Evaluation of the Effects of Primary Myotomy in Total Laryngectomy on the Neoglottis With the Use of Quantitative Videofluoroscopy

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Objective: To evaluate the influence of primary myotomy on characteristics of the neoglottis in patients after laryngectomy.

Design: Patient survey.

Setting: University Medical Center St Radboud, Nijmegen, the Netherlands.

Patients: Nineteen consecutive patients who underwent laryngectomy (12 with primary lateral myotomy of the upper esophageal sphincter [marked by metal clips]; 7 not requiring myotomy [according to intraoperative palpation]).

Interventions: Videofluoroscopy.

Main Outcome Measures: Visual assessments and quantitative measures of the neoglottis were used to study the relationships between myotomy, and anatomic and morphologic characteristics of the neoglottis.

Results: Quantitative measurements showed no difference between the neoglottic characteristics of the patients with (n=12) and without (n=7) myotomy, who were all judged to have moderate (n=4) or good (n=15) voice quality. Results for the entire patient group during phonation showed only 1 single neoglottic bar, no hypertonicity of the neoglottis, and a significant shortening of the neoglottic bar (P=.007). Results for the myotomy group during phonation showed elevation of the caudal clip (P=.046), shortening of the myotomy (P=.01), and decreased overlap of the cranial clip and the neoglottic bar (P=.007). Furthermore, significant relationships were found between the various quantitative measures of the neoglottis and those of the myotomy.

Conclusions: Quantitative videofluoroscopy enables study of the influence of myotomy on the anatomic and morphologic characteristics of the neoglottis. Our results suggest that a planned myotomy of the upper esophageal sphincter is beneficial when prosthetic voice rehabilitation is applied after total laryngectomy.

myotomy in the prevention of hypertonicity or spasm of the neoglottis were found to have an impact on the success of postlaryngectomy vocal rehabilitation.10-21

The effects of these surgical interventions were mostly studied by means of insufflation tests and/or radiographic contrast studies, by either plain photography or more dynamically by videofluoroscopy.22-25 With these imaging techniques, descriptions of the anatomic and morphologic characteristics of the neoglottis in particular were given. In a recent study, a new “quantitative videofluoroscopy” protocol was presented to evaluate the anatomic and morphologic features of the neoglottis in a more standardized manner.26

In the present study, this quantitative videofluoroscopy protocol was used to study the anatomic and morphologic characteristics of the neoglottis in a consecutive series of patients in whom the cricopharyngeus muscle–upper esophageal sphincter was hypertonic, either after a short myotomy or spontaneously, as judged by intraoperative palpation. Furthermore, with marking of the borders of the myotomy-treated sphincter with clips, quantitative videofluoroscopy allowed detailed study of the relationship between the neoglottic bar and the cricopharyngeus muscle.

METHODS

PATIENTS

The patient group studied consisted of a consecutive series of 19 patients treated at the University Medical Center St Radboud, Nijmegen, the Netherlands, during a 1-year period. All underwent a standard total laryngectomy and used tracheoesophageal speech by means of voice prostheses (Provox [Atos Medical AB, Hörby, Sweden], Nijdam [Medin, Groningen, the Netherlands], or Groningen [Medin]). These patients were part of a prospective study published earlier. The indication for total laryngectomy was a laryngeal carcinoma in 18 patients (9 glottic, 9 supraglottic) and 1 hypopharyngeal carcinoma. Four patients received no radiotherapy. Eleven patients were treated for a recurrence after radiotherapy, and 4 patients were treated with radiation postoperatively. There were 17 men and 2 women.

Ages, calculated at the moment of videofluoroscopy, ranged from 39 to 78 years, with a mean of 62 years. The interval between surgery and videofluoroscopy varied from 2 to 7 years, with a mean of 5.4 years. In 15 patients the voice quality was judged as good and in 4 patients as moderate by means of the criteria described by van den Hoogen et al.7

INDICATION FOR AND TECHNIQUE OF PRIMARY MYOTOMY

After removal of the larynx, the toxicity of the cricopharyngeus and upper esophageal musculature (referred to as upper esophageal sphincter) was evaluated by intraluminal palpation (by introduction of a finger). Guided by the toxicity of the upper esophageal sphincter, the surgeon decided whether to perform a primary, lateral myotomy of this musculature. In 12 patients, the upper esophageal sphincter was deemed to be hypertonic on palpation and the surgeon decided to carry out the procedure. To mark the length and position of the myotomy, a metal clip was placed at its cranial and caudal borders. In the remaining patients, the surgeon considered the upper esophageal sphincter not to be hypertonic on palpation, and no myotomy was carried out. This procedure was followed by T-shaped closure of the pharyngeal mucosa in 2 layers and closure of the constrictor pharyngeus musculature.

