Minimally invasive video-assisted cervical ventral slot in dogs
A cadaveric study and report of 10 clinical cases

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Introduction
Cervical disk herniation accounts for up to 44% of disk extrusions in dogs (1). Disk herniations causing neurological deficits or cervical pain, and which are non-responsive to medical treatment, require decompressive surgery. The standard procedure for cervical spinal cord decompression in the case of a disk herniation is a ventral slot (VS), which usually results in a favourable outcome (2). However, complications such as perioperative haemorrhage from venous sinus laceration, postoperative cervical swelling, seroma formation, and wound infection have been reported (3–5). Moreover, the small, narrow, and deeply located surgical field where the decompression procedure is performed makes VS a challenging procedure, especially in small dogs, and during the final steps of the procedure.

In humans, minimally invasive spinal surgery techniques are now routinely performed, with a significant reduction of complication rates, postoperative pain and discomfort, in comparison to conventional surgical procedures (6). The use of surgical microscopes, binocular loups, or video-assisted techniques allows excellent visualisation of the surgical target, despite the depth and narrowness of the surgical field. Although minimally invasive video-assisted (MIVA) spinal cord decompression techniques have already been performed in the lumbar and lumbo-sacral regions in dogs, experiences in the cervical region are still lacking (7, 8).

The Destandau Endospine™ device (DED) was designed for the endoscopic treatment of lumbar disk herniation in humans and has previously been used in veterinary surgery only on horses with chronic back pain for resection of the dorsal spinous processes (9–12). In humans, decompressive procedures with the DED are regularly performed under fluoroscopic guidance, thus allowing the surgeon to securely navigate to the correct surgical site and perform the entire procedure endoscopically. However fluoroscopic guidance is not routinely available in the veterinary operating room, nor was it available at our institution. We therefore considered that the DED might be advantageous for performing VS in dogs, but its usefulness should be investigated without fluoroscopic guidance. To this end, we first evaluated the feasibility of a minimally invasive approach and MIVA- VS using the DED without fluoroscopy in a...
cadaveric study. The main goals of this part of the study were: (i) to assess the reliability of the approach to the targeted intervertebral disk space (IVDS) without the use of fluoroscopy, solely using classic anatomical landmarks and palpation, (ii) to identify possible iatrogenic damage during the minimally invasive approach or drilling procedure, and (iii) to gain experience before initiating a clinical study. The technique was then applied in 10 consecutive clinical cases. The main goal of this latter part of the study was to describe the technique in a clinical setting, without aiming to compare the MIVA-VS to other techniques.

Materials and methods

Equipment

We used the commercially available DED surgical set (12). The DED provides continuous triangulation for the endoscope and two operating channels. One channel was used for the suction cannula, while the other channel, which is the larger of the two, accommodated the burr or hand instruments (Fig. 1). Endoscopic instrumentation included a 4 mm zero-degree telescope, a cold light source, and a digital single chip camera. Drilling was performed with an angulated drill hand piece connected to an electric high-speed motor system.

Cadaveric study

Cadavers

Entire frozen cadavers of eight dogs with a mean body weight of 20 ± 13 kg, (range: 4 to 40 kg) were used in the study (Supplementary Table 1 - available online at www.vcot-online.com). The dogs were euthanized at the National Veterinary School of Alfort for reasons unrelated to this study. They were all free of any cervical pathology, which was assessed by anatomical dissection at the end of the procedures. Cadavers were stored frozen at −20°C. Experiments were performed 24 hours after thawing of cadavers at room temperature.

Surgical approaches

The cadavers (n = 8) were positioned in dorsal recumbency as described for the ventral approach of the cervical spine (13). Briefly, the forelimbs were tied back and the maxilla and sternum were taped to the table, taking care to maintain the cervical spine in a straight position. Draping was performed as it would be for surgery to mimic visual landmarks that are available in a clinical situation.

To maximise cadaver use on the one hand, and to be as close as possible to the clinical situation on the other hand, two approach trials were performed on two non-contiguous IVDS on each cadaver. In the first six cadavers, cervical vertebra (C) 2-C3 was the primary targeted IVDS with the subsequent trials performed on C4-C5 or C5-C6. In the last two cadavers, targeting was performed so that all IVDS were approached at least once (see Supplementary Table 1, available online at www.vcot-online.com). In a pilot study in which we dissected several cadavers, we defined the following landmarks for skin incisions: (i) the caudal border of the larynx for C2-C3, (ii) mid-distance between the larynx and sternum for C3-C4 and C4-C5, and (iii) a point that was 2 to 3 cm proximal to the sternum for C5-C6 and C6-C7. To allow pinpointing by palpation only of the targeted IVDS, the following landmarks were also used: (i) the prominent ventral tubercle of C1, (ii) the ventral process of each vertebral body from C1 to C7, (iii) the large transverse processes of C6, and (iv) the proximal portion of the first rib. For each approach, a 2.5 to 5 cm (depending on the dog’s size) paramedian ventral skin incision was performed and centred over the target IVDS. In order to minimise iatrogenic trauma, the dissection was performed by passing between the sternocleidomastoideus and sternohyoid muscles rather than by dividing the sternocleidomastoideus muscle. Subsequent dissection was performed as described in the conventional midline approach to the ventral cervical spine, but limited to a single IVDS (2, 13). Once the IVDS was identified solely by palpation of the mentioned landmarks (Fig. 2), the longus colli muscles were elevated (over a single IVDS) and retracted with two small Gelpi retractors.

