VOCAL FUNCTION FOLLOWING VERTICAL HEMILARYNGECTOMY: COMPARISON OF FOUR RECONSTRUCTION TECHNIQUES IN THE CANINE

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The goals of laryngeal reconstruction have been prevention of aspiration, production of a functional voice, and maintenance of an adequate airway for decannulation. A number of procedures for partial laryngeal reconstruction have accomplished these objectives. However, few studies have attempted to compare patients' vocal characteristics following different reconstruction procedures. In this study, an in vivo canine model was used to compare acoustic and aerodynamic measures of vocal function for the following vertical hemilaryngectomy reconstruction techniques: 1) a superiorly based sternohyoid muscle flap, 2) a modified epiglottic laryngoplasty, 3) a new procedure using a layered vascularized buccal mucosal flap and a transversely oriented sternohyoid muscle flap, and 4) hemilaryngeal transplantation combined with arytenoid addition. Hemilaryngectomy provided the most efficient phonation of the four techniques. The vascularized buccal mucosal flap produced the best phonation of the autologous tissue techniques examined. Both vascularized buccal mucosal flap and hemilaryngeal transplantation subjects demonstrated a mucosal wave on stroboscopy. The results indicate that vocal function will improve as the layered structure of the vocal folds is more accurately replicated in a reconstructed larynx. Intraoperative findings and whole organ sections are presented.

KEY WORDS — laryngeal reconstruction, vertical hemilaryngectomy, vocal function.

INTRODUCTION

Although surgeons have described partial laryngeal reconstruction techniques for over a century, few studies have attempted to compare laryngeal function following reconstruction with different methods. In this study, four different methods for reconstruction of vertical hemilaryngectomy defects were evaluated in an in vivo canine model: 1) a sternohyoid muscle flap, 2) an epiglottic cartilage and mucosa composite flap with a separate sternohyoideus muscle flap, 3) a vascularized buccal mucosal flap and underlying sternohyoid muscle flap with laryngeal framework reconstruction, and 4) a hemilaryngeal transplant with arytenoid addition. We hypothesized that closer replication of the structural properties of the vocal folds would result in corresponding improvements in vocal function. Reconstruction after partial laryngectomy is intended to prevent aspiration, provide a functional voice, and maintain an airway adequate for decannulation. Thus, an ideal reconstruction technique should restore the sphincteric competence of the glottis; if the arytenoid is resected, it should provide a relatively rigid posterior structure to occlude against the intact arytenoid, producing glottal competence. Closure of the glottis should be firm, so that an adequate subglottic pressure can be produced to drive phonation. Finally, reconstruction should provide a cross-sectional lumen sufficient for respiration. An adequate airway is more likely when one arytenoid can be preserved.

Two types of mucosal flaps have been used in laryngeal reconstruction. Rotation or flaps are generally taken from the false vocal fold, aryepiglottic fold, and pyriform sinus. Free mucosal grafts are usually harvested from the oral mucosa. These flaps are intended to replace the excised laryngeal mucosa and lamina propria, which function as a superior glottic interface in the native state. However, such flaps have several disadvantages. First, if used alone, they do not provide enough bulk to replace the excised tissue, and therefore are usually combined with underlying muscle or cartilaginous flaps. Second, rotational flaps often produce distention of the pyriform sinus anatomy, potentially resulting in aspiration. Third, free mucosal grafts placed in the larynx typically undergo atrophy or necrosis. This atrophy may result in an incompetent glottis. Finally, such

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grafs ultimately do not differ histologically from muscle and myofascial surfaces that gradually muscosalize. 1-4 Therefore, many investigators believe the disadvantages of laryngeal reconstruction with rotational or free mucosal grafts outweigh their benefits.

Pedicled muscle flaps are much more commonly used for reconstruction of partial laryngectomy defects. 5-7 Potential donor muscles include the sternohyoid, omohyoid, and sternocleidomastoid. Some methods also include the overlying fascia or thyroid perichondrium. The muscle can be pedicled superiorly or inferiorly, or placed as a bipedicled flap.