VIDEOFLUOROSCOPY

Videofluoroscopy recordings were made of a sustained /a/ at comfortable loudness level and pitch, while x-ray films of the patient were made with the patient in a lateral position (Siemens Polystar; Siemens, Erlangen, Germany). To delineate the pharyngoesophageal segment optimally, the patient was asked to swallow high-density barium. This resulted in good visualization of the mucosal surfaces of the hypopharynx, pharyngoesophageal segment, and esophagus. The patient was asked to take one swallow of barium and to phonate afterward. A metal reference scale in centimeters was taped to the patient’s neck, to enable quantification of the different dimensions.

QUANTITATIVE VIDEOFLUOROSCOPY PROTOCOL

Videofluoroscopy images were analyzed according to the protocol described by van As et al.26 In brief, this protocol consists of a standardized visual assessment form, using clear dichotomies (yes/no), anatomic landmarks (cervical vertebrae C4, C5, and C6), and one subjective scale (hypertonicity, normotonicity, and hypotonicity), in combination with quantitative measurements of the neoglottis, making use of the image analysis software program Drawer (developed by M. B. van Herk, PhD, Netherlands Cancer Institute/Antoni van Leeuwenhoek Hospital, Amsterdam).

Recordings were visually assessed for the situation at rest, during swallowing, and during phonation separately by 2 observers, making use of consensus judgment. The neoglottis was judged normotonic when there was full or almost full closure during phonation; hypertonic when there was no closure of the neoglottis during phonation; and hypotonic when the neoglottis was fully closed during phonation combined with considerable dilation of the esophagus below the neoglottis during phonation.

For the quantitative measures, relevant frames for the situation at rest and during phonation were chosen from the videofluoroscopy recordings, with the use of a frame grabber. In the program Drawer, the relevant contours of the neoglottis (anterior and posterior esophageal wall, neoglottic bar) were outlined, and the reference points for several distances and the surface area were marked. All measurements were calculated in pixels and then transformed to millimeters by use of a scale in centimeters, which was adhered to the patient’s skin as a reference.

The Figure, A, shows a schematic drawing of the neoglottis, together with the quantitative measures performed. The following variables were measured: minimal distance during phonation, the distance during phonation between the neoglottic bar and the anterior wall of the esophagus (a in the Figure, A); minimal distance at rest, defined the same as during phonation; maximal subneoglottic distance during phonation, defined as the level of maximum distance; the line on which the measurements were made was placed perpendicular to the posterior wall (b in the Figure, A); maximal subneoglottic distance at rest, defined the same as during phonation; surface area of the neoglottic bar during phonation, the surface of the neoglottis in lateral view, indicated by the gray area in the Figure, A; surface area of the neoglottic bar at rest, defined the same as during phonation; prominence of the neoglottic bar during phonation, the prominence of the neoglottic bar toward the anterior wall; the line on which the measurement is based is placed perpendicular to the posterior wall at the most prominent place of the neoglottic bar (c in the Figure, A); and prominence of the neoglottic bar at rest, defined the same as at rest.
In addition to the measurements of the neoglottis, which were available for all patients (n=19), quantitative measurements were performed relative to the metal clips, placed during total laryngectomy on the cranial and caudal border of the myotomy (n=12). All measurements were performed with the upper edge of the neoglottic bar used as a starting point. From this point in a caudal direction, parallel to the cervical axis, distances were calculated to the cranial and caudal clip, and to the lower edge of the neoglottic bar. This resulted in the following measures: length of neoglottic bar, length of myotomy, cranial clip, and caudal clip (Figure, B).

