Case Report

Treatment of traumatic tracheal collapse with extraluminal titanium mesh screens

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Summary

A 12-year-old Thoroughbred gelding presented with a history of exercise intolerance and inspiratory stridor. Physical examination revealed a blunt crush injury to the ventral neck and underlying trachea of unknown duration. Tracheoscopy revealed a grade 3 tracheal collapse. Surgical management of the case involved placement of extraluminal titanium mesh screens circumferentially around the trachea for complete support. During the period of hospitalisation, the only post operative complication was seroma formation, which resolved with routine care. Follow-up after 5 years revealed no further evidence of exercise intolerance, inspiratory dyspnoea or stridor. The horse returned to his previous level of work as a show hunter.

Introduction

Traumatic injuries of the trachea are uncommon in horses but include incomplete or complete crush/rupture of the trachea from lacerations, kick injuries or collisions with fences. However, the most common cause of traumatic tracheal injury is secondary to stenosis from inadvertent damage to rings following a tracheostomy (Siger et al. 1998). Tracheal collapse in horses occurs most commonly as a result of direct trauma, with cranial and mid-cervical portions of the trachea being most susceptible, owing to its superficial location (Tetens et al. 2000). Tracheal collapse is a relatively uncommon disorder in horses, although Miniature Horses and ponies may have an increased incidence due to miniaturisation and tracheal cartilage deformations (Freeman 2005). Collapsing trachea is a common disorder in middle-aged toy and miniature dogs with a controversial and multifactorial aetiology (Motitz et al. 2004). Tracheal crush injuries can affect the normal function of the trachea through penetration and/or disruption of the tracheal layers. The wall of the trachea is composed of 4 layers: mucosa, submucosa, the musculocartilaginous layer and adventitia.

Blunt-force trauma can cause separation of the trachealis muscle from its usual attachments to the tracheal rings or may cause fracture of tracheal ring(s) (Collins and Dixon 2009). Either insult can result in a reduction in tracheal diameter if the affected rings heal in misalignment (Gronvold et al. 2005; Collins and Dixon 2009). Blunt trauma can exaggerate the normal dorsoventral flattening of the trachea. This can result in increased shear stress dorsolaterally at the junction of the cartilaginous rings and the trachealis muscle dorsally or in increased tension of the dorsal structures with resultant ventral compression (Trastle et al. 1995). Tracheal perforation following blunt-force impact to the mid cervical trachea is more commonly seen and has the added disadvantage of complications associated with subcutaneous emphysema (Collins and Dixon 2009).

Horses with primary tracheal obstructive disease may have varying degrees of exercise intolerance, increased respiratory effort, tachypnoea, dyspnoea, respiratory stridor and/or cough (Holcombe and Ducharme 2004; Wong et al. 2008). The clinical manifestation of tracheal collapse varies depending on the position and severity of airway narrowing (Couetil et al. 2004; Aleman et al. 2008). Resistance to airflow through the trachea is inversely proportional to the fourth power of its radius; a 50% decrease in tracheal diameter would result in a 16-fold increase in resistance (Couetil et al. 2004; Aleman et al. 2008). Resistance to airflow through the trachea is inversely proportional to the fourth power of its radius; a 50% decrease in tracheal diameter would result in a 16-fold increase in resistance (Couetil et al. 2004; Aleman et al. 2008).

Dorsoventral tracheal collapse is typically caused by a dorsoventrally flattened or deformed cartilaginous ring(s). The reduced dorsoventral distance is further decreased by...
exercise intolerance and dyspnoea. Physical examination revealed a 5 × 5 cm concave defect in the horse’s ventral mid cervical region overlying the trachea. There were no open wounds noted and no subcutaneous oedema. Digital palpation revealed moderate sensitivity and a cough was easily elicited. Remaining physical examination findings were unremarkable. Tracheoscopy was performed and revealed an intact tracheal mucosa with a moderate (grade 3) dorsoventral collapse noted on inspiration approximately 10 cm in length located within the mid cervical trachea (no picture was taken of the initial tracheoscopy). A traumatic tracheal crush injury, of unknown duration, of the mid cervical trachea was diagnosed. Surgical repair of the collapsing trachea was advised.