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Four trials of MIVA-VS in the last two cadavers were performed. Once the longus colli muscles were elevated, the DED was introduced (Fig. 2). We aimed to see the whole VS window in the endoscopic field of view. Therefore the nerve root retractor, which offered a long range of adjustment possibilities, was used to elevate the device above the VS. It was applied to the ventral cortex of the vertebral body to sustain the weight of the device and to provide the stand back distance necessary to view the whole VS window. Video-assisted drilling was performed with 2 to 4 mm burrs (Fig. 3). Once the vertebral canal was entered, neuro-surgical instruments were inserted through the working channel to remove the dorsal longitudinal ligament and to explore the epidural space under video assistance (Fig. 3). The procedure was considered completed when the spinal cord was visible along the whole VS window.

Assessment of the technique

Complications encountered during the approach or VS were recorded. For the VS, subjective quality of visibility was graded independently by two surgeons as improved, equal or inferior to the standard technique. The lengths of skin incisions were measured. Spines were then carefully dissected to check that the correct IVDS were exposed and if there was any iatrogenic damage. To this purpose, we evaluated the presence of lesions to any of the structures encountered during the approach (mainly the trachea, oesophagus, vagosympathic trunks, laryngeal recurrent nerves, carotid arteries and jugular veins) or within the spinal canal (mainly the venous sinus and spinal cord).

Clinical study

Animals

Ten consecutive client-owned dogs suspected of having a Hansen type 1 cervical disk extrusion and requiring a VS were included in the study (Supplementary Table 2, available online at www.vcot-online.com). There were not any exclusions based on signalment, but dogs suspected of a Hansen type 2 disk herniation or in need of a vertebral stabilisation were excluded (one case each).

Anaesthesia

After premedication with midazolam (0.2 mg/kg) and morphine (0.2 mg/kg), anaesthesia was induced using propofol (titrated to effect) and maintained with 1.5 to 2% isoflurane in oxygen. Cephalexin (30 mg/kg, IV) was administered to all dogs as antimicrobial prophylaxis at the time of induction. None of the dogs required mechanical ventilation after the procedure.

Surgical procedure

The surgical procedure was performed by the same team (DL, VV) for all dogs. Based on the results and experience acquired in the cadaveric study, we applied the following modifications to the surgical technique: (i) a midline approach was performed instead of the paramedian approach, and (ii) the ventral cortex and cancellous bone was drilled without video assistance. The DED was only used for drilling the dorsal cortex of the vertebrae and for disk curettage (Fig. 3).

Postoperative care

Analgesia was provided through the administration of morphine HCl (0.1 mg/kg SC) as needed for 24 hours, and administration of meloxicam (0.1 mg/kg orally SID) for seven days. Standard nursing care was provided during hospital stay. Dogs were discharged as soon as they were ambulatory.

Assessment of the technique

Recorded data included: perioperative complications, skin incision length, operative time and subjective quality of visibility (graded in the same way as in the cadaveric study).

Clinical outcome was assessed based on clinical examination by the surgeon (DL).
during hospitalisation and at five and 12 days postoperatively. A neurological examination was performed by a neurologist (JLT) on a daily basis during hospital stay and at one month postoperatively. Owners were contacted by telephone at least three months after the surgery to assess the long-term outcome.

Where appropriate, numerical data were expressed as a mean ± standard deviation and range.

Results

Cadaveric study
(Supplementary Table 1)

Skin incision

Except for one cadaveric specimen, the skin incisions were always centred over the targeted IVDS. In the latter, skin elasticity allowed correct exposure. Mean incision length was 38 ± 7 mm (range: 30 to 50 mm). In two cadavers, a skin incision of less than 30 mm did not allow introduction of the device and needed to be enlarged.

Intervertebral disk space targeting

In all 16 trials in eight cadavers, the longus colli muscles were elevated from the targeted IVDS without fluoroscopic guidance. All targeted IVDS were identified securely by palpation only. The targeted IVDS were C2-C3 (n = 6), C3-C4 (n = 2), C4-C5 (n = 4), C5-C6 (n = 3), and C6-C7 (n = 1).

