Voice and Airway Restoration: Endoscopic Placement of Molds and Stents

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Summary: Severe damage to the vocal folds and upper airways after translaryngeal endotracheal intubation occurs with greater frequency and to a greater extent than is usually surmised. Videolaryngoscopic techniques have led to prompt recognition of endolaryngeal/endotracheal lesions in the critical care setting. Traditionally, surgeons have treated obstructive sequelae such as glottic, subglottic, and tracheal stenosis by major transcervical and/or transthoracic resective and reconstructive surgery. Endolaryngeal core molds and endotracheal stents have conventionally been inserted by open surgical techniques. As a prototypic case illustrates, evolutional methods of endoscopic placement of prosthetic molds and stents combined with endoscopic optical/suction instrumentation and laser photoresection allow the physician to restore upper airway patency and phonatory vocal fold function without resorting to major surgery. Delta scan topograms provide radiographic imaging of the major airways. Key Words: Videolaryngoscopy—Glottic, subglottic, and tracheal stenosis—Major reconstructive surgery—Endoscopic prosthetic placement—Voice and airway restoration—Delta scan topograms.

Severe damage to the vocal folds and upper airways after translaryngeal endotracheal intubation occurs with greater frequency and to a greater extent than has been usually surmised. In previous publications, we have utilized videolaryngoscopic techniques that have led to prompt recognition of endolaryngeal and endotracheal lesions in the critical care setting, with specific implications for voice (1,2). In recent years, surgeons have moved toward aggressive treatment of secondary glottic, subglottic, and tracheal stenoses by open major transcervical and transthoracic resective and reconstructive surgical techniques. Endolaryngeal core molds are usually utilized in open laryngotracheal surgery to treat and prevent stenosis or stricture of the upper airway, in conjunction with tracheostomy. A technique believed to be a new endoscopic method of placement of a core-mold laryngeal stent (Fig. 1) (Hood Laboratories, Pembroke, MA, U.S.A.) without resorting to the standard midline laryngofissure technique described by Montgomery and Montgomery is presented (3).

The second purpose of this article is a description of the use of a tracheal T-tube (Fig. 2), sequentially placed as a laryngotracheal stent after removal of the endolaryngeal core mold. A special technical point is the meticulous positioning of the tip of the cephalad arm of the tracheal T-tube in a precise position above the vocal folds in a transglottic position (F. G. Pearson, personal communication).

As this patient and four other patients not described here still presently wearing T-tube stents illustrate, a tracheal T-tube, whether its cephalad tip is placed in a supraglottic, glottic, or subglottic
Laser surgical techniques, whether CO\textsubscript{2} or neodymium:yttrium-aluminum garnet (Nd:YAG), must be carefully selected and precisely utilized, in conjunction with ongoing management of voice and airway restoration techniques.

Finally, a new use of a currently available technique of radiological imaging, delta scan topograms or "scanograms," is recommended as an easy and inexpensive method of routine identification, screening, and follow-up observation of patients with known or suspected phonation or upper airway problems.

**BACKGROUND**

Jackson introduced mechanical dilation and use of core-mold methods of treatment of laryngotracheal stenosis in 1917 (5). A core-mold laryngeal stent is usually indicated and utilized in the prevention and treatment of laryngeal stenosis when the glottic stenosis involves the glottis, posterior glottis, supraglottis, and subglottis, singularly or in combination. Those indications have been presently extended to treat middle and anterior laryngeal glottic fusion or web formation. The stent is also used to facilitate endolaryngeal grafting with free mucosal or split-thickness grafts and to prevent endolaryngeal stenosis in situations where there is a disruption of the endolaryngeal mucosa. The laryngeal stent may be utilized as a direct support for intralaryngeal mucosal or dermal grafts to denuded areas of the endolarynx.

The standard technique for insertion of the laryngeal stent as described by Montgomery and Mont-
gometry uses a midline laryngofissure after preoperative radiographs and direct laryngoscopy have determined the location and extent of the stenosis. After removing obstructing scar tissue and advancing intralaryngeal mucosa to cover mucosal defects, the laryngeal stent is inserted and secured in place with transcutaneous anchoring sutures over silicone buttons. If a large mucosal defect remained after the endolaryngeal stenosis was resected, a split-thickness skin graft or mucosal graft from the nasal septum or buccal mucosa could be appropriately positioned on the laryngeal stent or sutured to the larynx to cover the defect.

