Laryngeal Aerodynamics After Vocal Fold Augmentation With Autologous Fat vs Thyroplasty in the Same Patient

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Objective: To analyze laryngeal aerodynamics in the same patient in 4 different circumstances: before the onset of unilateral vocal fold paralysis (UVFP), after the onset of UVFP, and after 2 types of surgical vocal fold medialization techniques to compare the results of surgery with the measurements made in that same patient when his larynx was healthy (before paralysis).

Design: Prospective self-paired study of 1 male patient. Measurements were taken before iatrogenic UVFP (of the patient’s healthy larynx), 1 week after the onset of iatrogenic UVFP (thoracic surgery), 3 days after vocal fold medialization with autologous fat, and 2 months after polytetrafluoroethylene thyroplasty.

Setting: University hospital.

Main Outcome Measure: Phonatory airflow and intraoral pressure.

Results: Airflow and intraoral pressure increased after the onset of UVFP. Airflow decreased to preparalytic values after both types of vocal fold medialization. Intraoral pressure decreased after fat injection but increased after thyroplasty, despite the favorable effects of this treatment on laryngeal resistance and vocal efficiency compared with preparalytic values.

Conclusions: Our study demonstrates the variability of intraoral pressure as an indirect measure of subglottal pressure after vocal fold medialization in UVFP, due to as yet unknown factors. Phonatory airflow, laryngeal resistance, and vocal efficiency seem to be more reliable indicators of aerodynamic results after vocal fold medialization.


Phonatory airflow and subglottic pressure are the aerodynamic forces driving laryngeal function in voice and speech. The airflow and pressure characteristics vary according to the laryngeal configuration and gesture. Laryngeal aerodynamics also vary according to age, sex, lung volume, laryngeal and tracheal sizes, and individual voice characteristics.

Unilateral vocal fold paralysis (UVFP) has been shown to cause increased phonatory airflow and pressure.1 Vocal fold medialization has been shown to decrease airflow by decreasing the glottal gap on phonation.2-3 However, the effect of vocal fold medialization on subglottal pressure seems to be more equivocal. Previous reports2-3 have been contradictory; some show an increase in pressure and others a decrease in pressure after medialization.

Our study was designed to maximally reduce variability by analyzing laryngeal aerodynamics in the same patient under 4 different laryngeal conditions: (1) with a normal larynx and voice, (2) after the onset of UVFP, (3) after vocal fold medialization by injection of autologous fat, and (4) after thyroplasty with polytetrafluoroethylene (PTFE). Our goal was to compare the effects of these 2 types of treatment on airflow and subglottal pressure with the measurements made in the same patient when his larynx was healthy.

METHODS

Twenty-five patients with left-sided bronchopulmonary carcinoma scheduled to undergo thoracic surgery with left mediastinal lymph node dissection were prospectively examined, their voices were recorded, and phonatory aerodynamic measurements were taken. No patients had any history of laryngeal dis-
after the onset of UVFP. Fat was harvested and injected of autologous fat under general anesthesia within 10 days underwent vocal fold medialization by intracordal injection thyroplasty with PTFE.9 His larynx was again examined and the injection of autologous fat, the patient underwent left vocal fold paralysis). PTFE, polytetrafluoroethylene; SPL, sound pressure level; UVFP, unilateral vocal fold paralysis (measurements made 1 week after the onset of iatrogenic unilateral vocal fold paralysis).

We made phonatory aerodynamic measurements using Aerophone II software (Kay Elemetrics, Pine Brook, NJ) and the associated software. We measured the mean airflow rate (MFR) for the production of the vowel /a/ (MFRa) during the production of the syllable /i/ for the production of the syllable /pi/; MPT, maximum phonation time; NL, normal voice and normally functioning larynx; Pio, intraoral pressure (measured during the occlusion of the stop consonant /p/); PTFE, polytetrafluoroethylene; SPL, sound pressure level; UVFP, unilateral vocal fold paralysis (measurements made 1 week after the onset of iatrogenic unilateral vocal fold paralysis).

