Neodymium:yttrium aluminum garnet laser ventriculocordectomy in standing horses

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Animals—Six horses between 2 and 32 years old.

Procedure—Under endoscopic guidance, the left laryngeal ventricle was everted with grasping forceps and excised with an Nd:YAG laser, using 60 watts of power in a noncontact fashion (6,403 to 9,197 Joules). Following removal of the ventricle, the vocal cord was photoablated. Horses were examined endoscopically 2, 7, 14, 21, 30, and 47 days after ventriculocordectomy, and 1 horse was euthanized on each of these days. At necropsy, the larynx was removed intact and examined grossly. Samples were collected for histologic examination of the ventriculocordectomy site.

Results—Endoscopic examination revealed granulation tissue by day 7; the start of epithelialization by day 21, and healing by day 47. At necropsy, 4 horses were found to have a small amount of ventricular mucosa remaining dorsally and 1 additional horse was found to have a mucocele. Granulation tissue was identified grossly and histologically in the horses euthanized between 7 and 30 days after surgery. Incomplete reepithelialization was evident histologically on day 14, and complete reepithelialization of the surgery site was evident by day 47.

Conclusion and Clinical Relevance—Results suggest that ventriculocordectomy can safely be performed with an Nd:YAG laser in standing horses. (Am J Vet Res 2001;62:531–537)

Ventriculotomy (ie, removal of the laryngeal ventricle) and ventriculocordectomy (ie, removal of the laryngeal ventricle and vocal cord) are frequently performed, alone or in conjunction with prosthetic laryngoplasty, as a treatment for laryngeal hemiplegia in horses. Ventriculotomy and ventriculocordectomy can be performed through a laryngotomy or by use of a laser inserted through the nasal passage. The neodymium:yttrium-aluminum-garnet (Nd:YAG) laser emits light with a wavelength of 1,064 nm. This type of laser is particularly useful for surgery of the respiratory tract, including the larynx, in horses, because the laser light can be transmitted via a flexible fiber and the laser can be used in a contact or noncontact fashion. Results of using a Nd:YAG laser in a noncontact fashion for ventriculotomy in standing horses have been reported. In that study, 70 to 98 W of power and 3,880 to 4,651 J of energy were used, and the authors concluded that Nd:YAG photovaporization of the laryngeal ventricle was feasible but that refinements in the surgical technique would be required before it could be recommended for clinical use. One of their concerns was that the mucosa of the laryngeal ventricle was not completely ablated. However, other investigators have reported good results following experimental or clinical laser ablation of the laryngeal ventricle, using an Nd:YAG laser in a noncontact fashion and delivering approximately 3,000 J of energy.

To avoid complications associated with inadequate removal of ventricular mucosa and minimize the risk of thermal injury to surrounding tissues, a technique for ventriculotomy using an Nd:YAG laser in a contact fashion through an oral approach was developed. This technique was different from the previously described noncontact techniques in that the laryngeal ventricle was everted with grasping forceps prior to contact excision, using a sculpted laser fiber. With this technique, the entire laryngeal ventricle and vocal cord is removed. This technique has been used clinically, but subjective and objective data on healing of the ventriculocordectomy site have not been reported. The purpose of the study reported here was to develop a technique for laser ventriculocordectomy, using an Nd:YAG laser in a noncontact fashion, in standing horses and document healing in horses undergoing this procedure.

Materials and Methods

Horse—Six horses ranging from 2 to 32 years old were used in the study. Three were castrated males, 2 were females, and 1 was a sexually intact male. For all horses, results of physical and endoscopic examinations performed prior to the study were unremarkable. The research protocol was approved by the institutional animal care and use committee.