**Surgical procedure**

On admittance to the hospital the horse was bright and alert with normal physical examination findings. Results of a preoperative CBC were within normal limits. An indwelling i.v. catheter was placed and the horse was administered flunixin meglumine (1.1 mg/kg bwt, i.v.), gentamicin (6.6 mg/kg bwt, i.v.) and cefazolin (20 mg/kg bwt, i.v.). The horse was premedicated with xylazine (0.4 mg/kg bwt, i.v.) and butorphanol (0.2 mg/kg bwt, i.v.). General anaesthesia was induced with ketamine (1 mg/kg bwt, i.v.) and diazepam (0.02 mg/kg bwt, i.v.) and maintained, via a 26 mm orotracheal tube, with isoflurane.

The horse was positioned in dorsal recumbency. The middle third of the cervical trachea was exposed via a 20 cm ventral midline incision. The sternothyrohyoideus muscles were divided, exposing the trachea and the surrounding fascia. The peritracheal fascia was bluntly dissected providing mobilisation of the trachea. Haemorrhage was controlled with electrocautery. The ventral aspect of the trachea was exposed and 6 unstable mid-cervical tracheal rings were identified by palpation to have an avulsed tracheal muscle and incomplete cartilage ring fractures/microfractures, causing disruption to the underlying mucosal attachments. The damaged rings were bluntly freed circumferentially from the surrounding tissues allowing visualisation and manipulation of the dorsal tracheal surface. Recurrent laryngeal nerves were identified and protected during blunt dissection. Periodic intraoperative tracheoscopy, through the orotracheal tube, which was cranial to the surgical site, revealed that manipulation of the damaged rings resulted in mucosal instability and a narrowing of the tracheal lumen from dorsal to ventral. Repair was achieved by placing two 1.3 mm diameter titanium mesh screens (100 × 100 mm) around the trachea, one screen on each lateral wall with the sheets abutting ventrally and overlapping by approximately 50 mm dorsally ([Fig 1](#)). The titanium mesh was conformed around the trachea and sutured to the tracheal rings using 2-0 monofilament stainless steel (suture choice of the surgeon). Sutures were placed dorsolaterally

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excessive dorsoventral movement of an elongated and weak dorsal tracheal ligament (Collins and Dixon 2009).

In dogs and horses, the site and extent of tracheal lesions can be determined by palpation, auscultation, radiography and endoscopy (Tate et al. 1998; Hedlund 1991; Siger et al. 1998). Palpation may reveal a dorsoventrally flattened trachea and may also elicit paroxysms of a characteristic cough. Auscultation of the trachea may magnify harsh, moist or wheezing tracheal sounds. Lateral radiographs, taken during both maximal inhalation and exhalation to demonstrate tracheal collapse, may not be diagnostic in all cases. Tracheoscopy is the most reliable way to diagnose tracheal collapse. It is invaluable in identifying the location of stenotic lesions and eliminating the upper respiratory tract as a source of noise, exercise intolerance and dyspnoea (Siger et al. 1998).

A well established grading system for tracheal collapse, based on endoscopic and/or pathological examination, was described for use in dogs (Tanger and Hobson 1982). This grading scale can apply to tracheal collapse and stenosis in horses and is as follows: grade 1 = the trachea is near normal with minor protrusion of the trachealis muscle into the lumen with <25% reduction of airway diameter; grade 2 = the trachealis muscle is widened and pendulous with mild flattening of the tracheal rings with 50% reduction of the airway diameter; grade 3 = the trachealis muscle is lengthened and is nearly in contact with the markedly flattened tracheal rings with 75% reduction of the airway diameter; grade 4 = severe flattening of the tracheal rings, which may invert dorsally with <10% airway diameter (Tanger and Hobson 1982; Hedlund 1991; Aleman et al. 2008).

Treatment of tracheal stenosis or collapse in dogs and horses depends on the aetiological factors, length of the lesion and accessibility of the affected trachea (Yovich and Stashak 1984; Siger et al. 1998; Tetens et al. 2000; Stlick 2006; Sun et al. 2008). Several surgical techniques have been advocated to treat tracheal collapse in dogs and horses. They include chondrotomy, plication of the dorsal membrane, resection and anastomosis, tracheostomy and application of various intraluminal or extraluminal prostheses (Ayres and Holmberg 1999; Tetens et al. 2000; Couetil et al. 2004; Payne et al. 2006).

