The impact of automatic retractors on the esophagus during anterior cervical surgery: an experimental in vivo study in a sheep model

Laboratory investigation

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**Object.** Postoperative dysphagia is a well-recognized complication of the anterior surgical approach to the cervical spine. However, its incidence and etiology remain unknown. The aim of this study was to investigate the impact of automatic retractor use on the esophagus and to describe the related pathological changes that might occur during cervical spine surgery.

**Methods.** A single-level cervical discectomy was performed via an anterior approach in 16 skeletally mature female sheep. Continuous retraction was applied with an automatic retractor system during surgery. The sheep model was chosen because of anatomical similarities to the human esophagus. The esophageal tract in every animal was examined using contrast radiographic examination. Eight animals were killed 3 days after the operation (Group 1). The remaining sheep were killed 4 weeks after the operation (Group 2). The esophagi were removed for histopathological study, which was performed using H & E and Masson trichrome staining. The changes in esophageal innervation were examined with nicotinamide adenine dinucleotide diphosphate–diaphorase histochemical staining.

**Results.** Only 1 animal (a Group 1 sheep) demonstrated any postoperative radiographic abnormality. In Group 1 sheep, histopathological study of the esophagi at the treated level revealed edema between the muscular fibers in the outer longitudinal and inner circular layers of the muscularis propria. At some points, obvious signs of vascular congestion, vascular damage, and inflammation were observed. In the Group 2 animals, there was mild-to-moderate fibrosis extending from the outer surface of the esophagus to the longitudinal layers of the muscularis propria in the area to which retraction had been applied. Enzyme-histochemical staining revealed the presence of normal myenteric plexus and ganglion cells, and nitrergic innervation in all parts of the esophagus wall.

**Conclusions.** The results of this study demonstrate that direct pressure induced by the medial retractor blade on the esophagus wall leads to local injury. Postoperative dysphagia in human patients who have undergone anterior cervical spine surgery could be a clinical manifestation of this phenomenon. (DOI: 10.3171/2009.6.SPINE09216)

**KEY WORDS**  
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The anterior approach has become a preferred method in cervical spine interventions because of its efficiency and simplicity. Previous studies have described the potential complications of this surgery in the treated area as well as the adjacent structures. Postoperative dysphagia, however, has been rarely mentioned in these studies. There is wide disagreement as to the true incidence of dysphagia. In one prospective study, the incidence of early postoperative swallowing difficulty was reported to be 49.3%. Another prospective investigation found that 50.2, 32.2, 17.8, and 12.5% of patients had dysphagia at 1, 2, 6, and 12 months after surgery, respectively. Long-term studies reported prevalence rates ranging from 11 to 31.5% at the 5- to 11-year follow-up periods after anterior cervical discectomy and plating.

It is well known that external compression increases the interstitial hydrostatic pressure in muscle tissue, thereby disturbing the local blood flow. Heese et al. found that the pressure induced by automatic retraction...
exceeded the mean arterial pressure, reporting that the epiesophageal pressure was at least twice as high as the mucosal perfusion pressure during the anterior cervical approach. The reperfusion trauma following the removal of the automatic retractor may result in edema in the esophageal wall. Furthermore, the abnormally elevated pressure may damage the neural structures, connective tissue, and muscle fibers if the increased pressure lasts long enough. Thus, it would seem natural to expect that surgical retraction during anterior cervical surgery could alter postoperative esophageal motility.

In the present study, we investigated the structural and histopathological changes that might occur in the esophagus during anterior cervical microdiscectomy. We examined the esophageal wall in a sheep model after the retraction injury induced during the anterior cervical approach and microdiscectomy.

**Methods**

**Study Design and Surgical Procedure**

Sixteen skeletally mature female sheep were used in this study. Their mean age was 1.5 years, and their weight was 50–65 kg. A C4–5 discectomy was performed in all the animals, using an anterior approach. All the operations were performed by the same surgeon (H.Ç.) and were identical in each animal. The experimental protocol was approved by the local authorities and complied with standard criteria.

Each animal was preanesthetized with 0.4 mg/kg atropine, administered intramuscularly; anesthetized with 10 mg/kg ketamine and 0.5 mg/kg diazepam, administered intravenously; and placed supine on the surgical table. Isoflurane and intravenous fluids were administered throughout the surgery. All anesthesia procedures were performed by veterinary surgeons.