Iatrogenic damage evaluation

The trachea, oesophagus, laryngeal nerves, vagosympathic trunks, common carotid arteries and jugular veins were found undamaged in all cadavers. The right cranial thy-roid artery was inadvertently severed in one specimen during a C2-C3 approach. Contrary to the initial goal of minimising muscle trauma, in three instances the paramedian approach passed through the ster-nocephalic muscle fibres rather than in between the sternocephalic and sternohyoid muscles bellies.

Minimally invasive video-assisted ventral slot preliminary experience

In two of four trials, a venous sinus was damaged during drilling. This was related to the tilting of the DED away from the mid-sagittal plane. In these instances, even if the entry point on the vertebral body was correct, drilling was offset towards the side and thus a venous sinus was damaged (Fig. 4).

The lens of the endoscope needed frequent cleaning, especially when drilling cancellous bone. Cleaning was time consuming and outweighed the benefit of the increased visibility during this initial phase of the procedure.

In all trials, visibility during drilling and vertebral canal exploration was graded as improved over the standard technique.
Clinical study (Supplementary Table 2)

Preoperative

Ten dogs with a mean weight of 12 ± 4 kg (range: 8 to 20 kg) were included in the study. The most commonly represented breeds were French Bulldogs and mixed breed dogs (2 cases each). Other breeds were Cocker Spaniel, Poodle, Pyrenean Shepherd, Coton Tulear, Shih Tzu, and Beagle (one of each). There were six male and four female dogs. Initial neurological examination revealed signs of cervical pain without neurological deficits for six dogs, ambulatory left forelimb paresis for one dog, and non-ambulatory tetra-paresis for three dogs. Disk herniation was diagnosed by myelography in three cases, computed tomographic in one case.

Perioperative

Nine dogs had a single-level MIVA-VS, and one had a two-level MIVA-VS, resulting in a total of 11 MIVA-VS being performed. The MIVA-VS was localised at the level of C2-C3 in 2/11 disks, C3-C4 in 2/11 disks, C4-C5 in 4/11 disks, C5-C6 in 2/11 disks and C6-C7 in 1/11 disks.

In all dogs, the skin incision was centred correctly over the targeted IVDS and the MIVA-VS was performed on the correct IVDS. Hansen type I disk extrusion was found in all cases. Mean skin incision length in the clinical setting was 39 ± 6 mm (range: 30 to 50 mm). Mean operative time was 52 ± 10 minutes (range: 40 to 70 minutes). There was not any perioperative damage to any of the major anatomical structures.

In three cases, bleeding from a venous sinus occurred and was controlled under video assistance by application of a piece of macerated muscle or a haemostatic sponge. The procedure could then be completed in both cases under video assistance without difficulty. Visualisation through the endoscope was graded as improved compared to the standard non-video-assisted technique, with disk material removal clearly facilitated (Fig. 3).

Postoperative and follow-up

The six dogs which had shown only signs of cervical pain, and the dog with a left forelimb paresis, were immediately ambulatory and were discharged the day after surgery. Neurological examination performed five days and one month postoperatively on these seven dogs was normal. The three dogs that had been non-ambulatory before surgery regained ambulatory function between five and 10 days after surgery. They were ambulatory with slight proprioceptive deficits at the neurological examination one month postoperatively. Telephone follow-up at least three months postoperatively was available for nine dogs. Eight dogs were considered normal; one dog which had been non-ambulatory preoperatively still showed signs of slight proprioceptive deficits. Subjectively, both surgeons who had performed the procedures were of the opinion that the dogs experienced less postoperative discomfort than with the conventional technique. Cervical swelling or seroma formation was not seen.

Discussion

The present study provides evidence that MIVA-VS can safely be performed without fluoroscopic guidance in dogs while respecting the principles of minimally invasive spinal surgery (14). The surgical technique we applied were consistent with those principles: (i) skin incisions were of adequate size and optimally placed; (ii) the route to the target was the least traumatic; (iii) iatrogenic damage was negligible; (iv) treatment was efficient without restriction due to the relatively small approach; and (v) no complication pertaining to the technique occurred.

We found that in all cases the targeted IVDS was correctly approached or drilled; a limiting factor to this statement is that in clinical cases we did not always have proof via postoperative imaging that the correct IVDS had been drilled. Nevertheless, disk material was retrieved from the vertebral canal in all cases, and all animals had a satisfactory clini-
cal outcome, which strongly supported the statement that in each case, the affected disk space was correctly approached. Furthermore, three cases were radiographed postoperatively confirming the correct targeting of the IVDS.