The purpose of this report is to review the clinical features, describe the surgical correction, post operative and long-term follow-up of a traumatically collapsed trachea corrected with a novel extraluminal support.
on each side and ventrally (using deep and wide bites) through the body of the cartilage. Dorsolaterally placed sutures attempted to incorporate the trachealis muscle, the number of sutures placed in the muscle depended upon its extent and laxity. Intraoperative tracheoscopy, through the orotracheal tube, ensured that the mucosa was not penetrated during suture placement. One normal/intact tracheal ring proximal and distal to the defect was included in the repair. Prior to closing the sternothyrohyoideus muscles, fenestrated tubing was placed adjacent to the trachea and exited ventrally through a stab incision separate from the skin incision. The incision was closed routinely and a stent bandage was sutured in place over the incision. The horse recovered from general anaesthesia uneventfully and without assistance. After recovery, a continuous suction drain was removed 48 h post operatively with no drainage noted. One week post surgery, a moderate inspiratory stridor was present only if the horse was excited or exercised mildly (trotted in hand) but no dyspnoea was noted. A seroma developed 6 days post operatively, which was drained following an aseptic scrub and stab incision. A culture of the drainage was performed. No aerobic or anaerobic growth was obtained on culture. A sterile pressure bandage was maintained over the surgical site and changed daily for 2 weeks post operatively. Intravenous antibiotics were discontinued 11 days post operatively and oral sulphonamethoxazole-trimetoprim (24 mg/kg bw t, per os, q. 12 h) was begun and continued for one month. The swelling over the surgery site gradually resolved as did the inspiratory stridor. The horse was discharged from the hospital 5 weeks post operatively and started on small paddock turnout one week later. At discharge there was no noticeable inspiratory stridor at rest or when the horse was excited. Mid cervical spine radiographs taken prior to discharge revealed no displacement of the titanium mesh and a mild narrowing of the trachea for the length of the extraluminal support. The narrowest tracheal luminal width at the site of implant measured 23 mm (Fig 2).

Post operative care

Post operatively the horse was maintained on flunixin meglumine (1.1 mg/kg bw t, i.v., q. 12 h), gentamicin [6.6 mg/kg bw t, i.v., q. 24 h] and cefazolin (20 mg/kg bw t, i.v., q. 8 h). The continuous suction drain was removed 48 h post operatively with no drainage noted. One week post surgery, a moderate inspiratory stridor was present only if the horse was excited or exercised mildly (trotted in hand) but no dyspnoea was noted. A seroma developed 6 days post operatively, which was drained following an aseptic scrub and stab incision. A culture of the drainage was performed. No aerobic or anaerobic growth was obtained on culture. A sterile pressure bandage was maintained over the surgical site and changed daily for 2 weeks post operatively. Intravenous antibiotics were discontinued 11 days post operatively and oral sulphonamethoxazole-trimetoprim (24 mg/kg bw t, per os, q. 12 h) was begun and continued for one month. The swelling over the surgery site gradually resolved as did the inspiratory stridor. The horse was discharged from the hospital 5 weeks post operatively and started on small paddock turnout one week later. At discharge there was no noticeable inspiratory stridor at rest or when the horse was excited. Mid cervical spine radiographs taken prior to discharge revealed no displacement of the titanium mesh and a mild narrowing of the trachea for the length of the extraluminal support. The narrowest tracheal luminal width at the site of implant measured 23 mm (Fig 2).

Long-term follow-up

The horse returned to the hospital 9 weeks post operatively for re-evaluation. When exercised on the lunge line there was an estimated 80% improvement in the inspiratory stridor, subjectively based on a decreased resonance, with no obvious exercise intolerance. On endoscopic evaluation a mild/moderate (grade 2) stenosis with a rigid...
Plica was noted in the left lateral aspect of the trachea that did not fluctuate with respiration. Since the horse had improved clinically and the plica was rigid, no changes were made in the exercise regimen that affected the horse’s return to light regular work.