The animal’s head was placed in a neutral position with a towel roll under the neck, thus preserving the cervical lordosis. Plain radiographs were obtained in all animals before the operation to evaluate the intervertebral disc space and to direct the dissection and minimize tissue disruption. Each animal was shaved, prepared, and draped in a sterile manner. A left anterolateral approach to the cervical spine was made through a 3-cm longitudinal skin incision. After the areolar tissue between the carotid sheath and the tracheoesophageal bundle was separated by finger dissection down to the anterior surface of the vertebral bodies, the vertebral bodies and intervertebral discs were exposed. The longus colli muscles were stripped bilaterally. The C4–5 disc level was confirmed with radiological assistance.

An automatic retractor was used to retract the skin, trachea, esophagus, and longus colli muscle in all sheep. Smooth-edged retractor blades provided retraction in the superior-inferior directions. The edges of the retractor blades were placed bilaterally under the longus colli muscles. The opening width of the retractor blades was determined by the sheep anatomy. The blades were opened until the uncinate processes were exposed on both sides of the intervertebral disc space (Fig. 1). Continuous retraction was applied during surgery. Discectomies were performed using an operating microscope. Before closure, the surgical site was examined for bleeding, and hemostasis was attained in all animals. The wound was irrigated with normal saline, the subcutaneous tissues were closed with 2-0 absorbable sutures, and the skin incision was closed with 2-0 silk sutures. A 20-mg/kg dose of ceftriaxone was administered before the operation as a prophylactic antibiotic. Carprofen (2 mg/kg/day) was administered for 3 days for pain control.

The animals were allowed to recover and move freely and were fed regularly. Eight animals were killed after 3 days (Group 1) and the remaining 8 after 4 weeks (Group 2). All the animals were killed with an intravenous injection of sodium pentobarbital. The cervical esophagi were subsequently removed for evaluation.

**Esophageal Contrast Study**

Barium esophagography was performed in each animal immediately before it was killed. The esophagi were assessed using contrast radiographic examination, which is frequently used by veterinarians for evaluation of motility problems in the oropharyngeal and esophageal regions and is also useful for differentiation of functional from morphological causes of dysphagia. Four variables were investigated in studies: contrast penetration into the laryngeal aditus, soft-tissue swelling, contrast material stasis, and aspiration.

Survey radiographs were obtained immediately before the contrast examination and were used to assess the status of the esophagus and surrounding tissues. With the animal unsedated and in an upright position, lateral esophageal radiographs were obtained 0, 15, and 30 seconds following deglutition of a 60-ml barium bolus. A high-density liquid barium sulfate suspension (85% w/v) was used for esophagography because it is relatively safe when aspirated and readily flows through narrow spaces. All contrast radiographic examination procedures were performed by veterinary surgeons.

**Histopathological Analysis**

After macroscopic inspection, esophagi were divided into pieces 2 cm in length: the segments to which retraction was applied, the adjacent segments, and distant segments (2 or more vertebral levels away). Tissue samples were obtained in 3 different areas of each segment.

**Hematoxylin-and-Eosin Morphological Examination.** Full-thickness esophageal tissue specimens were taken from each segment of the esophagi. The tissue was fixed with 10% formaldehyde and embedded in paraffin wax. Sections were cut at a thickness of 3–4 µm. The tissue was stained with H & E and Masson trichrome and studied under a light microscope.

**Enzyme-Histochemical Morphological Examination.** Pieces of tissue measuring 3–4 mm in thickness were obtained from the identical areas of the esophagus and frozen at −38 to −40°C. Sections of 3–4 µm were cut with a cryostat and stained for NADPH-diaphorase, an enzymatic marker of the soma of ganglion cells, using...
Bio-Optica’s lyophilized Enzyme-Histochemical Diagnostic Kit (Product Code 30–50112). Sections were incubated in the staining medium for 30 minutes at 37°C then rinsed 3 times in distilled water. The sections were dehydrated in ascending concentrations of alcohol. The slides were cleared and mounted and examined with a light microscope.

**Results**

The median retractor application time, from insertion to removal of the automatic retractor, was 55 minutes (range 50–65 minutes). No complication occurred during the surgery. The surgical procedures were well tolerated, and all animals resumed normal activity within 24 hours of surgery.