Muscle flaps provide excellent bulk to replace the excised hemilarynx and can be modified for various tissue defects. However, they also result in an adynamic glottic interface with a thinned mucosal layer that has poor viscoelastic and vibratory properties. Despite the disadvantages related to vocal function, many otolaryngologists contend that muscle flaps are the best option available for partial laryngectomy reconstruction because of their versatility and consistent results. 4

A wide variety of cartilaginous flaps have been described for partial laryngectomy reconstruction. 5-10 One approach utilizes a composite epiglottic flap with attached mucosa for reconstruction of near-total or vertical hemilaryngectomy defects. 11-14 In this method, the mucosa provides an intact laryngeal surface, while the epiglottic cartilage contributes structural support.

A few free tissue transfer methods for laryngeal reconstruction have also been described. Cases of human laryngeal reconstruction with iliofemoral, deltopectoral, 15 or radial forearm free flaps 16 have been reported, and reconstruction using a latissimus dorsi flap with free buccal mucosa and cartilage grafts has been described in the rabbit model. 17 To date, free tissue transfers have not been widely used for partial laryngeal reconstruction.

The present hypothesis is that vocal function will improve as the layered structure of the vocal fold is more accurately replicated in a reconstructed hemilarynx. A canine model was used to test the hypothesis. Modified muscle and cartilage flaps were chosen as the first two reconstruction methods for evaluation. The third technique was a pedicled mucosal flap with intact, vascularized submucosa. We hypothesized that this technique would provide more efficient phonation that either the muscle or cartilage flap, because it more closely replicates the native laryngeal lamina propria. A vascularized buccal mucosal flap was chosen because of its reliable blood supply. For replacement of the laryngeal mucosa, a transversely oriented, superiorly based sternohyoid muscle flap was placed at the level of the glottis. Finally, a microplate was fixed parallel to the neoglottis to stabilize the laryngeal framework where the thyroid cartilage had been removed.

The fourth technique, hemilaryngeal transplantation, is the most anatomically accurate method of hemilaryngeal reconstruction, and thus represents a theoretic ideal. In addition, it provides an opportunity to investigate the feasibility of partial organ transplantation. Reinervation of the thyroarytenoid muscle and an arytenoid adduction were included in this method.

MATERIALS AND METHODS

OVERVIEW OF EXPERIMENTAL DESIGN

Twelve adult male mongrel dogs were selected for the experiment. Three animals were assigned at random to each of three autologous reconstruction conditions; the remaining three subjects were retained as replacements for animals developing serious postoperative complications. Each animal was approximately 1 year old and weighed 20 to 25 kg. All had normal-appearing vocal cords and direct laryngoscopy; dogs with an unusually large posterior glottic gap on laryngeal closure were excluded.

Two additional animals (male littermate beagles, approximately 1 year old and weighing 12 to 15 kg) were assigned to the hemilaryngeal transplantation condition. Mixed leukocyte culture and genetic sequencing were performed to assess the major histocompatibility ractivity at the DLA-A region and verify a haplo-identical match.

Prior to laryngeal reconstruction, phonation was produced with transstraehal stimulation to accumulate baseline acoustic, aerodynamic, and videolaryngoscopic data. A stimulating electrode endotracheal tube was inserted through a tracheotomy. Following the procedure, the tracheotomy was closed and allowed to heal for 4 to 6 weeks prior to hemilaryngectomy and reconstruction.

When recovery was complete, a surgical intervention (hemilaryngectomy with autologous reconstruction, or hemilaryngeal transplantation) was performed. Two months following surgery, phonation was again evaluated with transstraehal stimulation. Laryngeal specimens were harvested after the second evaluation.

BASELINE ACOUSTIC, AERODYNAMIC, AND ENDOSCOPIC DATA

Preparation for Phonation. Each dog received acepromazine maleate (0.2 mg/kg) intramuscularly.
as a preoperative sedative. Pentobarbital sodium was administered intravenously to the level of corneal anesthesia. Additional pentobarbital was given to maintain this level of anesthesia throughout the procedure.