The stent is usually left in place 3-8 weeks following open surgical laryngeal reconstruction. When treating a patient with complete laryngeal stenosis involving the anterior commissure, Montgomery and Montgomery have recommended insertion of a silicone keel for some 2 weeks following removal of the laryngeal stent, to ensure reformation of a sharp anterior commissure and prevent the reformation of an anterior glottic laryngeal web. The keel can be placed via a laryngofissure or endoscopically. The laryngeal stent can be removed endoscopically via a laryngoscope under general anesthesia by gentle traction applied by grasping the black silk suture loop or “handle” on the superior or cephalad surface of the stent with toothed laryngeal alligator forceps. Care has to be taken to avoid dislocating the arytenoid cartilages or producing mucosal lacerations during stent removal (3).

It is of historical interest that the original T-tube may have been a metal one described by a British surgeon reporting in The Lancet in 1891. Montgomery in 1965 invented the silicone tracheal T-tube chiefly for the definitive treatment of tracheal stenosis, with the idea that it would be left in place for 3-6 months and when pulled out, the stenosis would be successfully treated (6). As Grillo et al. have pointed out, tissues respond in that way primarily in cases of partial-thickness stricture. However, in patients with a full-thickness stricture, even if a tracheal T-tube were to remain in the trachea for 5 years, the lumen will just narrow again and the definitive treatment of the stenosis must be surgical resection and end-to-end reconstruction (7).

Cooper et al., in their 36 patients with benign lesions, utilized the tracheal T-tube as the sole treatment in 12 patients. The upper limb of the tracheal T-tube was positioned above the vocal folds in five of their patients and below the vocal folds in seven patients. Extubation was successfully accomplished in nine of their patients without subsequent difficulty after the prosthesis had been in place for an average of 8.5 months, with a range of 1-12 months. In one of their patients with a complicated laryngeal and subglottic postintubation stricture, initial stenting with a T-tube failed to resolve the problem and laryngoplasty was performed with a good result. Tracheal T-tubes remained in place in two of their patients at 12 and 23 months, respectively, for tracheal strictures that were subglottic in location, with the upper end of the tracheal tube projecting above the vocal folds. In six of their patients who were treated with a tracheal T-tube as a temporizing device prior to definitive tracheal resection and reconstruction, the average duration of tracheal T-tube intubation before resection was 10 months, with a range of 4-20 months. One of their patients with a failed primary repair has a tracheal T-tube in place at 57 months (8).

The tracheal T-tube is nonirritating and preserves respiration through the nasopharynx, thereby preserving humidification. Most importantly, it preserves voice. Simply tilting the external arm of the T-tube upward or cephalad will facilitate suctioning distally into the trachea. Conversely, simply tilting the external arm of the tracheal T-tube caudad facilitates suctioning the proximal or cephalad arm of the tracheal T-tube (3).

Many patients do not require suctioning of their tracheal T-tube because of the patient’s ability to cough and clear secretions from the T-tube normally and satisfactorily. This assumes that the horizontal or external arm of the T-tube is kept plugged, as the cephalad or upper limb can become obstructed if the external or horizontal arm is left open, thereby diverting the air flow from the cephalad or upper limb. These silicone prostheses can be left in place for years without major complications (8).

