Electrophysiologic Activity of the Vestibular Fold

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Objectives: To assess the vestibular fold muscle after cordectomy and laryngeal reconstruction, the pattern of motor unit recruitment during sound emission, and the morphologic characteristics of motor unit action potentials.

Design: Prospective analysis.

Setting: Tertiary academic hospital.

Patients: We evaluated 11 men (mean age, 65.7 years; age range, 53-82 years) who underwent laryngofissure, cordectomy, and laryngeal reconstruction with a vestibular fold flap.

Interventions: Laryngeal electromyography with the insertion of a needle electrode for the assessment of the electrophysiologic activity of thyroartenoid muscle fibers and of the cricothyroid muscle on the operated on and nonoperated on sides. The thyroarytenoid muscle was evaluated by introducing a needle electrode through the thyroid cartilage and the cricothyroid membrane.

Main Outcome Measures: Activities of needle insertion, spontaneous muscle activity during rest, and pattern of motor unit recruitment.

Results: Seven patients (64%) had vestibular fold muscle fiber, all of whom showed motor unit recruitment in response to sound emission. No neurogenic muscle injuries were observed except in 1 patient with evidence of chronic injury.

Conclusion: After cordectomy and laryngeal reconstruction, thyroarytenoid muscle fibers are present in the vestibular fold, with motor unit recruitment during sound emission.


RESECTION OF A TUMOR IN the vocal fold implies deformation and anatomophysiologic functional modifications (especially phonation) due to the removal of the laryngeal sound source. Therefore, a great challenge in the treatment of early glottic tumors is to maintain the mechanism of voice production by satisfying myoelastic-aerodynamic principles elaborated in 1958 by van den Berg.1

Vocal changes due to removal of a vocal cord can be mitigated by glottic region reconstruction, filling the anatomical space created by surgery. Requirements for obtaining good phonatory function with reconstruction include the presence of a protuberance in the flap that is located at the same level as the opposite vocal fold, has a regular smooth surface, and provides appropriate glottic closure.2 The search for a reconstructive technique that can produce a "neovocal fold" and satisfactory phonation has led to the proposal of various techniques, most using flaps from the region close to the larynx or from the larynx itself, such as vestibular folds.3-14

The vestibular fold is composed of loose connective tissue consisting of elastic fibers containing fatty cells with muscle fibers from the thyroarytenoid (TA) muscle,15,16 the muscle that extends to the vocal fold. The muscle fibers present in this portion of the TA muscle are essentially of the fast twitch type,17 reflecting their specialization in respiration and protection of the airways. The vestibular folds have no function during phonation except in cases of laryngeal disorder.18,19

The vestibular fold positioned in the glottic region as a source of sound demonstrates vibratory behavior and often complete coaptation, promoting voice quality without dysphonia and without fundamental frequency (F0) variation.12,13 It not only protects the remaining vocal fold but also takes on phonatory function, suggesting that it comprises muscle activity responsible for contraction and tension similar to that of the vocal fold, with F0 and laryngeal physiologic effects after cordectomy or other surgical procedures.
Electromyography (EMG) is the most specific method for evaluating laryngeal muscle action. Studies of electrophysiologic activity can provide information about the presence of muscle in the vestibular fold and about the behavior of muscle fibers, as this musculature usually is not recruited during phonation.

The literature surveyed contained no EMG studies of vestibular fold muscle fibers, perhaps because of difficult access to this structure located in the supraglottic region, although the vestibular fold exerts an important function, especially in protecting the airways. When the vestibular fold is positioned at the glottic level, it can be evaluated using EMG. The objectives of the present study were to assess the vestibular fold muscle after cordectomy and laryngeal reconstruction, the pattern of motor unit recruitment during sound emission, and the morphologic characteristics of motor unit action potentials (MUAPs).

**METHODS**

The study was conducted among 11 men who underwent laryngofissure, cordectomy, and laryngeal reconstruction with a vestibular fold flap at the Division of Head and Neck Surgery, University Hospital, Faculty of Medicine of Ribeirão Preto, University of São Paulo, Ribeirão Preto, Brazil. The study was approved by the research ethics committee of the hospital, and all patients gave written informed consent to participate.