Surgical technique—Immediately prior to surgery, phenylbutazone (4.4 mg/kg [2 mg/lb] of body weight, IV) and dexamethasone (0.04 mg/kg [0.02 mg/lb], IV) were administered. Horses were placed in metal stocks and sedated with xylazine hydrochloride (0.4 mg/kg [0.2 mg/lb], IV) and butorphanol tartrate (0.01 mg/kg [0.005 mg/lb], IV). The horses’ heads were secured by attaching crosspieces to their halters. The rostral 5 cm of the mucosa of the left and right nasal passages was topically anesthetized, and a videoendoscope was passed into the left nasal passage via the ventral meatus. The videoendoscope was positioned in the nasopharynx so that the larynx could be examined. An endoscopic spraying device was inserted into the biopsy channel of the endoscope and used to deliver topical anesthetic to the left laryngeal ventricular mucosa, left vocal cord, and epiglottis. Six hundred-millimeter-long bronchoesophageal grasping forceps were passed into the right nasal passage to the...
level of the nasopharynx. Positioning of the grasping forceps adjacent to the ventricle was aided by extension of the horse's neck. Under endoscopic control, the grasping forceps were opened by an assistant surgeon and inserted into the midportion of the left laryngeal ventricle. The forceps were closed and rotated counterclockwise, and steady traction was placed on the forceps to evert the ventricle. A coaxial Nd:YAG laser fiber cooled with nitrogen gas was passed through the biopsy channel of the endoscope. The laser unit was set to deliver 60 W of power in a continuous mode. The tip of the laser fiber was placed 2 cm from the end of the endoscope and 1 to 2 cm from the everted laryngeal ventricle. The ventricle was excised, starting at its dorsal aspect and ending at its ventral, axial aspect. The laser was discharged in short bursts (3 to 5 seconds) of laser energy until the ventricle was removed. The excised ventricle was placed in neutral-buffered formalin and submitted for histologic examination. Following removal of the ventricle, the vocal cord was photoablated with the laser. Energy required to remove the ventricle and ablate the vocal cord was recorded. Phenylbutazone (4.4 mg/kg [2 mg/lb], PO, q 24 h) was administered for 7 days after surgery and dexamethasone (0.04 mg/kg [0.02 mg/lb], IV, q 24 h) was administered for 2 days after surgery.

Post-surgical evaluation—Horses were examined endoscopically 2, 7, 14, 21, 30, and 47 days after ventriculocordectomy, and 1 horse was euthanatized on each of these days. At necropsy, the larynx was removed intact and placed in Jorres fixative solution. Following fixation for a minimum of 24 hours, the dorsal aspect of the larynx was sectioned on the midline. The left hemilarynx was examined grossly for healing of the surgery site and completeness of removal of the left ventricle and vocal cord. Specimens were collected from a minimum of 3 areas and submitted for histologic evaluation. First, a vertical section through the dorsal border of the surgery site perpendicular to and through the arytenoid cartilage was obtained. Second, a midline horizontal section through the middle of the laryngeal ventricle, transecting the ventricle and vocal cord and perpendicular to the first section, was obtained. Third, another vertical section extending perpendicularly through the ventral-most aspect of the surgery site was obtained. Specimens were placed in neutral-buffered 10% formalin, and following routine paraffin embedding and sectioning, tissues were stained with H & E. Histologic examination was directed at determining the nature of the inflammatory response, the type and degree of replacement tissue, whether any portions of ventricular mucosa remained, and the depth of tissue necrosis, including necrosis of the ventral border of the arytenoid cartilage. Tissues outside the surgical site that were injured during the procedure and the right ventricle and vocal cord were also examined.

Results

Evaluation of the procedure—The procedure was tolerated well by all horses, and surgery time ranged from 10 to 30 minutes. Subjectively, simultaneous placement of the endoscope and grasping forceps was better tolerated if the rostral aspect of the nasal passage was topically anesthetized. Energy required to remove the ventricle and ablate the vocal cord ranged from 6,403 to 9,197 J. The most common problem encountered was loosening of the grasping forceps from the laryngeal ventricle. Repositioning of the grasping forceps was required if the assistant placed excessive traction on the grasping forceps or if the horse moved before the ventricle was completely excised. In general, the grasping forceps could be repositioned as needed until the ventricle was completely removed. Mild hemorrhage was evident at the surgery site during the procedure in 2 horses, and all horses had a small amount of blood emanating from the ventriculocordectomy site at the end of the procedure. None of the horses resented palpation of the larynx or experienced problems with prehension of food, ingestion of water, or coughing following surgery.