When it is necessary to stent the subglottic region, Dr. F. G. Pearson has made the innovative suggestion to place the upper end of the T-tube precisely just above the vocal folds in a transglottic position, rather than below the vocal folds in the commonly used subglottic position (personal communication). This avoids injury to the vocal folds from the tip of this cephalad arm of the T-tube and still allows deglutition without aspiration. In the series of Cooper et al., 24 tubes protruded above the vocal folds. In those patients, subsequent extubation was not associated with vocal fold dysfunction, even after the tube had been in place for a year or more (8).
When a tracheal T-tube is used to stent an area of subglottic damage, a protective fenestrated, e.g., Jackson-Pilling, type of small tracheostomy tube should be protectively left in place through the tracheostoma at the time the tracheal T-tube is removed to maintain a safe airway in case recurrent narrowing of the damaged area does occur. That can take several weeks to develop. The use of silicone tracheal T-tube stents adds flexibility to the management of complicated voice and airway problems. An endoscopic technique of sequential placement of a laryngotraheal core-mold stent, followed by tracheal T-tube insertion, is described and illustrated by a successfully managed case.

MATERIALS AND METHODS

The Hood laryngeal stent is an evolution of the Montgomery laryngeal stent. It is a molded, medical-grade silicone rubber material prosthesis designed to produce no tissue reaction and to allow reepithelialization of the endolaryngeal mucosa. The prosthesis used in the described prototypic case was manufactured by Hood Laboratories. It comes in four precise sizes for patient fitting: adult male, adult female, adolescent, and child sizes. The one used in our first case is the adult female size, LSF-25. These core-mold stents are easily sterilized by conventional techniques. They are made and molded to a precise hardness to provide support but not to injure surrounding tissue. They bend easily and are compressible and conform to the inner contour of the larynx. While these are usually inserted by surgical open laryngofissure, for example, in cases of complete subglottic stenosis too extensive for repair with pedicled mucosal flaps, endoscopic placement is easily learned and accomplished.

In the management of this first case, the techniques of Shapshay (9) were employed during endoscopic treatment of the glottic and subglottic laryngeal stenosis. The CO₂ laser was utilized to precisely remove scar tissue using the microspot micromanipulator (0.3-mm spot size) with power settings of 2–3 W and a 0.1-s exposure. To prevent restenosis, more likely in patients with thicker and more extensive stenoses, especially in those patients with combined supraglottic and glottic webs, he inserts an endoscopic 0.02-in reinforced Silastic keel. That keel is fixed in place with a percutaneous 24 Prolene (polypropylene) suture and is left in place 4–6 weeks.

The technique for placement of the keel consists of two Prolene sutures threaded on a straight needle, one passing through the skin and cricothyroid and the other through the thyrohyoid membrane. The lower suture is grasped endoscopically and is then passed through the anterior part of the stent in an imbricating fashion. The upper percutaneous suture is passed through the thyrohyoid membrane via a straight needle with a double strand or complete loop. The eye of the needle is then broken off, permitting the upper percutaneous suture to be used as a pulling loop for the lower single strand suture. The free end of the single lower suture with its attached stent is then pulled through the skin puncture as the stent is guided into place at the new anterior commissure.

When satisfactory stent position is achieved, the suture, now a continuous loop through the stent, is fixed over a button. Postoperative care includes broad-spectrum cephalosporin antibiotics, meticulous wound care with hydrogen peroxide and antibiotic ointment locally, avoidance of systemic steroids because of the delayed epithelialization associated with their use, and subsequent endoscopic removal via laryngoscopy under general anesthesia with removal of any associated granulation tissue at that time with the laser (9).

For posterior glottic stenosis, Shapshay attacks that more challenging problem, which is harder to expose endoscopically, with microflap techniques and CO₂ laser scar tissue ablation and welding processes via the operating microscope. He approaches subglottic stenoses caused by weblike concentric scar by means of treatment with radial CO₂ laser incisions, using a high-power density of 4–6 W at 0.5-s exposures with a 0.3-mm spot size. He dilates with ventilating bronchoscopes of gradually enlarging diameters, utilizing gentle rotation and advancement techniques, as do I. When the stenosis is further down in the trachea, requiring bronchoscopic exposure, laser fiber capability is used with the Nd:YAG laser-contact tips system. The synthetic sapphire contact tip has a high-power density and its interaction with soft tissue is similar to that of the CO₂ laser (8).