The subject was placed supine on the operating table and direct laryngoscopy was performed. The dog was intubated with a cuffed endotracheal tube for ventilator-assisted respiration. Cefazolin sodium (1.0 g) was administered intravenously for antimicrobial prophylaxis and continued for 7 days postoperatively. Dexamethasone sodium phosphate (8 mg intravenously) was administered to reduce laryngeal edema during phonation.

Following sterile skin preparation, a midline vertical incision was made from the sternal notch to just below the cricoid cartilage. Dissection was carried out in the midline and the strap muscles were retracted laterally. A low tracheotomy was made at the level of the sternal notch, through which a cuffed endotracheal tube was passed for assisted ventilation. The oral endotracheal tube was then removed.

A second tracheotomy was placed three tracheal rings superior to the first, and a recurrent laryngeal nerve (RLN)—stimulating endotracheal tube was inserted and directed superiorly so that its tip was located approximately 10 cm below the glottis. This tube (Fig 1) had foil electrodes attached to the cuff so that the RLN could be stimulated through the tracheal cartilage. 1,10 The tube was positioned so that the electrodes on the cuff were oriented with the stimulating electrodes adjacent to the tracheal-esophageal groove. A ground electrode was positioned at the anterior tracheal wall.

**Recurrent Laryngeal Nerve Stimulation.** With trans-tracheal stimulation of the RLN, phonation could be produced in each dog without risk of injury to the RLN. (Superior laryngeal nerve stimulation would have required an open dissection and was not performed.) Stimulation was provided via a nerve stimulator (WR Medical Electronics Co, model 2SLH, St...
Paul, Mins) connected to the tracheal electrodes. The stimulus was a 1.5-milli- 
second pulse duration and current of 3 to 5 mA. The stimulator and other equipment used in the in vivo 
model of phonation are depicted in Fig 2. 

Subglottic Pressure, Flow, and Acoustic Signal. 
Subglottic pressure was measured with a catheter-
tipped pressure transducer (Millar Instruments, model 
SPC 340, Houston, Tex) placed 2.0 cm below the 
glottis. The instrument was calibrated with a manom-
eter prior to each experiment. The pressure-regulat-
ing system exit port was connected to a flowmeter (Edwards High Vacuum International, model 825 
Series B, Wilmington, Mass). Air was bubbled through 
5 cm of heated water for humidification and warming to 
37°C when measured at the glottic outlet. This 
flow was directed through the glottis to drive phona-
tion during transtracheal stimulation of the RLN. 

Sound level measurements were made in decibels 
sound pressure level with an acoustic meter (Quest 
Electronics, model 211A, Oconomowoc, Wis) that 
was suspended at the entrance to the oral cavity. 

Subglottic pressure, flow, and acoustic signals were 
digitized simultaneously with a 12-bit analog-to-
digital converter (SA Instrumentation, model SA-
414, San Diego, Calif) and C-Speech signal process-
ing software (Pacific Medical, University of Wis-
consin, Madison, Wis). The signals were low-pass-
filtered at 3 kHz and sampled at 20 kHz for 2.8 
seconds in each trial. 

The acoustic power and aerodynamic power were 
calculated with the following formulae. 

\[ \text{Acoustic power} = \frac{2\pi r Pe dB}{%} \text{ and aerodynamic power} = \frac{Fm Sm c}{%} \text{ where:} \ 
\]

\[ r = \text{sound meter distance to the glottis in cm} \]

\[ Pe = \text{acoustic intensity in dynes/cm}^2 \]

\[ dB = (20 \log_{10}) Pe/0.0002 \text{ dynes/cm}^2 \]

\[ P_0 = 41.4 \text{ dynes/cm}^3 \]

\[ Fm = \text{flow in cm}^3/s \]

\[ Sm = \text{subglottic pressure in dynes/ cm}^2 \]

\[ 1 \text{ mm Hg} = 1.3332 \times 10^{-3} \text{ dynes/cm}^2 \]