**Radiographic Analysis**

Survey plain radiographs obtained immediately before contrast examination demonstrated the normal status of the esophagus and surrounding tissues. No changes were observed on these images. Following surgery, only 1 (12.5%) of 8 animals in Group 1 (Sheep 6) demonstrated radiographic evidence of a swallowing abnormality at 3 days after the operation (Fig. 2). The remaining 7 animals showed no contrast penetration into the laryngeal aditus, no evidence of soft tissue swelling, or contrast material stasis or aspiration. In all Group 2 animals, contrast radiographs obtained 4 weeks after surgery demonstrated the appearance of normal peristalsis.

We initially planned to perform preoperative barium esophagography to assess the esophageal structures. However, after it was performed in 2 animals, they stopped eating, developed acidosis, and finally died 2 days after the examination. The veterinary surgeons determined that barium was toxic for the microflora of the sheep rumen, and these 2 animals were not included in our study. We did not perform preoperative contrast radiographic examinations in any of our study animals, nor did we perform early postoperative barium esophagography in the Group 2 animals. Barium esophagography was performed in each animal immediately before it was killed. (This timing was chosen to prevent the possibility of barium-induced esophagitis.)

**Histopathological Analysis**

**Macroscopic Examination.** Gross examination of the areas of the esophagus to which retraction had been applied showed edema in Group 1 animals. In Group 2 animals there was no evidence of gross morphological changes (Fig. 3).

**Microscopic Analysis of H & E–Stained Specimens.** Specimens obtained from the parts of the esophagus to which retraction had been applied were examined. In Group 1, the specimens from the surgically treated level (C4–5) showed moderate-to-severe edema between the muscular fibers in the outer longitudinal layers and the inner circular layers of the muscularis propria. Focal areas showed obvious signs of vascular congestion, vascular damage (microhemorrhages), and inflammation (Fig. 4A–C). These findings were indicative of injury. The histopathological examination of the tissues sampled from the areas adjacent to the surgically treated level (C3–4, C5–6) demonstrated no or mild edema between the muscular fibers of the outer longitudinal layers. There was no evidence of congestion, microhemorrhages, or inflammation. Esophageal tissue was also sampled from areas 2 or more levels away from the surgically treated level, and these specimens appeared normal in both groups of animals.

In Group 2 animals, the areas of the esophagus to which retraction had been applied revealed mild-to-moderate fibrosis that extended up to the longitudinal layers of the muscularis propria from the outer surface of the esophagus. The degree of fibrosis was determined...
muscle fibers in the circular muscle layer (Fig. 4G–I). NADPH-diaphorase–positive nerve fibers between the other and to ganglion cells. There were large numbers of showed normal morphology of the myenteric plexus form same areas of the esophagi using NADPH-diaphorase second series of examinations was performed in all the

Discussion

Sheep cervical spines are frequently used as a model for human cervical spine research. Investigators have concluded that the sheep’s cervical spine is comparable to the human cervical spine.\(^{10,30,31}\) In this in vivo study, we examined the sheep esophagus because of its similarities to the human esophagus with respect to thickness and histological structure.\(^{20,22,34}\) We investigated the possible morphological, structural, and histopathological changes that may occur in the esophagus during and after anterior cervical spine surgery, with an emphasis on the potential for retraction injury during anterior cervical approach and discectomy.

The anterior approach to the cervical spine affords excellent exposure for anterior cervical discectomy and fusion. However, it requires retraction of the trachea and esophagus and tension on the musculature and nerves involved in swallowing. The incidence of postoperative dysphagia is uncertain. In several reports, the reported incidence after anterior cervical disc surgery varied from 4.1 to 67%.\(^{1,2,5,7,13,26,27,32,33}\) The etiology of this dysphagia remains speculative in most cases. Proposed causative mechanisms include direct surgical trauma, neuropraxia due to nerve traction, and postoperative edema.