Because we wanted to respect the anatomical pathways, we initially choose a paramedian approach in order to pass between the sternocephalic and sternothyroid muscles bellies instead of dividing the fibres of the paired sternocephalic muscle in the medial plane. Contrary to our initial plan, this approach was more traumatic since in three cases the approach passed through the sternocephalic muscle. We think that because we had a small skin incision it was more difficult to find the plane between the muscles bellies than when performing the classical approach with an incision from the larynx to the manubrium (13). Furthermore, the paramedian approach was responsible for a natural tendency of the DED to tilt from the mid-sagittal plane, which made drilling unsafe in respect to the venous sinus even if the entry point on the vertebral body was correct (Fig. 4). We therefore used a mini (approximately 40 mm) standard midline approach in all clinical cases. By employing such a mini-midline incision, retraction of major anatomical structures such as the vagus nerve, carotid sheath and trachea was limited. In fact, tissue retraction was only performed at the level of the longus colli muscle, thus limiting the invasiveness of the approach and reducing the risk of surgical trauma to the major structures.

In the present study, MIVA- VS was efficient despite the reduced surgical field. The manoeuvrability of instruments was not impaired by the small approach and the decompressive procedure was easily achieved. The DED could be effortlessly translated up and down along the nerve root retractor to either enlarge or reduce the field of view. It could also be tilted in the rostral-caudal and latero-medial directions during the drilling procedure. The easy triangulation promoted by the fixed 12° angle between the working channels and the telescope enabled the surgeon to consistently see the tip of instruments and suction cannula, which improved control and comfort during drilling and disk curettage (Fig. 3). Of course, as it is the case for all microsurgical techniques, good hand-eye coordination has to be acquired in MIVA endoscopic spinal surgery. Both reporting surgeons were familiar with arthroscopic techniques and did not experience any difficulties in performing triangulated spinal surgery. Nevertheless, a learning curve has to be taken into account when performing MIVA- VS. In our case, a part of this learning curve was mastered during the cadaveric study.

The combination of increased coaxial illumination and magnification, as provided by the DED, increased the quality of visibility during the final steps of the decompressive procedure. Drilling of the dorsal cortical bone of the vertebra, removal of the dorsal longitudinal ligament, and subsequent disk curettage was facilitated in all cases (Fig. 3). Although this assessment is subjective given the methods applied, both surgeons were familiar with the standard VS technique and they were strongly convinced of the advantages of improved visibility. The perceived advantages included the improved xenon illumination with a colour temperature and spectrum resembling daylight conditions, which allowed recognition of even the finest details of tissues and of colour (14). However, even under these improved visual conditions, venous sinus bleeding occurred in two clinical cases, suggesting that better visibility does not necessarily eliminate the risk of injury to these vascular structures. The rate of occurrence in the present study (2/11) is however in line with what was previously reported (4, 15). Also, contrary to what has sometimes been reported, these haemorrhages were not so severe as to prevent successful completion of the procedures (2, 4).

From our experience, the technique was easily applied in small and medium sized dogs. The MIVA- VS was indeed performed in dogs weighing between 8 and 20 kg. The only difficulty we foresee is in very large dogs where palpation through the minimally invasive approach of both the cranial (ventral tubercle of C1) and caudal landmarks (transverse processes of C6 and the first rib) may be challenging. Experience with clinical cases of large and giant breed dogs is needed to assess if there are real size limitations to the technique.

All previously non-ambulatory dogs were ambulatory within 10 days of the surgery, and all dogs with signs of pain were ambulatory immediately and had no appreciable signs of neck pain by day 5. These results are in line with the published data on VS (4, 5, 16, 17). From the standpoint of clinical outcome, all surgical procedures were successful. However, we do acknowledge the fact that the dogs on which we have performed surgery were relatively small (<20 kg), that they had disk extrusion versus protrusion, and that six of the 10 dogs were presented with signs of cervical pain only. These are considered positive prognostic factors for postoperative recovery and may thus explain, in part, the overall positive outcome in the cases described herein (2, 18). Further prospective studies on a larger number of dogs are certainly needed to draw definitive conclusions about the benefits of this mini-invasive technique.

**Conclusion**

This is the first report of MIVA surgical treatment of cervical disk herniation in dogs. The present study provides evidence that MIVA- VS using the DED can be performed without the use of fluoroscopic guidance, and that it can be a solid alternative to the conventional technique. The procedure allowed fast, safe and efficient treatment of disk extrusion in dogs, provided that the surgical anatomy is meticulously respected and that the equipment is properly used. However further clinical experience is needed to assess the benefits of this new technique on a larger scale.

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**Conflict of interest**

The authors declare no conflict of interest.

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