<table>
<thead>
<tr>
<th>Phonatory Task</th>
<th>Aerodynamic Parameter</th>
<th>NL</th>
<th>UVFP</th>
<th>Autologous Fat Injection</th>
<th>PTFE Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>/a/</td>
<td>MPT, s</td>
<td>14.8</td>
<td>3.5</td>
<td>11.1</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>SPL, dB</td>
<td>73.1</td>
<td>58.6</td>
<td>72.1</td>
<td>72.0</td>
</tr>
<tr>
<td></td>
<td>MFRa, mL/s</td>
<td>132.0</td>
<td>547.0</td>
<td>148.0</td>
<td>143.0</td>
</tr>
<tr>
<td></td>
<td>SPL, dB</td>
<td>71.8</td>
<td>68.2</td>
<td>73.3</td>
<td>74.1</td>
</tr>
<tr>
<td>/p/</td>
<td>MFRpi, mL/s</td>
<td>172.0</td>
<td>732.0</td>
<td>187.0</td>
<td>176.0</td>
</tr>
<tr>
<td></td>
<td>Pio, cm H2O</td>
<td>7.5</td>
<td>9.4</td>
<td>8.2</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>Resistance*</td>
<td>44.8</td>
<td>13.1</td>
<td>35.7</td>
<td>31.1</td>
</tr>
<tr>
<td></td>
<td>Vocal efficiency†</td>
<td>9.8</td>
<td>1.1</td>
<td>14.6</td>
<td>11.8</td>
</tr>
</tbody>
</table>

Abbreviations: MFRa, mean flow rate for the production of the vowel /a/; MFRpi, mean flow rate during the production of the syllable /pi/; MPT, maximum phonation time; NL, normal voice and normally functioning larynx; Pio, intraoral pressure (measured during the occlusion of the stop consonant /p/); PTFE, polytetrafluoroethylene; SPL, sound pressure level; UVFP, unilateral vocal fold paralysis (measurements made 1 week after the onset of iatrogenic unilateral vocal fold paralysis).

*Laryngeal resistance calculated by the Aerophone II software (Kay Elemetrics, Pine Brook, NJ) in centimeters of water per liter per second.
†Vocal efficiency calculated by the Aerophone II software in parts per million.

The data obtained is shown in Table 1. Maximum phonation time decreased after UVFP and increased after both types of treatment, almost to preparalytic values. Despite the visual control of vocal intensity, the sound pressure level was lower than 70 dB after UVFP for the vowel sound /a/ and the syllable /pi/ in comfortable phonation, whereas the sound pressure level was slightly higher than 70 dB in the healthy condition and after both types of treatment. The MFR increased 4-fold for both phonatory tasks after UVFP but returned to preparalytic values after both types of treatment. Intraoral pressure increased after the onset of UVFP and decreased, but not to the preparalytic value, after the fat injection. After thyroplasty, Pio increased again. Laryngeal resistance decreased after UVFP and improved after both treatments, although not to preparalytic values. Finally, vocal efficiency was dramatically decreased by the advent of UVFP but improved to even better than preparalytic values after both types of vocal fold medialization.

Table 2 and Table 3 review literature reports concerning airflow and Pio measurements, respectively. Phonatory airflow systematically decreases after medialization, be it by external thyroplasty with or without arytenoid adduction,2,5,12,13,15 or by injection of autologous fat,10 silicone,11 micronized acellular dermis,24,26 or hydroxyapatite.17 Furthermore, a recent comparison of the results of micronized acellular dermis injection com-
pared with results of thyroplasty did not reveal a significant difference in airflow between the 2 techniques.16 There does not seem to be any advantage of one technique or material over another in terms of reduction of phonatory airflow.

Our findings in measurements obtained in the same patient are in accordance with reports in the literature. Before treatment, airflow ranged from 340 to 955 mL/s in the reports cited in Table 2. The airflow rate of 547 mL/s for our patient after onset of the UVFP falls within this range. Airflow is affected by the size of the larynx (determined in part by the patient’s sex), by vocal intensity, and by the phonatory task.18-21 These variables could explain the range of results reported in the literature.

Values of less than 280 mL/s for English-speaking women and less than 320 mL/s for English-speaking men are considered to be within the reference range.13,18 The reference range measured for French-speaking men was reported to be 134 ± 43 mL/s (in comfortable phonation).22 Our measurements and the literature reports agree with this data, with a return to healthy values of phonatory airflow after vocal fold medialization.