Treatment of the prototypic case incorporated the techniques of Shapshay for laser treatment of laryngeal and tracheal stenosis (9) and techniques suggested by Tucker for percutaneous and endoscopic placement of a Teflon keel for an anterior laryngeal web (10,11). Utilizing the Jako-Ossoff suspension laryngoscope with the Tucker suspension arm, the larynx was exposed under general an-
esthesia administered via an endotracheal tube, such as the Mallinckrodt Laser-flex double cuffed endotracheal tube, via the previously established tracheostomy. Lysis of webs or granulation lesions is accomplished with microsurgical technique or with CO2 laser or contact-tip Nd:YAG laser techniques. Following this, two 18-gauge needles are placed through the skin of the anterior part of the neck to either side of the midline so that the more inferior of the two passes below the lower border of the thyroid cartilage and the more superior passes near or through the area of the thyroid notch, taking great care to avoid trauma to the thyroid isthmus or anterior communicating jugular veins or other vascular structures. Either a fine-wire suture or a fine Prolene suture is passed through each of these and is grasped endoscopically by the surgeon. The sutures are then let out through the mouth, where each is used to transfix the Teflon keel, or in our case the Hood laryngeal stent, one more cephalad and one more caudal. Sutures brought in through percutaneously placed needles through the contralateral side of the neck are then half hitched to the first set of sutures and pulled through in a reverse fashion out the contralateral side of the neck through those needles as guides. The needle tips are easily visualized within the lumen of the upper airways via the laryngoscope.

The sutures are then gently tightened by the assistant while the surgeon places the laryngeal keel or, in our patient, the Hood laryngeal stent, into premeasured position into its glottic and subglottic position. The sutures are then fixed to polypropylene buttons, which resist cutting through more than do Silastic buttons, to the right and left sides of the skin of the anterior part of the neck.

Endoscopic removal at an appropriate time is facilitated by the built-in "handle" suture that is an integral part of the molded Hood core-mold prosthesis. Simply cutting the sutures at the level of the cutaneous buttons and then endoscopically grasping the handle and removing the core-mold stent via a suspension laryngoscope allows easy removal (10,11).

The Montgomery technique for insertion of a tracheal T-tube involves inserting the caudad or inferior end of the intraluminal portion of the T-tube first, by folding the caudad arm of the tube on itself, along its longitudinal axis, with fingers or with hemostat, and the inserting this crimped end into the distal trachea via the tracheostoma, with a hemostat. That hemostat is then released. The cephalad or upper intraluminal portion of the T-tube is then grasped with the hemostat and is also directed into the trachea via the tracheostoma until the entire intraluminal portion is within the trachea. This second hemostat is released while still another hemostat grasps the external arm of the tracheal T-tube, to prevent the entire T-tube from being placed or pushed into the tracheal lumen. Release of the hemostat on the cephalad or upper arm of the tracheal T-tube and an anterior pull with the hemostat on the external arm of the tracheal T-tube will direct the cephalad or upper limb of the intraluminal portion into place (3).

I have modified this technique by using a Karl Storz optical suction grasping forceps, with a zero-degree Storz Hopkins-rod telescope, via a Wolf-Dumon laser bronchoscope, for direct visual placement of the cephalad or upper arm into a subglottic, glottic, or supraglottic position precisely. This is a modification of the techniques of Cooper et al. (8).

CASE REPORT

Medical history

A 24-year-old woman's automobile struck and wrapped itself around a tree. The woman had a linear, nondepressed skull fracture and a closed head injury with coma. Her original endotracheal intubation was with a size 8.0 oral endotracheal tube at 8:08 a.m. on Feb. 3, 1989, the date of the accident. She was weaned and extubated from the respirator at 15:30 h on Feb. 8. By 16:00 h on Feb. 8, she was in acute respiratory distress. Emergency transnasal flexible fiberoptic videolaryngoscopy was performed and revealed a severely damaged upper laryngotracheal airway, as if compression and corkscrew forces had been applied to these sites. She was reintubated and the next day she underwent direct suspension microlaryngoscopy, bronchoscopy, and tracheostomy with resection, and biopsies and dilation of her laryngeal, glottic, and subglottic tracheal stenoses. On Feb. 17, transnasal flexible fiberoptic videolaryngoscopy was performed and revealed complete synechial glottic airway closure with fusion of the vocal folds. Direct suspension microlaryngoscopy and bronchoscopy with dilation and CO2 laser and contact-tip Nd:YAG laser photoresection of recurrent laryngotracheal obstruction and stenosis was accomplished on Feb. 21, March 2, and March 24, 1989.