All patients were men, ranging in age from 53 to 82 years (mean age, 65.7 years), with postoperative follow-up ranging from 9 to 90 months (mean, 42.5 months). All patients had squamous cell carcinoma in the glottic region and were operated on from January 1998 to December 2003. All tumors had a small subglottic extension, and none compromised vocal fold mobility. Initial review of postoperative laryngeal images confirmed flap position relative to the nonresected vocal fold, laryngeal mobility provided by arytenoid movement, and no other laryngeal lesions.

Carcinoma was resected after laryngofissure under direct view with excision of the vocal fold, and a vestibular fold flap was used for reconstruction. The prepared flap was lowered and sutured so that the vestibular fold was at the same level as that of the contralateral vocal fold. The surgical technique has been previously described in detail.12-14

We excluded patients with the following characteristics: tumor recurrence after cordectomy, other laryngeal disorders or surgical interventions, cervical lymphadenectomy or neck radiotherapy, and diagnosis of other primary head and neck tumors. We also excluded patients who were unable to undergo EMG of the larynx, patients who had tumors extending toward the laryngeal ventricle, patients who had undergone resection of both vocal folds, and patients for whom positioning of the vestibular fold flap in the desired region was not obtained. Additional exclusion criteria were the presence of laryngeal immobility in the nonoperated vocal fold or in the operated hemilarynx and previous diagnosis of neuromuscular diseases.

Study patients underwent laryngeal EMG at the Unit of Clinical Neurophysiology, University Hospital. All procedures were performed by the same neurologist (P.B.) experienced in EMG accompanied by the same head and neck surgeon (H.R.), also trained in laryngeal EMG.

The patient was placed in the supine position with his head and neck slightly extended, and the skin was disinfected with 70% ethyl alcohol. Laryngeal cartilages and membranes were identified by palpation for introduction of a 0.45 × 50.00-mm-long needle-shaped concentric bipolar electrode (Spes Medica, Battipaglia, Italy).

The cricothyroid (CT) and TA muscles were punctured bilaterally. The laryngeal muscles were first percutaneously punctured on the nonoperated side in the following order: puncture of the TA muscle by transcartilage insertion, puncture of the CT muscle with insertion of the electrode through the CT membrane, and puncture of the CT muscle. For the TA muscle, electric potentials were recorded during spontaneous breathing at rest and during sustained production of the vowel /i/ at habitual frequency and intensity. For the CT muscle, electric potentials were recorded during sustained production of the vowel /i/ at acute intensity. Electromyographic activity was continuously monitored during needle insertion. Procedures were then repeated in the same sequence and using the same methods on the operated side.

The TA muscle was punctured using 2 different approaches in an attempt to guarantee that the musculature present in the anatomical region corresponding to the vocal fold (on the nonoperated on side and on the operated on side) was effectively evaluated. This was done to enhance the sensitivity of the procedure.

Electric activity was filtered and connected to an electromyograph for analysis. Recordings were stored in a model (Neu-
Table. Electromyographic Findings During Transcartilage Puncture and Transmembrane Puncture

<table>
<thead>
<tr>
<th>Patient</th>
<th>Transcartilage Puncture</th>
<th>Transmembrane Puncture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recruited Motor Units</td>
<td>Amplitude</td>
</tr>
<tr>
<td>1</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
</tr>
<tr>
<td>2</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
</tr>
<tr>
<td>3</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
</tr>
<tr>
<td>4</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
</tr>
<tr>
<td>5</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>6</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>7</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>8</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
</tr>
<tr>
<td>9</td>
<td>Not evaluated</td>
<td>Normal</td>
</tr>
<tr>
<td>10</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
</tr>
<tr>
<td>11</td>
<td>Muscle not located</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Vestibular Fold Flap on the Operated Side

<table>
<thead>
<tr>
<th>Patient</th>
<th>Recruited Motor Units</th>
<th>Amplitude</th>
<th>Duration</th>
<th>Polyphase Potentials</th>
<th>Discharge Frequency</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>–</td>
<td>Stable</td>
</tr>
<tr>
<td>2</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
<tr>
<td>3</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
<tr>
<td>4</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
<tr>
<td>5</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
<tr>
<td>6</td>
<td>Normal</td>
<td>Normal</td>
<td>–</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>7</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>8</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>–</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
<tr>
<td>9</td>
<td>Not evaluated</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
<tr>
<td>10</td>
<td>Did not go beyond the cartilage</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>–</td>
<td>Normal</td>
</tr>
<tr>
<td>11</td>
<td>Muscle not located</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Stable</td>
</tr>
</tbody>
</table>

Abbreviations: –, absent; ↓, decreased; ↑, increased; +, present.