STATISTICS

Paired t tests were used to compare the quantitative measures at rest and during phonation. To investigate relationships between the various quantitative measures, Pearson correlation coefficients were calculated; for minimal distance at rest, Spearman rank correlation coefficients were calculated because of concerns regarding assumptions of normality. Differences between the quantitative measures of the groups with and without myotomy were investigated by means of t tests for 2 independent samples; for minimal distance at rest and minimal distance during phonation, the nonparametric Mann-Whitney test was used because of concerns regarding assumptions of normality. Relationships between myotomy (yes/no) and the presence of a neoglottic bar at rest (yes/no) and tonicity (normotonic/hypotonic) were calculated with exact $\chi^2$ tests.

RESULTS

VISUAL ASSESSMENT OF ANATOMIC AND MORPHOLOGIC CHARACTERISTICS OF THE NEOGLOTTIS

At rest, 14 patients showed a single neoglottic bar (10 in the myotomy group and 4 in the nonmyotomy group), whereas 5 patients (2 with myotomy and 3 without myotomy) did not show a neoglottic bar. The presence of a neoglottic bar at rest was not related to whether a myotomy had been performed ($P=.30$). During phonation, all patients had a single neoglottic bar. Fifteen patients were judged to have a normotonic neoglottis and 4 a hypotonic segment. Three of the patients with a hypotonic neoglottis did not have a myotomy and 1 did. This relationship was also nonsignificant ($P=.18$). There was no significant correlation between tonicity and voice quality ($P=.12$). There was also no significant relationship between myotomy and voice quality ($P=.12$). The cervical levels of the neoglottic bars of individual patients at rest and during phonation are given in Table 1. At rest, the neoglottis was mostly situated between cervical vertebrae 5 and 6, whereas during phonation the neoglottis was mostly located between cervical vertebrae 4 and 5.

QUANTITATIVE MEASUREMENTS OF THE NEOGLOTTIS

Table 2 gives the results of the quantitative neoglottic measurements. The t tests between the myotomy group (n=12) and the nonmyotomy group (n=7) showed no statistically significant difference between any of the neoglottic measurements.

QUANTITATIVE MEASUREMENTS RELATED TO MYOTOMY CLIPS

All 12 patients in the myotomy group had a visible neoglottic bar during phonation. Table 3 gives the measurements related to the myotomy. The mean length of the myotomy at rest, calculated as the distance between the cranial and caudal clip, was 25.3 mm (range, 8.5-45.2 mm). At rest, the neoglottic bar was situated entirely above both myotomy clips in 2 patients. In the remaining 10 patients, the neoglottic bar was partially (n=4) or entirely (n=6) situated between the cranial and caudal border of the myotomy. The caudal clip was always inferior to the caudal edge of the neoglottic bar. During phonation there was always an upward shift of the neoglottic bar, resulting in 3 patients having their neoglottic bar superior to the cranial clip of the myotomy. The remaining 9 patients showed some overlap between the neoglottic bar and the myotomy, although less in comparison with the situation at rest. During phonation, the caudal clip elevated about 3 times as much as the cranial clip did. Paired t tests showed that during phonation a significant shortening of the neo-
glottic bar \( (P = .007) \), an elevation of the caudal clip \( (P = .046) \), a shortening of the myotomy \( (P = .01) \), and a decreased overlap of the cranial clip and the neoglottic bar \( (P = .007) \) occurred.

### RELATIONSHIP BETWEEN QUANTITATIVE MEASUREMENTS OF MYOTOMY AND NEOGLOTTIC BAR

Regarding the length of the myotomy at rest and during phonation, a negative correlation was found with the length of the neoglottic bar at rest \( (r = -0.62, P = .03; \) during phonation, \( r = -0.61, P = .03) \). This indicates that the myotomy was shorter in the more elongated neoglottic bars and vice versa.

Concerning the cranial clip of the myotomy, a positive correlation was found with the surface area of the neoglottic bar at rest and during phonation \( (at \ rest, r = 0.91, P < .001; \) during phonation, \( r = 0.78, P = .003) \). This indicates that the further down the cranial border of the myotomy was from the upper edge of the neoglottic bar, the larger the surface area of the neoglottic bar.

The caudal clip of the myotomy, both at rest and during phonation, showed a positive correlation with the prominence of the neoglottic bar during phonation \( (r = 0.64, P = .02, \) and \( r = 0.76, P = .004 \), respectively) and during rest \( (r = 0.64, P = .03, \) and \( r = 0.80, P = .002 \), respectively). These results together indicate that a lower-placed myotomy is related to a more prominent neoglottic bar during phonation.