The patient awakened from her coma and could speak sentences clearly, but the condition of her...
voice and airway deteriorated. By April 3, 1989, videolaryngoscopy revealed recurrent glottic fusion. She was referred to the Lahey Clinic, where on May 17, 1989, she had endoscopic CO\textsubscript{2} laser laryngotracheal surgery with the hope that her voice would return in a couple of days. When her voice did not return, on May 30, videolaryngoscopy showed an anterior laryngeal web with only a small posterior glottic gap. The patient and her mother preferred local care in Springfield, MA, U.S.A. Input was obtained during her case presentation at the Eighteenth Annual Symposium of Care of the Professional Voice in Philadelphia in June, 1989, and from other otolaryngological consultants. Considerations for placement of a keel between the vocal folds and a tracheal T-tube with its long, cephalad arm up into the conventional subglottic position, to stent open that stenosis, were deliberated. Keel dislodgement, fragmentation, and aspiration problems were discussed.

By June 22, 1989, videolaryngoscopy demonstrated nearly total glottic web fusion, and there was still the issue of her subglottic stenosis.

On June 28, utilizing a Jako-Ossoff laser suspension microlaryngoscopic system, she underwent endoscopic laryngoplasty with Nd:YAG laser contact tip techniques, including excision of cervical tra-

cheal obstructing granulation mass lesions, revision of tracheostomy, and endoscopic plus percutaneous placement of a Hood Laboratories core-mold laryngeal stent, appropriately sized for the patient (Fig. 3). The percutaneous and endoscopic needle placement techniques to hold the endolaryngotracheal prosthesis in place were extrapolated from techniques of glottic keel placement. Number 18/1\textsubscript{1/2}-in needles were placed percutaneously through the cricothyroid membrane with care to avoid trauma to any anterior communicating jugular vessels or to the substance of the thyroid gland. Four needles were placed and through these, orthopedic stainless steel wires were placed and grasped via the Jako-Ossoff microsuspension laryngoscope. A second wire was passed contralaterally and then passed through the midportion of the Hood laryngeal stent before placing the stent into the patient. A second pair of #18/1\textsubscript{1/2}-in needles was used for placement of the percutaneous wires. With two half hitches, the two right-sided wires were connected to the two left-sided wires and then brought out through the contralateral percutaneous needles, after having been passed first through the laryngeal stent, so that the knots were not pulled through the stent. Precise

endoscopic measurements were made and then the core-mold Hood laryngeal stent was placed endoscopically into the larynx and the sutures were tied down over buttons at the skin level.

Because one of the wires cut through one of the Silastic buttons, 8 days later the patient was returned to surgery and a new Hood laryngeal core-mold stent was placed with the same techniques. This time 3-0 Prolene sutures and polypropylene buttons were used, rather than Silastic buttons, as the polypropylene was firmer and more resistant to being cut through.

Following removal of the Hood laryngeal stent, placement of a tracheal T-tube with its cephalad tip in a supraglottic position was accomplished. The patient would still be able to speak in a whisper and swallow both liquids and solids without aspiration, providing that the tip of the cephalad arm of the tracheal T-tube did not impede epiglottic closure over the glottic opening and the tracheal T-tube during deglutition.

On Aug. 28, 1989, the patient underwent direct suspension microlaryngoscopy with removal of the Hood core-mold laryngeal stent, excision of laryngeal glottic granulation tissue, and resection of subtotally obstructing supratracheostomal endotra-

\textbf{FIG. 3.} Lateral soft tissue x-ray film of patient’s neck with Hood core-mold laryngeal stent in place on June 28, 1989, the date of endoscopic placement above a tracheostomy tube, 4 months and 3 weeks after her original endotracheal intubation.

cheal granulation excessive tissue, with endoscopic and percutaneous placement of a long-arm radiopaque silicone Minnesota Xomed tracheal T-tube stent. The cephalad arm of the T-tube was brought up through the vocal folds just to the level of the ventricular folds. The distal arm was placed below the tracheostoma, thereby stenting the entire upper airway and vocal apparatus (Figs. 4 and 5). Videolaryngoscopy on Sept. 1, 1989, revealed some acute supraglottic granulations. On Sept. 3, direct laryngoscopic excision of the polypoid tissue of the anterior larynx was accomplished and videolaryngoscopy and videobronchoscopy were performed.