In contrast, our findings and the literature reports regarding Pio show varying results after vocal fold medialization. Values of 3.3 to 8.1 cm H2O are considered to be in the reference range for English-speaking men13 and values of 4.9 to 8.8 cm H2O for French-speaking men using the same method.22 For our patient, the Pio values before UVFP and after vocal fold medialization by fat injection fell within the reference range. In our study, the Pio increased after the onset of UVFP in accordance with previous reports1 and with the reports cited in Table 3. However, the increase in Pio after thyroplasty was unexpected, especially because the acoustic result, reported previously,8 was favorable with a decrease in high-frequency noise and an increase in harmonic energy and

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Table 2. Previously Reported Average Mean Phonatory Airflow Rates (MFR) for the Vowel Sound /a/ Before and After Vocal Fold Medialization

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of Patients</th>
<th>Medialization Technique</th>
<th>Method</th>
<th>MFR, mL/s Before Treatment</th>
<th>MFR, mL/s After Treatment</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandenburg et al,10 1992</td>
<td>10</td>
<td>Autologous fat injection</td>
<td>Nagashima PS-77†</td>
<td>390</td>
<td>97</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Bielamowicz et al,1 1995</td>
<td>49</td>
<td>Thyro</td>
<td>Rothenberg mask</td>
<td>470</td>
<td>260</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>AA</td>
<td></td>
<td>490</td>
<td>300</td>
<td>.01</td>
</tr>
<tr>
<td>Hiro et al,11 1995</td>
<td>219</td>
<td>Silicone injection</td>
<td>Nagashima PS-77†</td>
<td>432</td>
<td>207</td>
<td>NA</td>
</tr>
<tr>
<td>Adams et al,19 1996</td>
<td>9</td>
<td>Thyro</td>
<td>Rothenberg mask</td>
<td>955</td>
<td>367</td>
<td>.009</td>
</tr>
<tr>
<td>Kraus et al,19 1999</td>
<td>28</td>
<td>Thyro + AA</td>
<td>Aerophone†</td>
<td>425</td>
<td>206</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Zeiels et al,10 1999</td>
<td>10</td>
<td>Thyro + CT subluxation</td>
<td>Aerophone†</td>
<td>Men: 724</td>
<td>167</td>
<td>&gt;.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Women: 190</td>
<td>210</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>McLean-Muse et al,6 2000</td>
<td>43</td>
<td>Thyro</td>
<td>Aerophone‡</td>
<td>616</td>
<td>295</td>
<td>&gt;.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micronized acellular dermis injection</td>
<td>Aerophone‡</td>
<td>361</td>
<td>229</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Shin et al,6 2002</td>
<td>20</td>
<td>Thyro</td>
<td>Aerophone II†</td>
<td>Men: 340</td>
<td>367</td>
<td>&gt;.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Women: 380</td>
<td>210</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Selber et al,10 2003</td>
<td>14</td>
<td>Thyro</td>
<td>Rothenberg mask</td>
<td>425</td>
<td>231</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Lundy et al,6 2003</td>
<td>8</td>
<td>Micronized acellular dermis injection</td>
<td>Spirometer</td>
<td>416</td>
<td>246</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Rosen and Thekdi,6 2004</td>
<td>5</td>
<td>Hydroxyapatite injection</td>
<td>Aerophone‡</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: AA, arytenoid adduction; CT, cricothyroid; NA, not available; thyro, thyroplasty.
*Values in boldface indicate a statistically significant change after treatment.
†Nagashima, Tokyo, Japan.
‡Kay Elemetrics, Pine Brook, NJ.

Table 3. Previously Reported Average Intraoral Pressure Before and After Vocal Fold Medialization

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of Patients</th>
<th>Medialization Technique</th>
<th>Method</th>
<th>Pio, cm H2O Before Treatment</th>
<th>Pio, cm H2O After Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adams et al,19 1996</td>
<td>9</td>
<td>Thyro</td>
<td>Glottal Enterprises*</td>
<td>12.97</td>
<td>9.4†</td>
</tr>
<tr>
<td>Zeitels et al,10 1999</td>
<td>10</td>
<td>Thyro + CT subluxation</td>
<td>Aerophone‡</td>
<td>Men: 13.5</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Women: 9.6</td>
<td>7.6</td>
</tr>
<tr>
<td>McLean-Muse et al,6 2000</td>
<td>43</td>
<td>Thyro</td>
<td>Aerophone‡</td>
<td>Men: 13.5</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Women: 8.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Shin et al,6 2002</td>
<td>20</td>
<td>Thyro</td>
<td>Aerophone‡</td>
<td>16.8</td>
<td>20.7g</td>
</tr>
</tbody>
</table>

Abbreviations: CT, cricothyroid; Pio, intraoral pressure; thyro, thyroplasty.
*Syracuse, NY.
†P = .04.
‡Kay Elemetrics, Pine Brook, NJ.
§P <.05.
regularity. Another report in the literature also found a statistically significant increase in Pio after thyroplasty.