RESULTS

Patient 9 experienced a coughing fit during 2 attempts to perform transcartilage and transmembrane puncture on the nonoperated on side. His examination was aborted.

In 2 patients, the TA muscle on the nonoperated on side was not located in the vocal fold; no EMG alterations were observed in the other patients. In 5 patients, transcartilage TA muscle puncture was aborted because the needle did not go beyond the thyroid cartilage. The upper half of the Table summarizes characteristics of MUAPs observed with TA muscle puncture of the vocal fold on the nonoperated on side.

In 6 patients, it was impossible to penetrate the thyroid cartilage on the operated on side to evaluate the vestibular fold, and patient 5 halted his examination and did not permit puncture of the operated on side. In the same 2 patients for whom no TA muscle was detected on the nonoperated on side, no muscle fibers were found on the operated on side. Muscle fibers evaluated in the vestibular fold on the operated on side showed no pathologic EMG changes except for 1 patient with evidence of chronic neurogenic injury.

The lower half of the Table summarizes characteristics of MUAPs observed when the vestibular fold flap was punctured on the operated on side. Again, no pathologic changes in insertion or spontaneous activities were observed.

The CT muscle was evaluated on the operated on side in 8 patients, with localization difficulty in 3 patients. On the nonoperated on side, difficulty in CT muscle localization occurred in 5 patients. No pathologic changes in needle insertion or spontaneous muscle activity were observed in any CT muscles evaluated, nor were any morphologic changes observed in MUAPs.

COMMENT

The use of the vestibular fold for surgical defect correction was first reported by Rethi,3 and subsequent studies4-14 by other authors described technical variations in the use of this flap. In 2002, Ricz12 described in detail a reconstruction technique using the vestibular fold that involved liberating the mucosa of the laryngeal ventricle roof to permit more extensive raw area closure and flap positioning at the same level as that of the opposite vocal fold. Results of this technique have been published.13,14 This procedure was used in the present study and proved effective in filling the resected space, especially in 4 patients with glottic carcinoma that extended toward the subglottis. According to Ricz,12 it is important to dislocate the roof of the laryngeal ventricle and to position the vestibular fold on the same plane as that of the opposite vocal fold. In previous studies10,12-14 of glottic reconstruction with the vestibular fold, F0 tended to increase. This may be explained by vestibular fold stretching owing to its de-
Glottic air pressure maintenance, important in the Bernoulli effect. This effect is critical in producing vibratory sound, favoring flap vibration. Therefore, subglottic air pressure may stimulate histologic changes in the vestibular fold, rendering it more similar to the resected vocal fold. The vocal fold acquires adult architecture only after undergoing adaptations during childhood, as it is only after age 10 years that the structural configuration permits development of the adult voice. Therefore, further study of the extracellular matrix composition (a well-known component of the vocal fold) is needed in the vestibular fold. Additional research is required to determine whether descent of the vestibular fold to the glottic region modifies histologic structure for performance of another function.

In the present study, EMG was aborted in 1 patient because of a coughing fit provoked by needle penetration of the airway during puncture on the nonoperated side. However, Miller and Rosenfield stated that EMG is well tolerated by patients, confirmed by Crespo et al. Examination of patients in the present study may have been more difficult because of factors such as the cicatricial area left by surgery or variables mentioned by Crespo et al, including age-related laryngeal musculature atrophy and excess fat in patients with obesity.

In 2 patients, no MUAPs, needle insertion, or spontaneous muscle activities were identified, indicating unsuccessful puncture. This occurred on nonoperated on and operated on sides. Difficulty in electrode insertion occurs because of obesity, individual anatomical differences, minimal horizontal or vertical cartilage mobility, lack of surface reference points to identify cartilage, and patient relaxation and collaboration. Electrode insertion through the thyroid cartilage failed in 5 patients (45%) on the nonoperated side and in 6 patients (55%) on the operated side. This was caused by thyroid cartilage calcification, which frequently occurs in older subjects.