Videoendoscopy and Videostroboscopy. All 
subjects underwent an endoscopic evaluation during 
phonation. Videoendoscopy was performed with a 
0° endoscope (Karl Storz Endoscopy-America Inc, 
Culver City, Calif) connected to a halogen light 
source via a fluid-filled light cable. For videostro-
boscopy, a laryngo-strobe (Storz, model 8000) was 
connected to the endoscope. Images were recorded 
with a charge-coupled device video camera (Toshi-
ba, model IK-C30A, Buffalo Grove, Ill) and a 1/2-in 
videotape recorder (Sony, model VQ-9850, Park 
Ridge, NJ). Recorded images were viewed on a video 
monitor (Sony, model PV-1341) for frame-by-
frame analysis. 

Test-Retest Reliability. To ensure that preoperative 
measures of phonation were truly representative, 
baseline measures were replicated for one subject 

prior to hemilaryngectomy. In this subject, phonation 
was produced with transtracheal stimulation, as de-
scribed above; after an interval of 1 month for recov-
ery, the in vivo model was reevaluated and a second 
set of baseline data were gathered. No significant differ-
ences were found between the two protoses for any 
measure of phonation. 

Hemilaryngeal Resection Technique 

The subjects received acepromazine maleate (0.2 
mg/kg) intramuscularly as a preoperative sedative. 
Propofol-benzothiadiazole was administered intravenously 
to the level of venaal anesthesia. The subject was 
placed supine on the operating table and a mixture of 
0.5% to 2.0% halothane and oxygen was adminis-
tered to maintain anesthesia throughout the proce-
dure. Amoxillin and gentamicin were given intravenously 
as antimicrobial prophylaxis and continued for 7 days postoperatively. Intraoperative mon-
itoring included a continuous electrocardiogram 
and a rectal thermometer. 

Following sterile skin preparation, a tracheotomy 
was performed at the fifth tracheal ring with an 
inferiorly based flap sutured to the skin edge. The 
oral endotracheal tube was removed and a sterile 
cuffed endotracheal tube was placed in the stoma for 
assisted ventilation. A midline vertical skin incision 
was made that extended from the level of the hyoid 
bone to the cricoid cartilage. 

A pedicled external thyroid perichondrium flap was 
used. The perichondrium was incised vertically 
a few millimeters lateral to the midline on the con-
tralateral side of the specimen and horizontally along 
the superior and inferior borders of the thyroid carti-
lage from the vertical incision to 5 mm anterior to the 
posterior edge of the ipsilateral thyroid cartilage. 
An elevator was used to raise the perichondrial flap off 
the underlying cartilage. A No. 15 blade was used to 
make the thyroid cartilage cuts in the midline and at 
the border of the posterior third and anterior two 
thirds on the ipsilateral side of resection. A midline 
thyrotomy was made and superior and inferior cuts 
were completed through the thyrothyroid and crico-
thyroid membranes. A mucosal incision was made in the midline of the posterior commissure. The specimen was excised, including thyroid cartilage, false vocal fold, thyroarytenoid muscle, arytenoid, and anterior two thirds of the ipsilateral thyroid cartilage.

RECONSTRUCTION TECHNIQUES

Superiorly Based Muscle Flap. This procedure has been described in detail by Calcaterra. Briefly, the sternothyroid muscle flap, including the outer layer of fascia, was made larger than the dimensions of the laryngeal defect in anticipation of muscle atrophy. The flap was raised superiorly to the hyoid bone with preservation of the vascular and nerve supply. The flap was rotated with the external fascial layer directed toward the laryngeal lumen. The fascia was sutured to the laryngeal mucosa posteriorly and inferiorty along the cricoid with interrupted absorbable sutures. The perichondrium was then approximated as described, with the anterior remnant of the muscle flap used to reconstruct the anterior commissure.

Epiglottic Cartilage and Mucosa Composite Flap. The epiglottis was mobilized as described by Tucker et al. The preepiglottic contents were dissected in a plane immediately anterior to the cartilage. The thyro-epiglottic and glossopiglottic ligaments were cut. The superior mucosal attachments of the epiglottis were carefully preserved to provide a pedicled vascular supply to the cartilage and mucosa on its laryngeal surface. The composite flap was then brought into the larynx and the inferior and lateral edges were trimmed to fit in the defect. The flap was sutured to the cricoid and free mucosal edge posteriorly and to the cricothyroid membrane inferiorly as described by Olson and Sullivan.

