Objective: To evaluate the use of tracheal autotransplantation for reconstruction of the hemicricoid cartilage defect that includes the hemicricoid cartilage and results from resection of laryngeal or hypopharyngeal cancer.

Design: The clinical records of 28 patients undergoing primary or salvage hemicrico-hemilaryngectomy for laryngeal (26 patients) and pyriform sinus (2 patients) cancer were analyzed for function and local control.

Setting: Academic center.

Patients: Case series review of 28 consecutive patients treated during a 3 1/2-year period who had an average follow-up period of 19 months.

Intervention: Twenty-five men and 3 women, aged from 28 to 79 years, underwent a hemilaryngectomy that included the hemicricoid cartilage, the ipsilateral thyroid lobe, and a unilateral or bilateral lymph node dissection. In 26 patients, these extensive defects were reconstructed with a tracheal autotransplantation that restored the larynx at the glottic and subglottic levels. In 2 patients, the defect was converted into a total laryngectomy because of tumor extension beyond the resection margins of a hemicrino-hemilaryngectomy.

Main Outcome Measures: The times to decannulation and retake of full oral feeding, the quality of speech, and the incidence and site of recurrent cancer were assessed.

Results: Of the 26 patients undergoing tracheal autotransplantation, 24 were decannulated and all regained the ability to maintain nutrition by mouth. Ultimate voice quality was “subnormal” to “moderately hoarse” in all patients. Five recurrences developed of which 2 were treated with total laryngectomy.

Conclusions: Functional reconstruction of extensive laryngeal defects can be achieved with an autotransplantation of cervical trachea, with favorable functional results and acceptable morbidity. This technique expands the limits of conservation surgery for selected laryngeal and hypopharyngeal tumors.

Arch Otolaryngol Head Neck Surg. 2000;126:1207-1215

The top of the cricoid cartilage serves as the lower line of resection in conventional vertical hemilaryngectomy and in the various forms of supracricoid laryngectomy in which the cricoid cartilage and at least one arytenoid have to be preserved. Because of the caudal resection margin, laryngeal tumors with subglottic extension to the level of the cricoid and hypopharyngeal tumors extending to the apex of the pyriform sinus are contraindications for conservation laryngectomy. The currently used conservation procedures have their critical margin posteriorly because the cricoid plate lies only a few millimeters below the posterior glottic level. Unilateral T3 glottic tumors with subglottic extension and/or arytenoid cartilage fixation and pyriform sinus tumors extending to the apex of the pyriform sinus necessitate an ipsilateral resection of the cricoid. Cricoid resection is incompatible with decannulation, and a total or near-total laryngectomy with a permanent tracheostomy is the indicated surgical treatment for most of these tumors.

Tracheal autotransplantation, described in 1998 as a “laryngeal reconstructive technique,” allows for reconstruction of full height cricoid defects. This technique augments the indications for conservation laryngectomy by moving the caudal resection margin...
PATIENTS AND METHODS

Twenty-six patients (23 men, 3 women), ranging in age from 28 to 79 years, were diagnosed as having cancer of the vocal fold. Two male patients displayed a tumor of the pyriform sinus with extension into the apex. All of the primary laryngeal tumors were staged T2 (n=6) or T3 (n=20) and the pyriform sinus tumors were staged T2. The extent of laryngeal or hypopharyngeal involvement is indicated by the defect classification proposed by Urken et al.(Table 1). All tumors were carcinomas with exceptions for patient 8 who displayed a synovial sarcoma of the right hypopharynx and patient 26 who displayed a chondrosarcoma of the left cricoid (Table 2).

Twenty-one patients in this series had received preoperative radiotherapy. Two patients received postoperative radiotherapy. The project was approved by the appropriate institutional review board and informed consent was obtained from the patients.