Endoscopic evaluation—On day 2, the ventriculocordectomy site appeared hyperemic and edematous, with the result that the surgical margins appeared larger than they had immediately after surgery. The surface of the surgical site was covered with yellow, fibrinopurulent exudate. On day 7, the surgical site was still covered with tenacious yellow, fibrinopurulent exudate and appeared hyperemic and edematous. In most horses, a bed of pink granulation tissue could be seen beneath the fibrinopurulent pseudomembrane. On day 14, the tissues appeared less edematous, and a bed of healthy granulation tissue filled the ventriculocordectomy site. In 2 horses, the fibrinopurulent pseudomembrane was still present but appeared to be sloughing from the granulation tissue. On day 21, the surgical site was no longer edematous and was smaller, presumably because of contraction, and a bed of smooth, pink granulation tissue with white margins was seen. One horse had evidence of mild ulceration in the middle of the ventriculocordectomy site. On day 30, white, pale tissue that appeared to be epithelium covered the surgery site. One horse still had a small area of ulceration in the midportion of the ventriculocordectomy site. On day 47, the ventriculocordectomy site was completely covered with epithelium and appeared healed (Fig 1).

Complications observed endoscopically—Four horses had endoscopic evidence of exposure of the ventral border of the left arytenoid cartilage. Three of these 4 horses did not have any gross evidence of inflammation of the left arytenoid cartilage, and the exposed portion of cartilage was covered with granulation tissue by day 21 in 2 horses and by day 7 in the third. The fourth horse was euthanatized on day 7, precluding further examination.

Three horses had endoscopic evidence of thermal injury to the contralateral vocal cord. Endoscopically, the damaged area of vocal cord appeared healed on day 21 in 1 horse. In 1 of these horses, axial superficial ulcers involving the right and left corniculate processes of the arytenoid cartilages were evident. The 1 horse that was followed up for 47 days after surgery did not develop any evidence of arytenoid chondritis or excessive granulation tissue formation at the ventriculocordectomy site.

Gross pathologic findings—In the horse that was euthanatized 2 days after surgery, removal of the laryngeal ventricle and vocal cord appeared grossly to be complete; the ventral borders of the arytenoid cartilage and ventricularis muscle were exposed, and a rim of greenish-white tissue (2 to 3 mm) surrounded the surgery site. Superficial laser burns were evident on the epiglottis and right vocal cord. In the horse euthanatized
7 days after surgery, a small amount of mucosa remained at the apex of the ventricle, where it extends beneath the arytenoid cartilage. The surgical wound was covered with a gray-green pseudomembrane that overlay granulation tissue. Laser burns were evident on the right vocal fold (29 x 15 mm) and floor of the larynx (3 x 8 mm) at the level of the cricoid cartilage. Two apposing superficial ulcers (6 and 4 mm in diameter) were seen on the axial aspects of the corniculate processes of the right and left arytenoid cartilages. In the horse euthanatized 14 days after surgery, a small rim of ventricular mucosa remained at the apex of the ventricle and extended dorso-laterally to within 3 mm of the ventral border of the arytenoid cartilage. Vocal cord removal was complete. The surgery site was ulcerated, edematous, and hemorrhagic, but granulation tissue filled the wound bed. A rim (2 to 3 mm) of migrating epithelium surrounded the granulation tissue bed. There was no necrosis or damage to the arytenoid cartilage. In the horse euthanatized 21 days after surgery, the opening to the laryngeal ventricle was completely obliterated. The surgery site was covered with a yellow-red mottled bed of healthy appearing granulation tissue surrounded by a 2- to 3-mm rim of contracted white scar tissue. Two smooth firm white nodular masses measuring 4 and 6 mm in length were present along the ventral border of the arytenoid cartilage. In the horse euthanatized 30 days after surgery, the opening of the laryngeal ventricle and vocal cord were completely obliterated. The surgery site was covered with a bed of dark red-yellow granulation tissue with a cobblestone texture and outlined with a rim of white contractile scar tissue. The ventromedial border of the left arytenoid cartilage was partially exposed. In the horse euthanatized 47 days after surgery, the luminal surface of the ventriculocordectomy site was healed. Pale, white lines of fibrosis radiated out from the center of the well-healed scar. The scar was 13 x 22 mm, had a shiny red center, and bulged slightly into the lumen of the larynx. On cross-section, the ventricular space was engorged with sticky, tenacious, gelatinous mucus (mucocele) and ventricular mucosa remained. The mucocele measured 19 x 35 mm.