A superiorly based sternothyroid muscle flap was mobilized, placed lateral to the epiglottic composite flap, and sutured to the cricoid inferiorly. The muscle flap provided bulk for midline closure of the epiglottic flap. For anterior closure, the mucosa and inner perichondrium of the epiglottic flap and thyroid cartilage were approximated with interrupted 5-0 absorbable sutures. The external thyroid perichondrium was then approximated over both flaps.

Vascularized Buccal Mucosa Flap. A third group of dogs was reconstructed with a vascularized buccal mucosa flap. The details of this technique will be published separately. Briefly, a 2 x 3-cm pedicled flap was elevated, based on the facial artery and vein. This was sutured into position in the hemilarynx. A transversely oriented, superiorly based sternothyroid muscle flap, as described by Hinojo, was positioned deep to the mucosal flap to provide adequate bulk for the neoglottis. A microplate fixed to the thyroid cartilage served both to stabilize the laryngeal framework and as a struts for the mucosal and muscle flaps at the level of the glottis.

Hemilaryngeal Transplantation With Arytenoid Adduction. Many aspects of the hemilaryngeal transplant protocol, including canine selection, immunosuppression, surgical preparation, and postoperative care, were identical to those used for orthotopic canine laryngectomy transplantation. Briefly, the vascular supply of the hemitransplant was based on the cranial thyroid artery and hypophyseal arch. The anterior branch of the recipient RLN was dissected and tagged for anastomosis to the thyroidosmiotical branch in the donor prior to removal of the specimen. The hemitransplant was sutured to the recipient cricoid with nonabsorbable suture and an arytenoid adduction was performed. The mucosa was closed in layers and miniplates were used to stabilize the laryngeal framework at the anterior commissure and posterior third of the thyroid cartilage.

POSTOPERATIVE CARE

Autologous Reconstructions. Each dog was given water on the first postoperative day, and soft food on the third postoperative day. All of the subjects were decannulated between the second and third postoperative weeks. The dogs were decannulated if they tolerated a sustained period of exercise with the tracheostomy tubes removed and their stomas occluded with surgical tape. After decannulation, the stomas closed spontaneously.

Hemilaryngeal Transplant. The postoperative care was as described by Berke et al., except that an esophagosotomy tube was utilized to provide nutrition as soon as bowel function returned. This was removed on postoperative day 7 and the animal was given water and soft food the following morning. The dog was not decannulated, so that the transplant hemilarynx could be evaluated with a flexible endoscope placed through the tracheostomy stoma. In this manner, the hemilarynx was monitored without sedation for gross signs of organ rejection.

POST-HEMILARYNGECTOMY ASSESSMENT

The dogs were assessed 2 months after hemilaryngectomy reconstruction. Acoustic, aerodynamic, and endoscopic data were collected by the methods described above. After data collection, a laryngectomy was performed and the subjects were painlessly euthanized.

The larynges were fixed in formaldehyde and...
axially sectioned at the levels of the supraglottis, ventricle, glottis, and subglottis for gross and histologic examination. The specimens were then embedded in paraffin, and hematoxylin and eosin slides were prepared from each axial section.

RESULTS

*The study group included nine mongrel dogs for evaluation of autologous reconstruction techniques and one beagle that underwent hemilaryngeal transplantation. The second beagle was painlessly sacrificed after serving as the transplant organ donor.

Two of the mongrel dogs died in the postoperative period, both of airway obstruction from plugged tracheotomy tubes. The first was in the sternohyoid group and died during the third postoperative day. The other underwent buccal flap reconstruction and died on the eighth postoperative day. An autopsy indicated that neither aspiration, pulmonary infection, nor embolism was the cause of death. Replacement animals were substituted for these dogs, as described above.