The operation technique was described in detail previously. The 2-stage transplantation of the trachea can be summarized as follows. In a first stage, the ipsilateral thyroid gland with the tracheoesophageal lymph nodes and the neck lymph nodes (region 1-3 for tumors of the pyriform sinus, transglottic tumors, and N+ necks; region 2-4 for the T3N0 laryngeal tumors) are removed. The cervical trachea, which is intended to be used for reconstruction of the laryngeal defect, is mobilized from the underlying esophagus without disruption of the tracheal continuity. A 4-cm segment of trachea, corresponding with the average height of the posterior larynx, is circumferentially wrapped by a flap consisting of fascia and subcutaneous tissue that is obtained from the volar side of the forearm. The radial forearm fascial flap consists of a 4×8-cm patch and is axially perfused by the radial artery and vein. The anterior part of the tracheal segment is wrapped by the proximal site of the fascial flap, whereas the membranous trachea is wrapped by the distal site of the fascial flap (Figure 1). The vascular pedicle of the flap is reanastomosed to the superior thyroid vessels at the tumor side with restoration of the blood supply to the flap. During a 14-day period, the fascial flap progressively perfuses the enfolded tracheal segment. Since this flap is buried and inaccessible, a proximal monitoring skin paddle is harvested and placed in a cutaneous suture line to assess the vascular supply during the postoperative period.

After 14 days, the neck is reopened, and the primary tumor is resected. The hemicrico-hemilaryngectomy includes the thyroid cartilage, the paraglottic space, the cricoid and arytenoid cartilage, and the true and false vocal folds at the tumor side. The contralateral anterior half of the membranous vocal fold and the anterior third of the contralateral thyroid cartilage were also resected if the tumor reached the anterior commissure (Figure 2A). Also, this resection allowed for removal of the medial and lateral wall of 1 pyriform sinus. Selected pyriform sinus tumors that involve the pyriform sinus apex can be resected with inclusion of the hemicricoid cartilage as long as the hypopharyngeal mucosa can be closed primarily (Figure 2B). In these resections, the upper portions of the epiglottis, hyoid bone, and the contralateral cricoid and arytenoid were spared. In our series, the anterior commissure was resected in 16 patients. The anterior section line was located in the anterior commissure because of tumor location in the pyriform sinus in 2 patients and because of uninvolved anterior site of the vocal folds in the other 14 patients. The presence of interarytenoid spread was an important contraindication.

Patient 19 had a transglottic lesion with the epicenter in the right ventricle. He underwent a resection involving a right hemicrico-hemilaryngectomy in combination with a supraglottic laryngectomy. This intervention resulted in the resection of the ipsilateral thyroid, cricoid, and paraglottic space in combination with the whole epiglottis and preepiglottic space. The full length of the uninvolved vocal fold was preserved (Figure 2C).

After obtaining safe tumor margins, the cervical trachea wrapped by the fascial flap was completely isolated from the airway on its newly created fascial vascular pedicle. The tracheal segment was transformed into a patch by removing the dorsal membranous trachea (Figure 1).

After transformation of the tracheal tube into a tracheal patch, the tracheal autotransplant patch was placed upward and sutured into the laryngeal defect. At the glottic level, we tried to obtain a patch position comparable to a unilateral laryngeal paralysis with the vocal fold immobilized close to the midline (Figure 3).

After insetting the patch, the mediastinal trachea was mobilized and sutured to the reconstructed cricoid cartilage. This end-to-end anastomosis was left open anteriorly. A tracheostome was formed by suturing the skin toward the anterior airway defect and a cuffed Shiley cannula was placed in the tracheostome.

After combined hemicrico-hemilaryngectomy with supraglottic laryngectomy (patient 19), the tracheal autotransplant patch was used to transform the laryngeal remnant into a classic supraglottic laryngectomy with one hemilarynx immobilized close to the midline. The closure was performed by creating a pexy between reconstructed laryngeal remnant and hyoid bone superiorly.

After 5 days, the Shiley cannula was removed and the patient started swallowing under supervision of the speech therapist. Voicing was stimulated by thumb closure of the tracheostome. The anterior tracheostome without cannula progressively diminished and the remaining tracheostome was closed under local anesthesia several weeks after the patient was discharged from hospital (Figure 4).