The horse returned to the hospital approximately 3 years later for treatment of a hoof injury. A tracheoscopy was performed prior to induction of general anaesthesia and intubation for delivery of inhalant anaesthetic. Findings included a mild (grade 1) stenosis of the trachea with stainless steel sutures visible through but not perforating the tracheal mucosa (Fig 3). Overall, the horse was doing well at this time and had no clinical respiratory abnormalities. A grade 1 tracheal stenosis was an acceptable outcome to the extraluminal stent procedure, considering that the horse was clinically normal.

A 5 year follow-up revealed that the horse had resumed his regular work level (show hunter) with no appreciable noise and an acceptable cosmetic appearance of the surgery site (Fig 4). For the purposes of this report, radiographs were taken and an upper airway endoscopy was performed. Radiographic findings included mild disruption of the titanium mesh in 3 places. The diameter of the tracheal lumen at the site of injury also measured 13 mm wider when compared to measurements taken in the post operative period following titanium mesh placement (Fig 5). Tracheoscopy findings included perforation of the stainless steel sutures through the mucosa in several places and one granuloma noted at the cranial-most extent of the extraluminal titanium mesh (Fig 6). Also, a mild (grade 1) stenosis of the trachea was noted at a distance measuring from 70–78 cm caudal from the nares. Perforation of the mucosa is not ideal but again the horse was clinically normal, therefore it was elected to continue monitoring the horse and perform periodic follow-up tracheoscopies. Upper airway endoscopic evaluation revealed no laryngeal dysfunction that could be associated with possible recurrent laryngeal nerve irritation from the extraluminal support.

**Discussion**

Tracheal collapse, extra- and intrathoracic, is an uncommon disorder reported in horses, but when present can be a challenge to correct. In dogs, indications for surgical corrections are recommended if they are refractory to medical management alone and have a grade 2–4 collapse [Payne et al. 2006]. The goal for treatment of tracheal collapse and/or stenosis is to increase the airway size sufficiently by restoring the normal oval to round tracheal lumen thereby normalising airflow to the lungs [Siger et al. 1998; Couetil et al. 2004]. This goal
is achieved by supporting the weakened or damaged cartilages from collapsing against normal airway pressures. Several surgical procedures have been developed to correct tracheal collapse in the dog and horse, all with variable success. Some of the treatment options include: chondrotomy, resection and anastomosis, plication of the trachealis muscle and application of many types of intra- and extraluminal prostheses (Couetil et al. 2004; Payne et al. 2006; Stick 2006). Many of these techniques have been unsuccessful, in both dogs and horses, because they either narrowed or failed to restore tracheal diameter, failed to support the tracheal cartilages or dorsal membrane, interfered with the mucociliary apparatus or interfered with tracheal flexibility (Gellasch et al. 2002; Freeman 2005; Wong et al. 2008). The use of intraluminal stents avoids invasive surgical procedures but has been reported in horses to have various complications, the most persistent and problematic being exuberant granulation tissue formation at the site of stenting and interruption of the mucociliary apparatus (Couetil et al. 2004; Wong et al. 2008). Currently, the diameter of commercially available stents is only large enough for miniature horses or foals making this option nonviable in this case (Wong et al. 2008). Resection and anastomosis, reserved for involvement of 5 or fewer tracheal rings, was also not an option in this case due to the large number of rings (6) involved in the tracheal collapse (Tate et al. 1981; Siger et al. 1998). Plication of the trachealis muscle would not have corrected the tracheal collapse in this case as the muscle was avulsed from the tracheal cartilages.

Application of extraluminal prostheses have been the only surgical procedures that have resulted in repeatable, long-term success in dogs and horses (White 1995; Freeman 2005). In this case, extraluminal support was the surgical treatment of choice whereby restoring a functional tracheal diameter without affecting the mucosal ciliary apparatus and providing rigid support for the tracheal wall (Stick 2006). Polypropylene prosthetic rings have commonly been the surgical technique of choice to provide external support to deformed tracheal rings because polypropylene is an inert, relatively flexible material (Siger et al. 1998; Freeman 2005; Stick 2006). Failures with these polypropylene extraluminal supports can be attributed to infection, adjacent soft tissue damage from movement against an unyielding implant, or damage to adjacent nerves (Siger et al. 1998; Freeman 2005). These prostheses, although flexible, are still relatively stiff and therefore placement can still be difficult such as breaking when placed, as they require predrilled holes (Ayres and Holmberg 1999; Freeman 2005). In mature horses, finding polypropylene rings may have a size restriction for diameter. Reports describe cutting a polypropylene syringe case longitudinally and drilling many small holes in to it (Yovich and Stashak 1984; Robertson and Spurlock 1986; Freeman 2005). This would have acted as a splint and would not have given the circumferential support needed in this case. It has been proposed in dogs that the stiff conformation of the ‘C’ shaped ring prevents the prosthesis from conforming to the trachea. Due to the lack of consistent contact, there could be areas of focal pressure with secondary tracheal necrosis (Ayres and Holmberg 1999). In this case, polypropylene extraluminal prosthetic rings had a potential limitation in that they lacked circumferential reinforcement to the trachealis muscle avulsions dorsally and the incomplete fractured tracheal rings laterally.