The only additional complication was a postoperative seroma that did not respond to repeated aspiration and pressure dressings. The seroma resolved and the wound healed in approximately 10 days after drainage and wound irrigation. None of the subjects developed weight loss or clinical signs of aspiration.

ACOUSTIC AND AERODYNAMIC DATA

Some trial and error was required before consistent tracheal stimulation of the RLN could be obtained. Therefore, the four preoperative and four postoperative trials with the highest calculated aerodynamic power were selected for each subject for further analysis. Figure 3A shows the average acoustic power for each condition, expressed as a percentage of the average preoperative values. Statistical significance could not be determined, because of the limited numbers of subjects and trials in each condition.

Figure 3B shows the aerodynamic power for each of the techniques, again expressed as a percentage of preoperative values. Aerodynamic power was highest for the hemiclone transplant dog; however, statistical
analysis was again limited by the small numbers of subjects and trials in each condition.

ENDOSCOPY AND WHOLE ORGAN SECTIONS

Sternohyoid Muscle Flap. Videendoscopy of the superiorly based sternohyoid muscle flap demonstrated an adequate cross-sectional airway at the level of the glottis. A representative endoscopic photograph obtained during RLN stimulation is included as Fig 4A. The flap had mucosalized and the suture lines were well healed. The muscle flap (left) had atrophied posteriorly, resulting in a large posterior glottic gap that could not be closed even with overcompensation by the intact arytenoid. The anterior commissure was rotated to the left of the midline with a shortened anterior-posterior (AP) diameter of the glottis. The native vocal fold (right) was shortened and bowed even when the arytenoid was adducted upon RLN stimulation. This apparently resulted from the loss of support at the anterior commissure after resection of the anterior two thirds of the left thyroid cartilage.

The whole organ section (Fig 4B) confirmed the endoscopic findings of anterior commissure rotation and a shortened glottic AP diameter. The anterior edge of the thyroid cartilage was bent posteriorly, shortening the glottis and preventing the native vocal fold from tensing with adduction. The muscle flap had migrated anteriorly and atrophied posteriorly. There was a small amount of new cartilage and bone formation where the perichondrial flap was positioned external to the muscle flap. There was a thin layer of mucosa overlying the muscle flap on the endolaryngeal surface.

Epiglottic Cartilage Flap. Videendoscopy of the epiglottic cartilage and mucosa composite flap demonstrated an adequate cross-sectional airway at the

Fig 5 Left epiglottic cartilage and mucosa composite flap, 2 months postoperative. A) Endoscopy with right RLN stimulation. B) Whole organ axial section of glottis.

Fig 6 Left vascularized buccal mucosa and sternohyoid muscle flap with micropate laryngeal framework reconstruction, 2 months postoperative. A) Endoscopy with right RLN stimulation. B) Whole organ axial section of glottis.
level of the glottis. A representative endoscopic photograph obtained during RLN stimulation is included as Fig. 5A. The epiglottic mucosa on the endolaryngeal surface of the flap was intact and well vascularized. The posterior edge of the cartilage flap had pulled away from the cricoid in all three subjects, producing a large glottic gap. The remainder of the epiglottic flap was in the midline and met the contralateral vocal fold during RLN stimulation. There was a sharp anterior commissure where the epiglottic cartilage was sown to the anterior thyroid cartilage, and a normal AP diameter of the glottis. There appeared to be some tension of the native vocal fold with RLN stimulation, perhaps due to cartilaginous support at the anterior commissure.

Whole organ sections (Fig. 5B) confirmed the endoscopic findings of midline flap position, normal AP glottic diameter, and posterior glottic gap. There was little new cartilage or bone growth from the perichondrial flap.

Buccal Mucosa Flap. Videendoscopy of the buccal mucosa flaps indicated an adequate cross-sectional airway at the level of the glottis. A representative endoscopic photograph obtained during RLN stimulation is included as Fig. 6A. The vascularized mucosa flap (left) was fixed to the midline posteriorly. No glottic gap was present upon RLN stimulation. The anterior commissure was sharp and did not deviate from the midline. There was a normal AP diameter of the glottis. The native vocal fold adducted to the midline and tensed with RLN stimulation.