All patients were functionally studied. After closure of the tracheostomy, voice quality was expressed as belonging to a group with “moderately hoarse” (from “near normal” to “breathy but easily understandable”) voices (rate 1). Rate 2 was defined as a poor voice (whispering, aphonic). The regaining of the swallowing function was expressed in terms of the number of postoperative weeks to reach full oral intake. Use of the oronasal airway was expressed as the number of weeks needed postoperatively to close the tracheostome. A computed tomographic image of the larynx was obtained 2 months postoperatively.

from the top to the lower edge of the cricoid cartilage at the side of the tumor. The technique involves a 2-stage procedure of cervical tracheal revascularization by wrapping the trachea in a vascularized radial fore-
series of 28 consecutive patients treated using the technique of tracheal autotransplantation.

## RESULTS

### MORBIDITY

All of the patients were discharged from hospital between the 2 operation stages except for patient 3 who could not be extubated and had to stay in the intensive care unit for 2 weeks. Patient 14 had a flap failure after the first operation stage because of non-salvageable thrombosis of the arterial anastomosis and needed to undergo a second forearm fascial flap. Patient 21 showed a flap failure after the second operation. In this patient, the venous anastomosis of the skin flaps was damaged during reelevation of the skin flaps. The fascial flap and the tracheal patch displayed venous congestion during the operation and the fascial flap showed evolution toward complete avascularity during the following days. Two days after the second operation, a reintervention was planned and the avascular fascial flap was removed. A pectoralis major muscle was transferred to the neck in an attempt to save the tracheal patch (Figure 5A). We did not succeed in salvage patch revascularization and the patient showed evolution to a laryngeal stenosis (Figure 5B). Currently, the functional status of this patient is comparable to a near-total laryngectomy with a neolarynx that may be used for voice but with a definitive tracheostome for respiration. Conservation laryngectomy seemed impossible during the second operation stage in patient 17 because of a positive margin posteriorly and in patient 20 because of a positive margin at the contralateral arytenoid.

### RESPIRATION

Twenty-four patients were ultimately decannulated. One patient (patient 21) had laryngeal stenosis after patch necrosis and 1 patient (patient 22) underwent a total laryngectomy because of persistent aspiration. On average, the tracheostomy was closed after 62 days (range, 28-140 days). The tracheal patch provided the optimal reconstructive tissue to restore the glottic and subglottic airway lumen (Figure 6). Tracheostomy closure was delayed because of prolonged aspiration (>10 weeks) in patients 1, 7, and 16. Their tracheostomies were closed after solving the aspiration problem. Tracheostomy closure was delayed in 1 patient (patient 11) because of substenosis at the level of the tracheostome. His tracheostome was closed along with an augmentation tracheoplasty.

### SWALLOWING

Normal swallowing was achieved in 22 patients by the second postoperative month. Three patients (patients 1, 7, and 16) had a delay in regaining full oral feeding because of unfavorable morphologic conditions at the glottic level with a glottic patch that was placed too laterally with resulting glottic insufficiency. To obtain a better glottic closure, we decided to do a medialization laryngoplasty under local anaesthesia in these 3 patients. Therefore, the anterior suture between the patch and laryngeal remnant was reopened and the posteroanterior length of the patch was reduced under direct visual control of glottic closure during speech and swallowing (Figure 4 and Figure 7). After this intervention, prompt recovery of the swallowing function was noted.

Patient 22 underwent a total laryngectomy because of persistent aspiration. Initially, he was able to restart oral feeding during the first weeks after tracheal transplantation. Then, aspiration became worse and we noted a fixation of the remaining arytenoid cartilage with incomplete closure of the reconstructed glottis. A total laryngectomy was performed 2 months after tracheal transplantation. Resection of 1 pyriform sinus (patient 8) had no influence on swallowing function indicating that 1 intact hemilarynx with corresponding pyriform sinus is sufficient to allow for preservation of laryngeal functions (Figure 2B and Figure 8).