By Oct. 27, 1989, the patient underwent removal of the Minnesota Xomed tracheal T-tube and direct laryngoscopy with excision of granulation polypoid tissue in the right anterior vocal fold and left subglottic area, with videobronchoscopic resection of endotracheal and paratracheostomal granulation tissue.

Videolaryngoscopy on Nov. 8, 1989, revealed some marked supraglottic activity, but phonation and vocal fold appearance and function were improving (Fig. 6). Another videolaryngoscopy on Dec. 27, 1989, revealed remarkable voice improvement. There was no recurrence of the anterior laryngeal web, but the patient had supraglottic hyperactivity and supraglottic phonation.

Strobvideolaryngoscopy on Feb. 28, 1990, confirmed that the patient had dysphonia plicae ventriculares. Fundamental frequency was 200 Hz, but her range was from 100 to 540 Hz. Sniffing, whistling, inspiratory phonation, phonation building from a soft whisper, attempts at articulated whistling, "glottal clicks," "donkey-bray" techniques, coughing-phonation techniques, tongue trills, humming, aspirated vowels, diadochokinesis, and other techniques were done. Analysis of the strobvideolaryngoscopy of April 18, 1990, with meticulous frame-by-frame review revealed definite periods where there was excellent midline adduction of both vocal folds with only a small, posterior glottic gap present. Glottic vocal fold closure without ventilricular fold hyperactivity was best achieved when the patient was relaxing and not thinking about phonating. Both her vocal folds did fully abduct as well.

A delta scan topogram on May 17, 1990, revealed patency of the air column from the level of the ventricular folds and vocal folds all the way down the tracheoobronchial tree (Fig. 7). This patient represents our initial case of voice and upper airway restoration by means of endoscopic techniques utilizing laryngotracheal core-molds and tracheal T-tube stents. She currently attends and works at the University of Massachusetts in Amherst, MA, U.S.A.

Four other similar patients are presently wearing tracheal T-tubes and may be the subjects of future articles.

**DISCUSSION AND RESULTS**

The described technique of endoscopic placement of the Hood laryngeal stent obviates the need for open surgical laryngofissure. Since this case was complicated by subglottic and cervical tracheal stenosis, rather than using a glottic endolaryngeal keel, a tracheal T-tube was placed above a temporary tracheostomy (3).

While I have utilized the Minnesota Xomed tracheal T-tubes and the Montgomery Safe-T tracheal T-tubes, my preference is the Hood Laboratories radiopaque, long tracheal T-tubes. These permit secure surgical placement to maintain the upper airway in acute injuries and to support the trachea.

**FIG. 4.** Lateral soft tissue x-ray film of patient's neck with Minnesota Xomed long-arm silicone radiopaque tracheal T-tube stent with cephalad tip in supraglottic position, on Aug. 28, 1989, exactly 2 months after placement of Hood laryngeal stent.
The new, surgical-grade, radiopaque silicone fabrication is strong, flexible, and biocompatible and is nonabrasive, assuring patient comfort. These prostheses enable surgical management of tracheal, subglottic, and glottic stenoses and the reconstruction of the cervical and thoracic resected trachea. They are designed to maintain patency of the laryngotracheal airways and to provide respiration through these airways. They allow normal humidification and good phonation. The radiopaque tracheal T-tubes come with standard, long, and extra-long limbs, thereby serving as both a tracheostomy tube and a tracheal stent. The extra-long limbs can by-
pass and stent a tracheal stenosis between the tho-
racic inlet and the carina or, if reversed with the
cephalad tip placed in a supraglottic position, can
stent the endolarynx and cervical trachea for laryn-
geal web and tracheal stenosis lesions. All are avail-
able in a multitude of adult male, adult female, ad-
olescent, child, and even infant sizes.