Findings on analysis of the whole organ sections (Fig. 5B) were consistent with the endoscopic findings. The airway appeared small because of the position of the opposite vocal fold, but was adequate, with the native vocal fold abducted in the live animal. The miniplate had been incorporated into new cartilage and bone growth, apparently potentiated by the preserved overlying perichondrium.

**Hemilaryngeal Transplantation.** On endoscopic examination, the transplanted hemilarynx was similar in appearance to the native side (Fig. 7A), although the fold was immobile and some edema was present. The native vocal fold abducted normally with respiration; the transplanted fold was fixed by an arytenoid adduction. The mucosa appeared to be healthy, without granulation or scarring. The vascularized mucosa flap (left) was fixed in the midline throughout the glottis and had no glottic gap during RLN stimulation. The anterior commissure was sharp and did not deviate from the midline. There was a normal AP diameter of the glottis. The native vocal fold adducted to the midline and tensed with RLN stimulation. At 2 months posttransplant, the transplanted vocal fold also demonstrated some tension with stimulation of the RLN.

On whole organ section, the airway appeared to be narrow (Fig. 7B), but it was adequate clinically when the native vocal fold was abducted. Adduction of the transplant arytenoid was noted, with suture visible in the transverse section.

**STROBOSCOPY**

All dogs in the study underwent stroboscopic endoscopy. A mucosal traveling wave could not be elicited in any of the animals who underwent muscle or epiglottic flap reconstruction. The buccal flap and hemitransplant dogs revealed a traveling mucosal wave that was synchronous with the wave in the native vocal fold. In the buccal flap dogs, there was increased propagation of the mucosal wave superi-
only to the supraglottis along the mucosal flap.

DISCUSSION

Previous studies of laryngeal reconstruction methods have emphasized issues of aspiration, voice, and airway. However, few authors have compared different reconstruction techniques by assessing phonation. Blaugram et al. evaluated speech following reconstruction with mucosal and skin flaps. They found that phonation in these patients was primarily supraglottic, and that fundamental frequency was low and restricted in range. Preservation of the arytenoid improved both aerodynamic and acoustic parameters. Hirano et al. argued that such comparisons among different reconstruction techniques are problematic because functional results are not predictable, and because of a lack of standardized methods for evaluating vocal function.

This study evaluated four surgical techniques for reconstruction following total partial laryngectomy in the canine model. Preoperative and postoperative measurements of vocal function were obtained to study the effects of each procedure on each individual subject. Aerodynamic power and acoustic power were measured because they are complementary indicators of vocal function. Aerodynamic power is a function of subglottic pressure, which in turn is a function of both glottic closure and tension. Acoustic power is related to both glottic closure and the periodicity of vibration, and reflects the ability of the larynx to produce acoustic intensity.

The canine larynx has provided insight into the physiology of the human larynx in normal and diseased states. However, several anatomic differences have implications for hemilaryngeal reconstruction. The arytenoid is longer in the dog and occupies about one half of the length of the posterior glottic gap, in comparison to one third in the human. The interarytenoid muscle in the dog is less developed and the posterior commissure closes less tightly during phonation. Animals demonstrating a posterior glottic gap upon transtracheal RLN stimulation during preoperative phonation were excluded from the study. Following hemilaryngeal reconstruction, loss of tissue bulk could prevent the intact arytenoid from closing the posterior glottis, thus creating a glottal gap with deleterious effect on postoperative phonation. Because the arytenoid is larger in the dog, the consequences of a posterior glottic gap during phonation may be greater than in humans.

Hirano has emphasized the importance of the layered structure of the larynx. He described three anatomic and functional compartments of the larynx: the cover, consisting of the epithelium and the super-

fi
cial layer of the lamina propria; the transition, consisting of the intermediate and deep layers of the lamina propria; and the body, formed by the vocalis muscle. During speech, the mucosa must move fluidly over the underlying muscle to produce the normal, wave-like motion at the glottis. After severe laryngeal trauma, for example, the mucosa and superficial lamina propria are scarred to the underlying muscle, producing nonvibratory segments of the vocal fold and aperiodic vibration.