### VOICE

Most patients had a voice that was moderately hoarse and easily understandable and for simplicity, no further gradations were made into this group (rate 1). In these patients, the glottic morphologic features at the glottic level was comparable to a laryngeal paralysis in

### Table 1. Classification Scheme for Defects of the Laryngopharynx

<table>
<thead>
<tr>
<th>Designation</th>
<th>Cartilage Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>No defect of cricoid</td>
</tr>
<tr>
<td>C1</td>
<td>Defect of upper border of hemilarynx</td>
</tr>
<tr>
<td>C2</td>
<td>Defect of entire hemilarynx</td>
</tr>
<tr>
<td>Th0</td>
<td>No defect of thyroid</td>
</tr>
<tr>
<td>Th1</td>
<td>Hemilarynx defect</td>
</tr>
<tr>
<td>Th2</td>
<td>Upper half of thyroid cartilage</td>
</tr>
<tr>
<td>Th3</td>
<td>Three quarters resection of thyroid cartilage</td>
</tr>
<tr>
<td>Ep0</td>
<td>No defect of epiglottis</td>
</tr>
<tr>
<td>Ep1</td>
<td>Half of the epiglottis (vertical)</td>
</tr>
<tr>
<td>Ep2</td>
<td>Defect of suprahypopharyngeal epiglottis</td>
</tr>
<tr>
<td>Ep3</td>
<td>Defect of infrahypopharyngeal epiglottis</td>
</tr>
<tr>
<td>VC0</td>
<td>No defect of vocal cords</td>
</tr>
<tr>
<td>VC1</td>
<td>Defect of unilateral anterior half of the membranous cord</td>
</tr>
<tr>
<td>VC2</td>
<td>Defect of posterior half of the membranous cord including vocal process</td>
</tr>
<tr>
<td>VC3</td>
<td>Defect of body of arytenoid</td>
</tr>
<tr>
<td>HP0</td>
<td>No defect of hypopharyngeal mucosa</td>
</tr>
<tr>
<td>HP1</td>
<td>Defect of pyriform sinus, apex intact</td>
</tr>
<tr>
<td>HP2</td>
<td>Defect of pyriform sinus, apex involved</td>
</tr>
<tr>
<td>SLN</td>
<td>Superior laryngeal nerve</td>
</tr>
<tr>
<td>RLN</td>
<td>Recurrent laryngeal nerve</td>
</tr>
</tbody>
</table>

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In most patients, the tumor was resected with safe margins. After a mean follow-up period of 19 months, 23 patients were free of tumor. Five patients had a local recurrence. Two patients (patients 9 and 10) were salvaged by performing a total laryngectomy. Three patients (patients 12 through 14) could not be treated curatively.

**COMMENT**

Tracheal autotransplantation allows for conservation laryngectomy for unilateral glottic tumors with arytenoid cartilage fixation and infraglottic tumor extension reaching the upper border of the cricoid cartilage. Two major contraindications for all classic conservation procedures: 1. Major contraindications for all classic conservation procedures. 2. Optimal functional results are reached when the patch is positioned in the exact location. A morphologic and functional situation comparable to a unilateral paralysis in the midline is reached when the anteroposterior patch length at the glottic level approaches the length of the vocal fold measured between anterior and posterior commissures. In our series, the patch was too long at the glottic level in 4 patients with resulting glottic insufficiency. In these cases, a reduction procedure was necessary to improve the posteroanterior...
patch length. A reduction of the patch length turned out to be a minor procedure under local anaesthesia. Therefore, our current policy is to take a posteroanterior patch length that is similar or slightly bigger than the posteroanterior length of the vocal fold measured from the anterior to posterior commissures. If incomplete glottic closure is encountered, then a reduction laryngoplasty at the time of closure of the tracheostomy is performed. More patch length can be included at the subglottic level to create a reliable airway lumen. Patches of revascularized cervical trachea are far superior to all other reconstruction techniques in building up an airway lumen. Immediate airway support is reached when the patch is sutured to the laryngeal remnant. There is no need to use a stent and healing of the cartilaginous margins is unnecessary for obtaining a stable airway lumen. The tracheal transplantation patch has an unique position in the repair of hemicrico-hemilaryngectomy defects. Other reports on reconstructive techniques after resection of a hemicricoid were rather sporadic.3 The largest series of decannulated patients after hemicrico-hemilaryngectomy was reported by Urken et al6 making use of a sensate radial forearm flap in combination with rib cartilage for repair of the hypopharynx and infrastructure of the larynx. This technique was designed to functionally reconstruct the larynx and the depth of the pyriform sinus after resection of pyriform sinus tumors. The technique is indicated in cases with extensive hypopharyngeal extension so that primary pharyngeal closure becomes impossible. In our technique, no reconstruction of the hypopharynx was performed so that only the defect that could be closed primarily (ie, the apex-involved defect of the pyriform sinus) was combined with the technique of tracheal autotransplantation.