One known cause of swallowing difficulty after the anterior approach to the cervical spine is vocal cord paresis.\(^ {2,16,18}\) Vocal cord paresis or paralysis is associated with transection or traction injury to the recurrent laryngeal nerve. But this is a rare cause of vocal cord paresis and is likely to occur only when significant retraction and consequent pressure occur during surgery. The incidence rate of recurrent laryngeal nerve injury after anterior cervical discectomy has been reported as 0.07–11%.\(^{2,16,18}\) The right recurrent laryngeal nerve innervates part of the upper esophageal sphincter and has been implicated in dysphagia because its course is longer than that of the left recurrent laryngeal nerve, potentially predisposing it to stretch injury.\(^{25}\)

The esophagus is a tubular organ composed of 3 lay-

ers (mucosa, submucosa, and muscularis propria) and is of similar structure throughout its whole length. Histologically, the wall of the pharynx/esophagus consists of a strong muscular portion, which is divided into a circular and a longitudinal layer. The physiologically narrowest area of the lumen of the pharynx/esophagus is behind the cricoid cartilage at the C5–6 level. The transitional zone between pharynx and esophagus is located at the C6–7 level.\(^ {21}\) In view of this anatomical structure, authors have investigated the effect of operative level on postoperative dysphagia. Tortolani et al.\(^ {28}\) measured the intraesophageal pressure secondary to retraction during anterior instrumentation in a cadaveric study. They investigated the effects of surgical level on pressure during retraction. Although they observed greater esophageal pressures during surgical treatment of the lower cervical spine, Bazaz et al.\(^ {2}\) reported no correlation between the vertebral level treated and the postoperative development of dysphagia in a prospective series of 249 consecutive patients who underwent anterior cervical spine surgery. Frempong-Boadu et al.\(^ {2}\) reported early-postoperative swallowing abnormalities documented by modified barium swallow in 67% of patients. These authors also found no correlation between swallowing and spinal level treated. Similarly, retrospective analyses demonstrated no correlation between operative level and the risk of postoperative dysphagia.\(^ {13,26}\)

Our study is distinct because it is focused exclusively
on the effects of retraction on the esophagus during anterior cervical discectomy. We performed simple disectomies because we wanted to minimize the disruption of adjacent structures. Thus, the observed pathological esophageal changes were attributed to the use of the automatic retractor and could be directly linked to the continuous pressure during retraction of the esophagus. Plain radiographs were obtained in all sheep before the operation to evaluate the intervertebral disc space and to direct the dissection and minimize tissue disruption. The opening width of the retractor blades was determined by the sheep anatomy; the blades were opened until the uncinate processes were exposed on both sides of the intervertebral disc space. We must emphasize that, in this experiment, we followed the exact same surgical procedures as are followed in the treatment of human patients.

Injury to the muscular portion of the esophagus can lead to a disturbance of peristalsis and disrupt the propulsion of swallowed materials to the stomach. Heese et al. measured the pressure induced by retractor blades onto the pharynx/esophagus intraoperatively to gain more information regarding traumatization of the pharynx/esophagus wall. In 45% of their patients the epiesophageal pressure reached or even exceeded the mean arterial blood pressure during anterior cervical discectomy and fusion. Without any exception the epiesophageal pressure was higher than the mucosal perfusion pressure of 25 mm Hg. The authors hypothesized that direct pressure induced by the medial retractor blade on pharynx/esophagus mucosal wall leads to local ischemia. To test their hypothesis, they measured local blood flow inside the pharynx/esophagus wall during anterior cervical surgery. In all patients, the open retractor led to hypoperfusion ranging from 21 to 93% of the baseline level of perfusion. They detected a remarkable reactive hyperemia at the end of the procedure in 46% of their patients. They concluded that local ischemia of the pharynx/esophagus wall may be the crucial step in the development of postoperative dysphagia due to reactive hyperemia and edema. In our study, histopathological examination of esophagi at the level of the treated segment demonstrated edema, congestion, inflammation, and microhemorrhages indicative of injury. These findings suggest the possibility of dysphagia in the early postoperative period. The areas of the sheeps’ esophagi to which retraction was applied also exhibited varying degrees of fibrosis and degeneration of muscle fibers, suggesting the possibility of a myopathic process that may cause dysphagia in the late postoperative period.