In the reported case, a unique type of extraluminal support not previously reported in dogs or horses was utilised. Titanium mesh screens are utilised in man for reconstructive procedures of the craniofacial skeleton and orthognathic surgery of the maxilla and chin. These devices are used in nonloading areas that are not subject to extreme muscle forces. There are 2 types of titanium mesh screens, rigid (1.5 mm thickness) and flexible (1.3 mm thickness). Since this is a human product still under patent, titanium mesh stiffness calculations cannot currently be released. Two 1.3 mm flexible titanium mesh screens were utilised to span the tracheal defect and provide stiff support circumferentially with uniform contact to minimise areas of focal pressure. The stiff support could be reinforced dorsally, where the mesh screens overlapped, as this is where the trachealis muscle was avulsed and the trachea needed the most support. The authors believe that the flexible mesh screens allow for increased tracheal flexibility when spanning multiple annular ligaments compared to the polypropylene prostheses. The titanium mesh screens also are less likely to break or kink due to their inherent flexibility, whereas breaking of the polypropylene prostheses can be of concern especially once secured to the trachea. Also, no predrilled holes, which increase the likelihood of the polypropylene breaking, were needed due to the mesh architecture. Although the horse in the reported case was reluctant to bend his neck immediately post operatively, this was probably associated with the application of the stainless steel prosthesis which is thought to interfere with the mucociliary apparatus (black arrow).

![Image](https://example.com/image.png)

Fig 6: Five year follow-up tracheoscopy, mild tracheal stenosis present. Incidental findings include perforation of the stainless steel through the tracheal mucosa (black arrow).
surgical procedure itself and not the implant. Soon after surgery the horse was freely able to move his neck normally, as well as years later. The mesh screens are made of commercially pure titanium which is a very biocompatible material, further limiting the concern of infection (Paquay et al. 1997). Overall, healing process to the titanium mesh is very similar to the regular sequence of events in all connective tissue wound healing processes (Paquay et al. 1997). The major concern in using this extraluminal metal device is that metal within a living tissue is prone to corrosion. However, titanium is a reactive metal that spontaneously forms an insulating oxide film within the tissues, which becomes a potent barrier against dissolution of the metal (Steinemann 1996). Since the metal is highly biocompatible there is little foreign body reaction, little inflammation and hence decreased susceptibility to infection. There was also the concern of the probability of a similar blunt-force trauma, simply due to the superficial location of the mid-cervical trachea, occurring to the horse and causing an indentation in the titanium screen and therefore causing recurrent tracheal stenosis/ collapse. The implanted titanium mesh screens, used in this case, were well tolerated by the tissues and there was an acceptable cosmetic result.

Complications in this case were limited to the seroma that developed post operatively. The development of this seroma was not unexpected due to the blunt dissection and creation of dead space around the trachea. The fluid was cultured, since an implant was placed, but no growth was obtained. The area was maintained in a pressure wrap until its resolution. Avascularity of the trachea secondary to removal of surrounding tissue circumferentially over several tracheal rings for mobilisation is not of concern in horses because of extensive collateral blood supply (Tate et al. 1981; Kirker-Head and Jakob 1990; Siger et al. 1998); this is of concern in dogs and man as there is no evidence of collateral blood supply to the trachea (Kirby et al. 1991). An intermittent cough was evident post operatively and the inspiratory noise persisted for up to 2 weeks prior to resolution. This is not unusual due to tracheitis from tracheal manipulation, peri-tracheal swelling and mucosal irritation associated with suture placement. Dogs frequently cough as much or more during the first 2–3 weeks post operatively as preoperatively (Hedlund 1991; Coyne et al. 1993). It is also possible that the temporary inspiratory stridor following surgery could have been due to neurapraxia of the recurrent laryngeal nerve. No post operative endoscopy was performed so the occurrence of temporary laryngeal paralysis is unknown. The immediate level of improvement post operatively is also directly unknown, but an absence of linear correlation between tracheoscopy and histology has been reported in dogs, suggesting that tracheoscopy is not an accurate method of evaluating early or mild alterations in tracheal mucosal viability (Coyne et al. 1993).