A 2-stage procedure is necessary to obtain safe revascularization of the tracheal transplant. The fact that the autotransplantation technique occurs in 2 stages has its advantages and disadvantages. From a reconstructive viewpoint, the 2 stages contribute to the safety of the procedure. In cases of failure of the radial forearm flap, a second flap can be obtained without compromising the vitality of the unique tracheal transplant. The trachea will not become necrotic even in cases of flap failure because the preserved, intrinsic mucosal vascularity of the trachea is sufficient after the first operation stage. The risk to compromise of the vascularity of the transplanted trachea during the second stage is very low because no manipulation of the vascular pedicle of the radial forearm flap is necessary during the transplantation stage. The venous anastomosis was damaged during the second operation in 1 patient. This turned out to be a serious complication with loss of the tracheal transplant. Since we had this complication, we routinely place an additional polytef (Gore-Tex)
Figure 2. Resection specimen. A, Resection specimen after removal of T3 glottic cancer with defect classification C2 Th1-3 Ep0 VC1RL, 2L, 3L (where C indicates cricoid; RL, right left; L, left). HP indicates hypopharynx; Th, thyroid; Ep, epiglottis; VC, vocal cords. The anterior third of the contralateral vocal fold and thyroid cartilage (arrows) is also resected because the tumor reaches the anterior commissure. Scale is in centimeters. B, Resection specimen of patient 8 (defect classification: C2 Th1 Ep0 VC123R HP2). The submucosal located synovial sarcoma (arrowheads) was resected by removal of the ipsilateral thyroid, vocal folds, cricoid, and pyriform sinus. The opposite vocal fold was completely preserved. Scale is in inches. C, Resection specimen of patient 19 (defect classification: C2 Th1 Ep2,3 VC123R). Transglottic cancer with extension to subglottic (arrows) and supraglottic (arrowheads) areas. Scale is in inches.

Figure 3. Schematic presentation of reconstruction at the glottic level. A, Hemicricolaryngectomy with 1 intact vocal fold. The optimal reconstruction is provided by a patch connecting the posterior and anterior commissures. The tracheal patch has to be unfolded to bring its outer convexity into a paramedial position. The intermediate position is indicated by an x and is defined as the medial edge of the arytenoid during quiet breathing. B, Hemicricolaryngectomy including the anterior commissure. The optimal reconstruction is provided by a patch connecting the posterior commissure and the anterior section margin. The outer extent of the patch convexity has to be located medially of the paramedian position.

Figure 4. Closure of tracheostomy. Outlining of skin flaps. The tracheostome is closed several weeks after the tracheal transplantation following the “trough principle.” Skin flaps around the tracheostome are incised and inverted; the lower and upper skin flaps are sutured over the skin-lined tracheostome. The monitor flap is removed simultaneously. The anteroposterior length of the tracheal patch can be shortened during tracheostomy closure in cases of persistent aspiration or aphonic voice. Therefore, the anterior suture line between the patch and native larynx is reopened (dotted line). Movement of the preserved vocal fold can be visualized from below and the patch can be shortened until optimal glottic closure is obtained (see also Figure 7).
membrane between the vascular anastomoses and the overlying skin after the first operation.