The lengths of all three arms of the tracheal T-
tube can now be easily customized to the individual
patient by utilizing the CK 1000 Montgomery Cus-
tomizing Kit, obtained from Boston Medical Pro-
ducts, Inc., Waltham, MA, U.S.A. Each contains a
special Dremelco free-wheeler high-speed (20,000-
Hz) cordless grinding tool with keyless chuck, a
special tube cutter with a unique cutter blade that
cuts from the middle outward to ensure a straight
cut of the tube, various grinding stones, and mea-
suring and marking instruments, all within a conve-
nient carrying case. This allows customizing the
tube in the operating room with standard easy sub-
sequent sterilization prior to placement into the pa-
tient. This reduces the number of trips a patient
may need to make back to surgery, to ensure exact-
ness of fit and placement (3).

Eliachar et al. have utilized rigid Hopkins-type
telescopes for transstomal perioperative endo-
soscopic examination of cases managed with silicone
T-tubes to monitor the airway during the stenting
period and to determine the timing for removal of
the tubes. Immediate postremoval endoscopic fol-
low-up observation was most valuable, in their
hands, in determining the patency and stability of
the newly reconstructed airway (12). Adding rou-
tine videorecording techniques to these examina-
tions, whether transnasally, transorally, or trans-
stomally, greatly improves the diagnostic capabili-
ties and therapeutic prognostication in these cases.

Koufman et al. have discussed advances in mi-
crosurgery of the larynx with endoscopic manage-
ment of subglottic stenosis. The carbon dioxide la-
sor with bronchoscopic adaptors was successfully
employed to reestablish an adequate subglottic lu-
men in 13 cases of subglottic stenosis. Ten of these
13 patients, or 77%, had a satisfactory airway rees-
tablished within 1 year by laser vaporization tech-
niques with adjunctive corticosteroid therapy, anti-
biotic therapy, tracheostomy, dilation, and laryn-
geal stenting (13).

Woo et al., in a patient population of 50 head-
injured patients who had tracheostomy, observed
these patients during rehabilitation by flexible fi-
beroptic videolaryngoscopy examinations. Phona-
tion dysfunction occurred in 16 and airway stenosis
in 13 of the patients. Significant airway stenoses
involved both laryngeal and tracheal sites. Dyspho-
nia resulted from intubation, peripheral laryngeal
and nerve injuries, or central laryngeal movement
dysfunctions (14).

England et al. assessed the pattern of respiratory
movements of the vocal folds in relation to air flow
and respiratory system resistance in healthy human
volunteers with fiberoptic laryngoscopic motion
pictures. The results of this study indicate that the
human larynx participates in the regulation of res-
piratory air flow by providing a variable, controlled
resistance (15). It is important to remember that
patients coming to the physician or speech/language
pathologist with hoarseness may be manifesting
laryngotracheal obstructive phenomena inferior to
the vocal folds, in addition to or rather than a vocal
cord pathologic condition.

Dutu and Mangiulea have carried out pulmonary
function studies in 13 patients in whom the diagno-
sis of a central laryngeal or tracheal stenosis had
been confirmed by endoscopy. They concluded that
pulmonary function abnormalities did not allow a
prognosis of the extent of the obstructive lesion and
did not correlate with endoscopic findings. In one
case, there were no pulmonary function alterations
despite a severe tracheal stenosis (16).

In addition to the importance of documentation
by videolaryngoscopy and strobovideolaryngos-
copy techniques, delta scan topogram imaging is a
modern, readily available, and relatively inexpen-
sive diagnostic tool for imaging the entire laryn-
gotracheobronchial airways tract in screening pa-
tients with voice and upper airway disorders. Delta
scan topograms are the routine images generated by
most computerized axial tomography (CAT) scan
machines prior to imaging of the neck or chest. The
CAT scan technician, if simply and personally in-
structed, can readily adjust the image to bring out
the entire laryngotracheobronchial airways system,
with good definition and contrast.