**Histologic examination of biopsy specimens**—
Tissue specimens obtained at the time of surgery were histologically compatible with normal ventricular mucosa. The mucosa consisted of squamous to pseudostratified columnar epithelium with serous and mucous glands. Some sections had small submucosal lymphoid aggregates. Tissue margins were hyperosinophilic and hyalinized, which was considered consistent with thermal injury.

**Histologic examination of necropsy specimens**—
Histologic examination of tissue specimens from the horse euthanatized 2 days after surgery revealed that soft tissues surrounding the excised ventricle were edematous and hemorrhagic, with vasculitis and coagula-
tive necrosis consistent with thermal injury. The inflammatory process was primarily neutrophilic with lesser numbers of phagocytic macrophages. The ventral border of the arytenoid cartilage showed signs of coagulative necrosis (Fig 2). The only remaining ventricular mucosa that was identified was located in the ventral aspect of the ventricle and had undergone coagulative necrosis. In the horse euthanatized 7 days after surgery, the ventral border of the arytenoid cartilage was necrotic and covered by a pseudomembrane. Some of the mucosa remained in the apical portion of the ventricle, but was ulcerated. The inflammatory process consisted of large numbers of macrophages, plasma cells, and neutrophils. Necrosis extended into subjacent skeletal muscle. A fibrinocellular crust composed of fibrin and degenerate neutrophils covered a bed of granulation tissue. In the horse euthanatized 14 days after surgery, histologic evidence of necrosis of the arytenoid cartilage was absent. Three millimeters dorsal to the ventral border of the arytenoid cartilage, some ventricular mucosa remained. Remaining portions of mucosa were folded, ulcerated, and hemorrhagic and overlay proliferative granulation tissue. Granulation tissue filled the bed of the surgical wound and re-epithelialization was beginning (Fig 3). Some re-epithelialization originated from intact glands. The inflammatory process consisted mainly of lymphocytes and plasma cells with lesser numbers of neutrophils. Necrosis extended into adjacent skeletal muscle. In the horse euthanatized 21 days after surgery, the ventral border of the arytenoid cartilage had some necrosis. The cartilage edge was irregular, infiltrated with neutrophils, and surrounded by granulation tissue. Dorsally, there was approximately 3 mm of ventricular mucosa that remained beneath the arytenoid cartilage. A granulation tissue bed up to 3-mm thick covered the luminal surface of the surgical defect and was coated with a fibrinocellular rim up to 1-mm thick that consisted of necrotic tissue, fibrin, hemorrhage, and neutrophils. Epithelium at the edges of the defect was hyperplastic and consisted of stratified squamous epithelium with rete peg formation and migration over the granulation tissue bed. In the horse euthanatized 30 days after surgery, the ventral margin of the arytenoid cartilage was necrotic (short arrows) and forms one edge of a microabscess walled off by granulation tissue (long arrows). H&E stain; bar = 250 mm.
tenoid cartilage was necrotic with a walled-off microabscess at the ventral tip (Fig 4). This was surrounded by mature, well-developed granulation and fibrous connective tissue. There was no evidence of ventricular mucosa in any of the sections examined. The surgical defect was ulcerated with fibrin, hemorrhage, edema, neutrophils, and necrotic cellular debris overlying a bed of mature, well-developed granulation tissue. Margins were re-epithelialized, more so dorsally. In the horse euthanatized 47 days after surgery, no necrosis of the arytenoid cartilage was evident. The luminal surface of the surgical defect was completely healed and covered with stratified squamous epithelium (Fig 5). Underlying tissue consisted of thick, mature, fibrous connective tissue, with blood vessels and multiple small foci of hemorrhage and hemosiderin-laden macrophages. A few foci of lymphocytes, plasma cells, and macrophages were present immediately adjacent to the stratified squamous epithelium. Ventricular mucosa remained and consisted of pseudostratified, tall columnar epithelium with large numbers of goblet cells. The ventricular lumen was filled with mucus and degenerate cells (mucocele).