The EMG findings showed no abnormality during TA muscle puncture of the vocal fold (ie, no change after corpectomy and maintenance of function during phonation). No EMG change was observed in the CT muscle. Located outside of the laryngeal frame and without protection of the thyroid cartilage, the CT muscle is susceptible to iatrogenic surgical injury, especially during undermining of the external perichondrium. However, this was not observed in our patients.

Vestibular fold flap analysis identified motor units in 7 of patients (64%) with needle insertion into the operated side of the larynx, with MUAP recruitment occurring in all of them during sound emission. Therefore, muscle fibers were clearly identified when flap evaluation was possible and showed electric activity during phonation.

Anatomical evidence shows that the TA muscle extends along the vocal process, called the “vocal muscle,” and that this is divided into 2 compartments. More deeply in the vocal fold, another muscular compartment has been defined with fibers extending toward the vestibular fold. No studies in the literature indicated to date indicated that the flap prepared for glottis reconstruction is composed of TA muscle fibers, much less that this muscle recruits motor units during sound emission. The findings herein confirm not only the presence of muscle fibers in the flap but also their function in phonation. The vestibular fold participates in phonation only in specific situations such as laryngeal disorder or excessive muscle tension.

Vestibular folds usually are protective in the airways, and their fiber is of the fast twitch type for this function. When the vestibular fold becomes part of the sound source, this musculature contracts, permitting coaptation with the remaining vocal fold, and participates in voice production, modulation, and (especially) F0 determination.

The EMG findings obtained with electrode insertion into the vestibular fold flap showed no needle insertion activity changes in any patient, nor were any spontaneous muscle activities observed (fibrillation, fasciculation, or positive acute wave). In 1 patient, motor unit recruitment was reduced, and MUAP amplitude and duration were increased and accompanied by polyphasic potentials and greater firing frequency, characteristic of chronic neurogenic injury. In this patient, small EMG differences were detected between transmembrane and transcartilage puncture that may be explained by evaluation of different motor units within the same muscle or by sensitivity to the examination, although the findings agreed with a diagnosis of chronic neurogenic injury.

The presence of chronic neurogenic injury in only 1 patient suggests that the muscle compartment present in the vestibular fold may have a source of innervation differing from that of the remainder of the TA muscle. Indeed, surgical resection of the muscle in the vocal fold was expected to compromise upper fiber innervation because of discontinuity due to surgery, but this did not occur. Therefore, we question whether innervation of this supraglottic compartment differs from that of the vocal fold muscle or whether reinnervation occurred. This could explain the presence of vestibular fold adduction among patients in whom the vocal fold is paralyzed on the same side, as observed by Pinho et al.

Results of the present study demonstrate that the vestibular fold contains TA muscle fibers that are activated during phonation and continue to be innervated after surgical injury. Vestibular fold muscle fibers show motor unit recruitment during sound emission, with normal MUAPs morphologically similar to those of the nonoperated on vocal fold.

This study confirms the complexity of laryngeal muscular activity and supports the theory of compartmentalization proposed by other investigators. Muscle fiber use during phonation may cause biochemical changes, transforming them into fibers more resistant to fatigue that are needed for phonation. Hoh reported that muscle fiber stimulation may favor this transformation. Further study of the vestibular fold is needed relative to its habitual function and anatomical position.
mechanisms are poorly understood under physiologic conditions and in pathologic phonation.

Lowering of the vestibular fold permitted EMG evaluation and confirmation of muscle activity in the fold and during sound emission. From an anatomocephalologic viewpoint, this enhances our mechanistic understanding of the electrophysiologic behavior of phonation when a vocal fold is absent and is replaced by the vestibular fold.

The findings herein serve as a basis for reconstruction technique. Our study provides data on the phona
tive activity of the vestibular fold during glottic adduction and the tensioning necessary for vocal modulation. This information enhances the prospects for patient rehabilitation when open surgery is chosen for treatment of glottic tumors.

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Author Contributions: Drs Ricz, Bastos, Aguiar-Ricz, and Martins Mamede had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Ricz, Marques, and Martins Mamede. Acquisition of data: Bastos. Drafting of the manuscript: Ricz, Bastos, and Marques. Critical revision of the manuscript for important intellectual content: Marques and Martins Mamede. Administrative, technical, and material support: Ricz, Bastos, and Marques. Study supervision: Marques and Martins Mamede.

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