Posteroanterior (PA) chest x-ray films are noto-
riously inadequate for accurate imaging of the major
airways, although copper filters can improve PA
chest film quality somewhat (7). A full CAT scan is
quite expensive and its summation techniques may
give misinformation about endolaryngeal or endo-
tracheal luminal caliber. For routine screening of
new patients and follow-up observation of previous
patients, PA and lateral soft tissue films of the neck
are useful. These and a delta-scan topogram (scano-
gram) of the neck and chest in a frontal projection are routinely informative.

Strobovideolaryngoscopy was performed utilizing the Bruel & Kjaer model 4914 medical stroboscope with modification WH 1910, with a Karl Storz 8702 D 90° laryngopharyngoscope, a Nagashima SFT-1 70° forward angle laryngoscope, or an Olympus ENF-P2 rhinolaryngoscope. Meticulous slow-motion and frame-by-frame analysis of stroboscopic and videolaryngoscopic imaging has made possible some diagnostic and therapeutic considerations and implementations not available by any other technique (17). In this case, it was only these tediously reviewed images that allowed accurate assessment of glottic closure, opening, and phonation mechanics.

Early recognition and treatment of voice and airway problems requires liberal application of videolaryngoscopy and strobovideolaryngoscopy examinations. Coordinating these special and advanced techniques for voice analysis with the special role provided by speech/language pathologists and coordination of efforts with these invaluable health professionals is of immeasurable help to patients who have combined voice and airway problems (18).

Use of a tracheal T-tube stent permits the luxury of waiting long periods while the patient has a satisfactory airway and satisfactory vocal communication and enjoys uninterrupted good nutrition in the interim.

Due to the critical care requirements of the patients, preoperative pulmonary function tests and measurements of laryngeal air flow and arterial blood gases have not been possible and follow-up observation of these items has been limited. For this reason, measurement of the phonation quotient, which is the vital capacity divided by the maximum phonation time, shown to correlate closely with mean flow rates, has not been documented. Because the phonation quotient provides an objective measure of the efficacy of treatment, particularly in upper-airways lesions, we hope to have this data base available on the patients observed here in a future study and publication. Objective measures of phonatory ability, such as maximum phonation time (normally 34 s in men and 26 s in women), physiological frequency range of phonation, and musical frequency range of phonation have also necessarily been deferred for future documentation and publication. Some measurements of fundamental frequency and frequency range of phonation have been included in the five case reports, recognizing the approximate normal values of 120 Hz for men and 225 Hz for women (19).

CONCLUSIONS

This case illustrates that the placement of a Hood laryngeal stent sequentially followed by placement of a tracheal T-tube and supplemental speech/language pathology rehabilitation can result in a functional upper airway and the restoration of voice, even in cases of upper airway obstruction and complete aphonia.

The placement of a tracheal T-tube, with its cephalad tip in a precisely placed supraglottic position after laryngotracheal endoscopic reconstruction, can provide a useful voice, respiration, and deglutition during ambulatory rehabilitation.

A technical modification utilizes the Wolf-Dumon laser bronchoscope with the Karl Storz optical suction grasping forceps techniques for optimal, direct vision placement of the cephalad arm of tracheal T-tubes.

While CO₂ laser techniques are time-honored endoscopic methods in the management of glottic and subglottic lesions, synechial and cicatrical sequelae can develop, which are challenging problems. Contact-tip, low-power Nd:YAG laser techniques with suspension microlaryngoscopic and optical-suction bronchoscopic forceps instrumentation offer improved modalities of therapy when used with meticulously precise techniques and timing.

The use of delta scan topograms, a modification of CAT screening techniques, for specific use in screening, assessment, management, and follow-up observation of patients with voice and upper airway disorders, is a technique widely available, simply awaiting wider use and application. In a matter of minutes, the CAT scan technician can focus the image and, rather inexpensively, give permanent radiographic imaging evaluation of laryngotracheobronchial airways not available by other conventional imaging techniques and much superior to plain chest roentgenograms, with or without copper filters, or full chest tomograms.

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REFERENCES