold vibration after thyroplasty appears to be in line with the reduction of laryngeal tension (as indicated by the reduced \( F_0 \)). The nonparalyzed vocal fold no longer needs to be overadducted to yield complete glottal closure for phonation, and laryngeal tension is reduced, thereby reducing the vibratory irregularity.

Percent jitter and RAP are objective indicators of the fluctuations of rate of vocal fold vibration. The reduced frequency perturbation measures were the result of improved vibratory behavior of the vocal fold after medialization thyroplasty. This may suggest that both the benign and malignant UVFP patients achieved better control over the rate of vocal fold openings and closings. This notion is supported by the subjective perception reported by their ear, nose, and throat doctors, which indicated significant improvement in patients’ voice quality, with reduced hoarseness and better phonation. According to Yiu, Murdoch, Hird, and Lau (2002), jitter and RAP perceptually correlate with the breathiness, roughness, and fry quality of the voice. The finding of improved vocal quality after medialization thyroplasty is consistent with those reported previously (D’Antonio et al., 1995; LaBlance & Maves, 1992; Omori, Slavit, Kacker, Blaugrund, & Kojima, 2000; Shin, Nam, Yoo, & Kim, 2002).

However, such improvement was not obvious in the amplitude perturbation measure: percent shimmer. Our data indicate that shimmer values were significant at the 0.05 level, but not at the 0.01 probability level. It follows that, for both benign and malignant patients, medialization thyroplasty was able to improve the regularity of vocal fold excursion during phonation to some extent. However, according to Figure 5, it is apparent that such improvement in amplitude perturbation was more pronounced in UVFP patients of a malignant etiology.

**NHR**

Our data on NHR did not show significant reduction after medialization thyroplasty (see Figure 6). The procedure appears to be unable to reduce the noise component (unwanted energy in the sound) in the voice. According to Yiu et al. (2002), noise contributes to the fry quality of the voice. It follows that medialization thyroplasty could be less indicative to the removal of the fry and raspy quality of the UVFP voice. High-frequency noise in the voice is generated through irregular vibration of the vocal folds. This reflects the greater abnormal vibratory pattern of the vocal folds, especially the outer edges, including the epithelium and superficial layer of the lamina propria. The reduced NHR may be related to the fact that many of our UVFP patients already suffered some loss of soft tissue due to denervation and subsequent vocal fold muscle atrophy. Consequently, altered histology of the epithelial layer and superficial layer of the lamina propria were present in their vocal folds even after medialization thyroplasty. However, more research including stroboscopic and high-speed imaging of the vibrating vocal folds is needed to confirm such findings.

**MPT**

One of the major symptoms of UVFP is the severely shortened MPT. This is mainly due to the fact that air is constantly leaking through the glottal gap, even during the closed phase of a glottal cycle, as a result of the inability to achieve complete vocal fold closure. The diminished MPT is apparent in Figure 7.

After the paralyzed fold was medialized, MPT was significantly prolonged. This appears to be more obvious in malignant patients than in benign patients (see Figure 7). Malignant UVFP patients experienced a greater improvement in sustaining phonation after the surgery. This is partly a result of improved vocal fold adduction and better vibration. As a faithful functional measure of glottal competence, MPT is an indication of both the respiratory support and glottal impedance toward the outward airstream during phonation. The increased MPT indicated that, after medialization thyroplasty, patients were able to produce speech with more efficient consumption of air during phonation. Before thyroplasty, with UVFP, air was constantly leaking through the glottis even during the closed phase of a glottal cycle due to the incomplete glottal
Comparison Between Benign and Malignant Causes

Data from the present study showed no significant differences in all of the measurements between benign and malignant patients. Yet, except for NHR, the improvement in vocal parameters was consistently greater for UVFP of a malignant etiology than that of a benign etiology (see Figures 3–5). The greater improvement might be contributed partly by the worse preoperative condition of malignant UVFP patients, as indicated by the higher percent jitter, RAP, and percent shimmer values before medialization thyroplasty. The poorer preoperative condition in malignant patients could be explained by their debilitated conditions. Twenty-three of our 34 UVFP patients had a malignant etiology such as lung cancer or esophageal cancer. Some of these patients had already been undergoing other treatment for their cancerous condition, in addition to thyroplasty for vocal fold medialization. Cancer treatments may include radiotherapy or chemotherapy, which may have worsened the vocal structures, including the vocal folds. Tissue becoming more dry and less elastic, combined with worsened blood supply after radiotherapy, is not uncommon in cancer patients receiving radiation therapy. Such changes to the vocal mechanism inevitably deteriorate the preoperative voice quality.

However, despite the poorer preoperative voice condition in malignant patients, the patients experienced greater improvement after medialization thyroplasty. This is indicated by the greater “net change” in the perturbation measures. The improvement in voice quality benefited from medialization thyroplasty appears to be more pronounced if the UVFP is of a malignant etiology. This is in contrast to some concerns about the efficacy of medialization thyroplasty in neoplastic patients. The limitation in the current study is the small sample size. This would affect the confidence of the result obtained. However, the results can still be viewed as a useful pilot assessment of the acoustic impact of medialization thyroplasty in Chinese patients with UVFP.

In conclusion, our data show that medialization thyroplasty is justifiable in malignant UVFP patients. The administration of medialization thyroplasty in UVFP patients should be advocated in order to improve the voice quality of these individuals. This aspect of post-thyroplasty acoustic changes in malignant UVFP patients should be researched in further detail.

REFERENCES


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