From an oncological viewpoint, the 2-stage reconstruction technique may be seen as disadvantageous. Removal of the tumor occurs 14 days after the dissection of the neck and this is a reversal of the usual order. It goes against “good oncological practice,” which requires either that the tumor be removed en bloc with the cervical nodes, or that the tumor be removed before dissection of the neck. Theoretically, the order reversal could increase the rate of recurrences in the neck. Theoretically, the order reversal probably has only minor importance in nonirradiated cases. Postoperative administration of radiotherapy is indicated when lymph nodes are involved or in cases with close section margins. Untreated, unilateral T3 glottic and transglottic cancers as well as selected T2 pyriform sinus tumors are good indications for the technique. The major indications after irradiation are formed by unilateral T2 to T3NO glottic tumors and in these tumors, local tumor control is usually the main concern.

Two patients in our series underwent a total laryngectomy during the second operation stage because of tumor extension beyond the suspected margins. Owing to the 2-stage approach, the first operation and the transfer of the radial forearm flap becomes unnecessary in cases in which a total laryngectomy is indicated. It is important to stage the tumor as accurately...
as possible to keep the cases of a total laryngectomy as low as possible.

The indications for the technique of tracheal transplantation may be divided into indications before and after irradiation. Before irradiation, the unilateral glottic tumor with fixation of the vocal fold is a good indication. Currently, these tumors are treated with radiotherapy with or without chemotherapy with an average chance for local control of about 50% to 60%. Surgical treatment for the recurrent or persistent tumor means total laryngectomy. This treatment policy may change when a function and an organ-saving surgical procedure become available. For unilateral glottic tumors, tracheal autotransplantation allows for a resection with margins comparable to a total laryngectomy and with a predictable good function. The decision about postoperative irradiation can then be based on the pathologic condition of the hemilaryngectomy specimen and the lymph nodes.

Another indication is formed by the unilateral transglottic tumor. In these cases, a combined resection of the supraglottic larynx with a hemiradical-hemilaryngectomy is necessary. The larynx that remains after this combined resection is comparable to the laryngeal remnant and with a predictable good function. The decision about postoperative irradiation can then be based on the pathologic condition of the hemilaryngectomy specimen and the lymph nodes.

After irradiation, the unilateral stage T2 to T3 glottic cancer without extension to the ventricle and without extension to the posterior midline may be treated using this technique. This tumor was the most frequent indication in our case series. When dealing with irradiated tumors, one has to be alert for submucosal spread within the cricovocal membrane toward the contralateral side because tumor spread in an irradiated patient is less predictable.

The tracheal autotransplantation technique can be used in irradiated cases without fear of wound complications because the tracheal patch and its surrounding fascia are supplied by nonirradiated fascial blood vessels. At first sight, the absence of wound healing complications such as list usage or separation of the end-to-end anastomosis may be striking when considering the postirradiation status of most patients. This can be explained by the fact that the irradiation fields for glottic tumors usually contain only the upper part of the cervical trachea. Thus, tracheal anastomosis occurs between the nonirradiated thoracic trachea and the revascularized cervical trachea on one side, and on the side of laryngeal preservation, the anastomosis occurs between the nonirradiated thoracic trachea and the irradiated laryngeal remnant. Another important fact is the formation of the anterior tracheostome that prevents extensive traction anteriorly between trachea and reconstructed larynx. Also, the tracheostome allows for a safe airway during the first postoperative weeks awaiting laryngeal decongestion and functional recovery.
has been shown previously that normal mucociliary clearance recovers over the reconstructed site when the tracheal patches are applied in their original proximal distal direction.  

In conclusion, tracheal autotransplantation brings major progress in the functional surgery for advanced laryngeal cancer. It may help in reducing the amount of total laryngectomies and contribute to a further increase in organ-sparing treatment possibilities.

Accepted for publication May 18, 2000.

This work was supported by a grant from the Research Council of Katholieke Universiteit, Leuven, Belgium.

Presented in part at the annual meeting of the American Head and Neck Society, Palm Desert, Calif, April 27, 1999.

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