There are several explanations for these discrepancies. First, the Aerophone II allows for the direct measurement of airflow, but measurement of the subglottic phonatory pressure is indirect. According to the phonatory model proposed by Smitheran and Hixon, the Pio during the unvoiced stop /p/ equalsizes with the subglottic pressure, due to the open glottis and the closed lips during the unvoiced stop. Measuring the Pio during the occlusion of the /p/ of the syllable /pi/, repeated at a rate of approximately 1.5 syllables per second, permits an indirect measure of the phonatory subglottic pressure. This indirect method may lead to erroneous results in UVFP as a result of the abnormal laryngeal function. During voicing of the consonant /p/, the vocal folds cease to vibrate (devoicing) and are abducted. Active devoicing is the result of an active, abrupt, and voluntary abduction of the vocal folds. Passive devoicing is the result of the progressive increase in pressure in the vocal tract caused by the occlusion during the consonant. If this pressure is such that transglottic pressure is insufficient for vocal fold vibration, voicing ceases. In UVFP, voicing is of poor quality and may be more sensitive to passive devoicing than in the case of a healthy larynx. Then, when producing the /p/, the vocal folds will not necessarily be abducted, and the Pio will not necessarily be equivalent to the subglottal pressure. On the other hand, active devoicing is also, in theory, compromised in UVFP as a result of the immobility of 1 of the vocal folds. The lack of rapid and complete abduction may also compromise the equilibration of pressures in the vocal tract. The glottal gap in UVFP may create turbulence in the vocal tract that could interfere with the Pio transducer's measurements. Finally, vocal fold medialization places the paralyzed vocal fold in a position that definitively decreases the glottal surface area, even when the normal vocal fold is abducted. This may compromise pressure equilibration while producing the stop consonant or create different types of turbulence. Thus, the entire method of the indirect measurement of the subglottal pressure needs to be validated for UVFP.

Many factors influence subglottal pressure and Pio in reference subjects. Vocal intensity is a major factor because pressure increases as intensity increases. To our knowledge, our study is the first to analyze Pio using a protocol that includes a visual control of vocal intensity. Subglottal pressure is recognized as the principal factor in regulating vocal intensity in the healthy larynx, and auditory feedback is necessary for control of the subglottal pressure. A variation in vocal intensity during measuring could explain the discrepancies found in the literature concerning Pio in UVFP. Having a target intensity standardizes the acoustic energy output. The aerodynamic energy output follows the acoustic energy output. In patients with UVFP, for the same acoustic output, a higher-than-normal aerodynamic output is necessary. All future studies of aerodynamic measurements should control for vocal intensity. However, the difference in vocal intensity between the measurements in our patient (74.1 dB after PTFE and 73.3 dB after fat injection) (Table 1) is not sufficient to explain the difference in subglottal pressure that we observed.

It is not clear whether or how subglottal pressure varies with age or sex; Holmberg et al reported contradictory results. This could explain the discrepancies in the literature but not in our study. There seems to be a high variability within individuals on repeated testing, which may explain the lack of statistical significance for some studies and the discrepancies among studies and in the findings presented herein.

In our study, the maximum phonation time improved to almost preparative values after both types of vocal fold medialization. This implies that the pneumonecetomy was not responsible for the difference in Pio after PTFE thyroplasty compared with injection of autologous fat. The viscosity of PTFE is higher than that of autologous fat, which is very close to the viscosity of the normal vocal fold. This difference in viscosity could have affected the results of Pio in our study, even though laryngeal resistance was not increased after PTFE thyroplasty compared with fat injection (Table 1). It is generally believed that previous injection of autologous fat does not compromise the results of subsequent thyroplasty. It is possible, however, that vocal fold scarring after inflammation occurred in our study’s patient and is at the origin of the difference in subglottal pressure between the 2 surgical techniques. Finally, the fat injection was performed early, within the first 10 days following paralysis. Thyroplasty was performed 10 months later. Vocal fold denervation atrophy and fibrosis probably occurred during this time-lapse and may have altered the aerodynamic properties of the paralyzed larynx, leading to the increased Pio after thyroplasty.

In conclusion, our study confirms the variability of Pio after vocal fold medialization in UVFP owing to as yet unknown factors. Aerodynamic studies should standardize vocal intensity to have comparable Pio results. Intraoral pressure as an indirect measure of the subglottal pressure may not be reliable in UVFP. Phonatory airflow, laryngeal resistance, and vocal efficiency seem to be more reliable indicators of aerodynamic laryngeal function after vocal fold medialization than Pio.

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