Far the reconstruction of hemilaryngeal defects, mucosal, muscle, and cartilage flaps have been most commonly used. Mucosal flaps alone do not adequately replace tissue bulk. When used as free grafts over muscle or cartilage, they generally undergo atrophy or necrosis. Muscle or cartilage flaps reconstruct tissue bulk, but when they are allowed to mucoselize, the normal vibratory properties of the glottis are lost, because the submucosa is thin and lacks the biomechanical characteristics of the lamina propria. Following muscle or cartilage flap procedures, the hemilarynx usually vibrates poorly, as in the severely traumatized larynx. An ideal alternative for the endolaryngeal submucosa would have the viscoelastic properties of the native lamina propria. A vascularized full thickness mucosal flap, such as the buccal flap used in this study, offers a theoretically acceptable autologous replacement for the laryngeal mucosa and lamina propria. The data in this study suggest that the viscoelastic properties of the buccal flap submucosa are more similar to those of the native lamina propria than either a mucosalized muscle flap or a cartilage and mucosa composite flap.

On stroboscopy, a mucosal wave occurred in the vascularized mucosal flap and hemilaryngeal transplant subjects. In subjects receiving muscle and cartilage flaps, no wave was identified and phonation was consistently aperiodic and perceptually rough. The lack of a mucosal wave is consistent with the clinical experience of many surgeons performing hemilaryngeal reconstruction in human patients.

The endoscopic data and whole organ axial sections provide anatomic evidence consistent with the phonation data in Fig 3. Both the muscle and cartilage techniques produced a posterior glottic gap. The muscle flap underwent atrophy and migration and the cartilage flap consistently pulled away from the posterior cricoid. This result deceptively affected glottic closure and subglottic pressure, therefore reducing values for both acoustic and aerodynamic power. The muscle flap lacked framework reconstruction for the resected thyroid cartilage and therefore had no support for the anterior commissure. The results were a
shortened glottic AP diameter and a native vocal fold that was unable to vibrate. The reconstructed hemilarynx. The cartilage flap provided some support of the anterior commissure. Unfortunately, in every dog the posterior edge of the epiglottic cartilage detached from the cricoid, producing a posterior glottic gap.

The vascularized buccal mucosa flap, combined with a muscle flap and laryngeal framework reconstruction, provided the best autologous repair of the excised stenotic defect. This method replaced the thyr- roid cartilage support and the bulk of the intrinsic laryngeal musculature, resulting in both a normal AP glottic diameter and medialization of the entire neo- glottis.

Hemilaryngeal transplantation was studied to in- vestigate the results of an idealized autologous recon- struction. Although technically feasible, this is not an option for human partial laryngeal reconstruction at this time. Nonetheless, the dog that underwent hemilaryngeal transplantation achieved the best results in this study. Postoperative acoustic and aerodynamic- power values were better than the preoperative baseline values, probably because of the tight glottic closure achieved by arytenoid adduction, which pro- duced greater acoustic intensity and higher subglottic pressure.

In conclusion, three methods of autologous hemilaryngeal reconstruction and hemilaryngeal transplant- tion were compared in the dog. As expected, hemilaryngeal transplantation produced minimal scar, aerody- namic, and stroboscopic results, because it most closely replicated the layered laryngeal anatomy. The vascularized buccal mucosa flap also produced a favorable surface for laryngeal vibration, and func- tioned better than the cartilage and muscle flaps studied. Only the hemilaryngeal transplant and buc- cal mucosa flap produced a mucosal wave. The endoscopic and whole organ axial sections provided additional anatomic data that support the concept that when the excised hemilarynx is replaced by increas- ingly similar tissue, there is a successive improve- ment in vocal function.

REFERENCES


13. Sjoliiok E, Prada laatunen rekonsstruktioon eristäminen epiglotit. (Reconstructive anterior and lateral laryn- goectomy with the use of the epiglottis for the pedicle graft). Cink Otolaryngol 1965;16:328-34.