Tissues from the right laryngeal ventricle were histologically compatible with normal ventricular mucosa. The mucosa consisted of squamous to pseudostratified columnar epithelium with serous and mucous glands. Some sections had small submucosal lymphoid aggregates.

**Discussion**

Ventriculectomy and ventriculocordectomy have been used to prevent dynamic collapse of the vocal cord in horses with laryngeal hemiplegia. When ventriculectomy is performed alone, it is hoped that fibrosis between the lateral laryngeal wall and the vocal cord will stabilize the vocal cord, preventing dynamic collapse, and previous studies have documented the clinical effectiveness of ventriculectomy performed as the sole procedure in horses with laryngeal hemiplegia. We believe that ventriculocordectomy may have advantages over ventriculectomy when performed as the sole procedure for treatment of laryngeal hemiplegia. Intuitively, it seems likely that ventriculocordectomy would better prevent dynamic collapse of the vocal cord, because the vocal cord is removed with this procedure. In addition, we believe that the ventral aspect of the rima glottis will be smoother following healing of a ventriculocordectomy than following healing of a ventriculectomy. However, studies comparing healing in horses undergoing ventriculocordectomy alone versus horses undergoing ventriculectomy alone or comparing dynamic collapse of the larynx during exercise on a high-speed treadmill in horses undergoing ventriculocordectomy alone versus horses undergoing ventriculectomy alone have not been published. Therefore, whether ventriculectomy or ventriculocordectomy, when used as the sole procedure, will yield better results in horses with laryngeal hemiplegia is speculative.
Results of the present study suggest that ventriculocordectomy can safely be performed with an Nd:YAG laser in a noncontact fashion in standing horses and that the surgery site can be expected to heal in 30 to 47 days. In most horses, the laryngeal ventricle and vocal cord were completely removed, although small fragments (≤3 mm) of ventricular mucosa were seen in 3 horses grossly and in 5 horses histologically. When performed alone, the procedure avoids the risks of general anesthesia, does not require that a laryngotomy be performed, and can be performed on an outpatient basis. When performed in combination with laryngoplasty, this procedure may reduce the overall time of anesthesia, as ventriculocordectomy could be performed first with the horse only sedated, and the horse would only have to be anesthetized for the time required to perform laryngoplasty.