Peristalsis in the smooth muscle esophagus is coordinated centrally at the level of the dorsal motor nucleus of the vagus nerve and peripherally at the level of the myenteric plexus. Swallow-induced peristalsis in the smooth muscle esophagus is initiated by the dorsal motor nucleus, but its timing and the force of peristaltic contraction are determined by myenteric neuromuscular interactions. The major neurotransmitters that control the timing and amplitude of the peristaltic sequence are acetylcholine, an excitatory neurotransmitter, and nitric oxide, an inhibitory neurotransmitter. It is likely that their integrated effects produce normal peristalsis. There is a direct correlation between the degree of inhibition and the velocity of peristalsis: less inhibition is associated with more rapid peristalsis. High-amplitude contractions may provoke chest pain or dysphagia, that is, diffuse spasm. Injury of the intrinsic neuromuscular system of the esophagus can also lead to a derangement of peristalsis and disrupt the propulsion of swallowed materials to the stomach. Our enzyme-histochemical morphological findings indicated that neuronal networks in the esophagi were not damaged by retraction. There were abundant NADPH-diaphorase-reactive cells in the smooth-muscle parts of the esophagus. The ability of the smooth muscle to relax and regulate normal peristalsis in the esophageal body and the relaxation of the lower esophageal sphincter were demonstrated by the existence of myenteric plexus and ganglion cells and nitrergic innervation in all parts of the esophageal wall.

In our study, sheep were evaluated for preoperative dysphagia by examination for clinical signs under the su-
Positive clinical signs of dysphagia, including the throat clear, reflexive cough after swallow, and “wet voice” (liquid audible in laryngeal area on phonation after the swallow), were absent in all animals preoperatively. We could not perform an objective evaluation of swallowing before surgery due to the toxic effects of barium; however, as these were 1.5-year-old previously healthy sheep, it is reasonable to assume they had normal swallowing prior to the experiment. There are several diagnostic methods that can be used to evaluate esophageal function. The barium swallow study is commonly used as the initial evaluative test for patients with dysphagia, primarily to provide a roadmap prior to an upper endoscopy. The modified barium swallow study allows the detection of dysfunction or the inability to initiate the pharyngeal portion of the swallowing process, aspiration, nasal regurgitation, obstruction to the barium flow, and the presence of a residual bolus in the pharynx after swallowing. Fiberoptic endoscopic evaluation of swallowing provides detailed information regarding the pharyngeal stage of swallowing and allows the assessment of whether a patient aspirates oral/pharyngeal secretions, food, or liquid. Upper gastrointestinal endoscopy is the gold standard for diagnosing important anatomical lesions that can lead to dysphagia. Esophageal manometry evaluates esophageal motor pattern, contraction amplitude, and lower esophageal sphincter pressure and function.

It is possible that dysphagia may be caused by a number of local or systemic disorders (examples include a large anterior osteophyte, a pharyngeal mass, diabetes...
mellitus, thyroid disease, lupus erythematosus, dermatomyositis, cerebrovascular disease, motor neuron disease, myopathies, and psychiatric disorders). Patients may have subclinical swallowing abnormalities as a result of such conditions. Therefore, there is an important role for pre-surgical otolaryngological evaluation to investigate various causes of potential dysphagia. In addition, more attention should be given to patients scheduled to undergo anterior cervical surgery to better educate them about the possibilities of postoperative swallowing difficulties as well as to look for factors that may worsen clinical outcomes. Dysphagia can have a substantial impact on patients’ quality of life. It can be associated with significant complications, such as aspiration pneumonia, weight loss, and malnutrition. If it is necessary to treat patients with significant dysphagia that predisposes them to increased risk of aspiration, they should be under the care of a speech pathologist or an otolaryngologist following surgery. Treatment measures should include diet modification, postural changes during swallowing, and/or throat clearing. If aspiration of all liquids and solid food boluses is observed during the modified barium swallow study or fiberoptic endoscopic evaluation, it must be recommended that these patients abstain from any oral intake by mouth. A feeding tube should be used until the risk of aspiration resolves.

Conclusions

The histopathological results presented here clearly demonstrate that direct pressure induced by the medial retractor blade on the esophagus wall leads to edema, congestion, inflammation, and microhemorrhages, which lead to fibrosis. Postoperative dysphagia could be the clinical manifestation of this cascade, although further research is needed to establish whether duration has an effect on the degree of damage and to assess the effect of this damage in terms of postoperative outcome. Further work is also required to investigate alternative retractor designs and use with a view to reducing such damage.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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