### COMMENT

In the present study, analyzing the effects of myotomy during total laryngectomy on the neoglottis, striking observations were made. By means of the visual assessment protocol and quantitative measurements recently described by van As et al., a group of 12 consecutive patients with myotomies were compared with a group of 7 patients without myotomies, operated on in the same period. There was a nonsignificant relationship between the presence of a neoglottic bar at rest and whether the patient had a myotomy. Although 5 patients had no neoglottic bar at rest, there was always a neoglottic bar during phonation. This suggests that always performing a myotomy, except in situations where the upper esophageal sphincter is already hypotonic on palpation, still results in the presence of a neoglottic bar during phonation. As known from other studies, the presence of a neoglottic bar is a prerequisite for good tracheoesophageal speech. The fact that all voices were judged as good \( (n = 15) \) to moderate \( (n = 4) \) is in accordance with this. Although in 4 patients the neoglottis was judged to be hypotonic, but still with a clearly visible neoglottic bar, this does not contradict the former observation, since van As et al. also found a reasonable voice quality in approximately half of the patients with a (slightly) hypotonic neoglottis.

Many studies have reported on the necessity of additional surgery to control the tonicity of the neoglottis in tracheoesophageal or esophageal speech. It is difficult to compare most of these studies, as there are reports about esophageal and tracheoesophageal speakers, and clear differences in timing of the surgical procedures, i.e., primary or secondary.

Mahieu et al. prefer to perform a myotomy as a primary procedure. Unwillingness of the patient to undergo another operation and difficulty of an operation in a previously operated-on and possibly irradiated region led to this preference. Some authors suggest performing a unilateral myotomy at the time of surgery to prevent any spasm or hypertonicity. Mahieu et al. suggest performing “a 4-6 cm myotomy of the inferior constrictor pharyngeal muscle, the cricopharyngeal muscle and a small section of the upper esophageal musculature” after deeming the neoglottis hypertonic.

Since myotomies are carried out as a primary procedure during total laryngectomy, it is nearly impos-

### Table 2. Measures of the Neoglottis in Patients With and Without Myotomy

<table>
<thead>
<tr>
<th>Measure</th>
<th>All Patients (N = 19)</th>
<th>No Myotomy (n = 7)</th>
<th>Myotomy (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal distance at rest, mm</td>
<td>1.1 (3.0)</td>
<td>2.6 (4.7)</td>
<td>0.18 (0.62)</td>
</tr>
<tr>
<td>Minimal distance during phonation, mm</td>
<td>2.4 (4.1)</td>
<td>4.7 (5.8)</td>
<td>0.99 (1.8)</td>
</tr>
<tr>
<td>Maximal subneoglottic distance at rest, mm</td>
<td>8.1 (4.0)</td>
<td>7.5 (5.0)</td>
<td>8.5 (3.5)</td>
</tr>
<tr>
<td>Maximal subneoglottic distance during phonation, mm</td>
<td>15.5 (6.2)</td>
<td>15.2 (7.1)</td>
<td>15.7 (5.9)</td>
</tr>
<tr>
<td>Surface area of neoglottic bar at rest, mm²</td>
<td>143.9 (114.7)</td>
<td>77 (81)</td>
<td>183 (116)</td>
</tr>
<tr>
<td>Surface area of neoglottic bar during phonation, mm²</td>
<td>168.2 (115.3)</td>
<td>139 (107)</td>
<td>185 (121)</td>
</tr>
<tr>
<td>Prominence of neoglottic bar at rest, mm</td>
<td>6.9 (5.1)</td>
<td>4.3 (3.7)</td>
<td>8.4 (5.3)</td>
</tr>
<tr>
<td>Prominence of neoglottic bar during phonation, mm</td>
<td>11.3 (5.2)</td>
<td>9.7 (4.3)</td>
<td>12.2 (5.6)</td>
</tr>
<tr>
<td>Ratio of maximal subneoglottic distance during phonation-at rest</td>
<td>2.1 (0.7)</td>
<td>2.2 (0.75)</td>
<td>2.1 (0.72)</td>
</tr>
</tbody>
</table>

*Data are given as mean (SD).