The bronchoesophageal grasping forceps used for eversion of the laryngeal ventricle were invaluable during this procedure. Without this instrument, the surgeon cannot be certain the ventricle will be completely removed. However, others have reported good clinical results without complete removal of the laryngeal ventricle were identified related to their use. It is our opinion that the laryngeal ventricular mucosa should be topically anesthetized to minimize patient discomfort associated with eversion of the laryngeal ventricle with the grasping forceps. Photoablation of the vocal cord was easy to perform and did not require use of the grasping forceps. We recommend that if ventriculocordectomy is performed in combination with prosthetic laryngoplasty, ventriculocordectomy be performed first. Laryngoplasty results in lateralization of the vocal cord, and eversion the laryngeal ventricle with the grasping forceps would be difficult if prosthetic laryngoplasty was performed first. In clinical cases involving horses undergoing laser ventriculocordectomy followed by prosthetic laryngoplasty, we have not noticed any complications associated with healing of the ventriculocordectomy site.

The complications of arytenoid cartilage necrosis, laser burns to the contralateral vocal cord, and mucocele formation observed in this study can be avoided with careful surgical technique. Arytenoid cartilage necrosis can be avoided by not ablating the vocal cord at its origin from the vocal process and minimizing the delivery of laser energy to the dorsal portion of the laryngeal ventricle. However, because the ventricle extends dorsally for up to 14 mm above and behind the ventral margin of the arytenoid cartilage, minimizing necrosis of the ventral border of this cartilage may lessen the likelihood of complete removal of the mucosal lining of the ventricle (Fig 6). Ventricular mucosa that remains may result in mucocele formation.

A mucocele forms when mucous glands from remaining ventricular mucosa continue to secrete mucous into the space left following removal of the ventricle and an opening permitting drainage is no longer present.5,7 The mucus is isolated in the remaining ventricular space once the luminal aspect of the surgical incision epithelializes. Mucoceles can be prevented by removing the entire mucous membrane lining of the ventricle or allowing a small portion of the ventricle to remain open dorsally, preventing accumulation of mucous in the ventricular space.4,5 Mucoceles have only been reported following the use of noncontact laser techniques and do not appear to be a complication of contact techniques.5,6 In one study of 106 horses, 4 horses developed an abscess (n = 3) or mucocele (1) at the ventriculectomy site.1 The authors of that study emphasized the importance of completely removing the laryngeal ventricular mucosa to decrease the likelihood of these complications.4 Examination of clinical cases treated with the technique described in the present study would be required to determine the incidence, clinical relevance, and pathologic sequelae of mucocele formation. The solitary mucocele in this study did not have evidence of abscess formation or inflammation at the time of necropsy.

In subsequent clinical cases using the described technique, we have by photoablating the central two-thirds of the vocal cord with the laser, thus permitting exposure of the vocal process and ventral border of the arytenoid cartilage. Despite histologic evidence of arytenoid cartilage necrosis, endoscopically the exposed cartilage became covered with healthy appearing granulation tissue and visible cartilage thickening and mucusal edema characteristic of arytenoid chondritis did not develop. Injury to the contralateral vocal cord can be avoided by ensuring that the laser beam is maintained perpendicular to the ventricle. As the ventricle is excised the laser should be discharged in short bursts to gradually ablate the full thickness of the ventricle. Once the caudal portion of the mucous membrane is encountered short bursts of energy and traction on the grasping forceps will allow removal of the ventricle without delivering laser energy to the contralateral vocal cord. In 1 horse in the present study, the laser burn of the contralateral vocal cord was healed by day 21.

Use of the Nd:YAG laser in a noncontact fashion leaves a smaller margin of error, compared with use in a contact fashion.2,3,6 When the laser is used in a noncontact fashion, more thermal injury is transferred to the surgical site and adjacent tissues at higher power settings.2,3,6,7 The result is increased latent necrosis of lased tissues secondary to scatter of laser light into underlying tissue.2,3,6 In the study reported here, more energy was used, compared with previous studies7 in which <4,000 J of energy was used.4,5 However, the goal of these previous studies was to ablate or Blanch the ventricular tissue and not completely remove it.3,5 The goal of the present study was different, and the technique was designed to completely remove the laryngeal ventricle and photovaporize the vocal cord, requiring more energy. Therefore, some of the complications reported in this study could be the direct result of prolonged energy delivery to the lased tissues.

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