Incidental findings at the 5 year follow-up examination revealed 3 radiographic areas of breakdown in the titanium mesh screens and several areas of mucosal perforation by the stainless steel sutures and one granuloma on the tracheoscopy. Mucosal perforations by the suture may have been avoided had a different suture material other than stainless steel been used. Mucosal perforations are of mild concern given the incidence of granulation tissue noted with intraluminal stenting in both dogs and horses (Payne et al. 2006; Wong et al. 2008). Once the granulation tissue forms, it is reported in the current literature to be difficult to eliminate (Couetil et al. 2004). Risks of infection, granuloma formation and mucosal ulceration increase if suture material enters the tracheal lumen (Freeman 2005). The tracheoscopy performed at the 3 year follow-up revealed no mucosal perforations of suture material. The development of these perforations noted on tracheoscopy, and also the breakdown of the mesh noted on radiographs by the 5 year follow-up may indicate some fatigue/breakdown of the sutures and/or the titanium mesh. Metal implants may undergo severe fretting corrosion at any metal-on-metal contact (Kraft et al. 2003). This fretting decreases fatigue strength of the metals. Due to the interactions that can happen between metals, it would be suggested in the future to avoid overlapping the titanium mesh screen implants, using it with stainless steel sutures, or other metal implants/sutures. It is the authors’ opinion that the use of 2 different metals led to the breakdown of the mesh more than the dorsally overlapped mesh screens. It is not uncommon to have fracture of metal intraluminal stents, but these stents are used in high motion areas of the trachea and the stents are prone to cyclical fatigue (Mittleman et al. 2004). These findings of mucosal perforation and titanium mesh breakdown were noted incidentally on follow-up examinations, it is important to note that despite these findings the horse has been continuing to function at his normal level of activity with no stridor or dyspnoea.

Radiographs taken during the immediate post operative period revealed residual mild tracheal narrowing and a tracheal width at its narrowest of 23 mm, with space noted radiographically between the edge of the soft tissue and the inner edge of the titanium mesh. Radiographs taken 5 years post operatively revealed that the trachea was no longer narrowed at the site of the implant and that the tracheal width at its narrowest is now approximately 36 mm. There is no magnification between these 2 sets of radiographs as evidenced by the consistent vertebral body measurements of 35 mm. It has been reported in the literature that radiographic tracheal height can be measured independent of respiratory phase in sedated horses (Carstens et al. 2009). This increase in tracheal height indicates that the titanium mesh screen and sutures placed dorsilaterally in the tracheal ligament aided fibrosis of the ligament to the titanium. It is likely that the titanium screens also provided a framework for the ligament to contract therefore returning the lumen to a normal diameter, consistent with the remainder of the cervical trachea. Chondrotomies are partial or full
thickness incisions that can be made if necessary across the width of each affected tracheal ring to allow reshaping (Freeman 2005). In this case, it is presumed that the incomplete/microfractures acted as partial chondrotomies allowing remodelling of the damaged rings, which were anchored to the prosthetic mesh.

In conclusion, the tracheal collapse caused by blunt-force trauma in this case, was successfully managed by placement of 2 extraluminal titanium mesh screens sutured circumferentially around the trachea. Evidence of functional repair included post operative endoscopic findings as well as the horse’s ability to return to his previous level of work with a 5 year follow-up of no inspiratory noise, exercise intolerance or stridor. Titanium mesh screens can successfully be used extraluminally to treat tracheal collapse by reinforcing the trachea circumferentially.

Manufacturer’s address

Synthes CMF, West Chester, Pennsylvania, USA.

References


563