### Table 3. Measurements at Rest and During Phonation Relative to the Metal Clips Placed at the Cranial and Caudal Borders of the Myotomy

<table>
<thead>
<tr>
<th>Measurement</th>
<th>At Rest</th>
<th>During Phonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of neoglottic bar, mm</td>
<td>31.9 (12.6)</td>
<td>23.1 (13.7)</td>
</tr>
<tr>
<td>Distance to cranial clip, mm</td>
<td>15.3 (12.9)</td>
<td>14.1 (14.7)</td>
</tr>
<tr>
<td>Distance to caudal clip, mm</td>
<td>40.6 (14.5)</td>
<td>35.9 (16.0)</td>
</tr>
<tr>
<td>Length of myotomy, mm</td>
<td>25.3 (12.3)</td>
<td>21.7 (13.0)</td>
</tr>
</tbody>
</table>

*\( N = 12 \). All distances are measured caudal from the upper level of the neoglottis. All measures showed a significant difference between rest and phonation \( (P < .05) \).
sible to objectify the impact of the myotomy on the neoglottis. In a recent study by van Weissenbruch et al, patients were randomized for an additional toxicity treatment without judging the toxicity of the upper esophageal sphincter during the operation. Their study compared patients after laryngectomy who underwent primary unilateral pharyngeal myotomy with patients who underwent pharyngeal plexus neurectomy and patients who did not undergo additional treatment at all. Theirs is one of the few studies with a control group containing untreated patients. They found that patients who underwent primary myotomy and neurectomy were most successful in obtaining good tracheoesophageal speech. Besides the discussion on the necessity of toxicity control after laryngectomy, there is also no consensus in the literature about the exact muscles responsible for the toxicity of the neoglottis, nor the optimal surgical procedure and whether to close the muscular layers.

To the best of our knowledge, there has been no previous report on objective data of the myotomy itself or the relationship between the myotomy and the neoglottis.

In the present study, the upper and lower borders of the myotomy were marked with clips, giving an opportunity to visualize and quantify the relationship between the myotomy and the neoglottic bar. With respect to the position of the neoglottic bar in relation to the myotomy during phonation, the neoglottic bar was seldom situated totally between the myotomy clips. If overlap was demonstrated, it was seen less during phonation. This sustains the theory that the cricopharyngeus muscle–upper esophageal sphincter is not the most essential part of the neoglottic bar. According to Wetmore et al and Chodosh et al, the bulging mucosa and/or the constrictor muscles cranal to the cricopharyngeus muscle contributed mostly to the vibration and created the neoglottic bar. These authors also found a considerable number of patients (530% of 16) with a double neoglottic bar, with the lower bulge not contributing to voice production. In our series, no double neoglottic bar was found, which can probably be explained by the fact that we have always performed a myotomy of the upper esophageal sphincter when there was suggestion of hypertonicity.

Also on the basis of this latter theory, ie, that the cricopharyngeus muscle–upper esophageal sphincter is not the most essential part of the neoglottic bar, Hirano et al recommended a cricopharyngeus myotomy and a tracheal ring cartilaginous implantation. They suggested that, in this way, better neoglottic closure during phonation can be obtained and subneoglottic obstruction can be prevented to achieve optimal neoglottic vibration. Taking all of these theories into account, this may imply that a myotomy of the cricopharyngeus muscle–upper esophageal sphincter should be performed in every patient, unless the muscles are already hypotonic.

On the basis of the quantitative measurements in relation to the position of the myotomy clips, some interesting observations were made. For instance, the longer the myotomy, the shorter the neoglottis. Also, a lower-placed myotomy results in a larger and more bulky and prominent neoglottic bar. Furthermore, overlap of the myotomy and neoglottic bar results in less prominence of this bar. Since a prominent neoglottic bar is beneficial for voice quality, this probably indicates that the myotomy should not be carried out more cranially than the upper esophageal sphincter itself. The often-advocated long myotomy, including the constrictor pharyngeus muscles, therefore, may not be optimal.

In conclusion, quantitative videofluoroscopy enables study of the relationships between myotomy of the upper esophageal sphincter and the anatomic and morphologic characteristics of the neoglottis. In a group of 19 patients, most having good tracheoesophageal voice quality, one clear neoglottic bar was always visible and none of these patients showed signs of hypertonicity. Therefore, in our opinion, a primary, lateral myotomy of the upper esophageal sphincter (unless it is already hypotonic) is an essential part of surgery when primary prosthetic voice rehabilitation is applied after total laryngectomy.

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