FULL PAPER *Surgery*

Zygomatic arch-atlas wing stabilization in 5 dogs with atlanto-occipital dislocation

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ABSTRACT. The aim of this work was to present a novel minimally invasive surgical stabilization technique for canine atlanto-occipital dislocation and to report the associated magnetic resonance imaging (MRI) findings. All 5 dogs in this case series underwent 1.5 T MRI of the head and neck and 3 underwent both MRI and computed tomography (CT). Atlanto-occipital dislocations were diagnosed based on the increased joint space between the occipital condyles and the atlas on MRI. Surgery was performed immediately with a never previously described fixation technique based on an external ligature. The stabilization was performed via 4 holes drilled in the zygomatic processes and in the atlas wings on each side. A nylon monofilament of 1 mm diameter was inserted in the 4 holes, and an O-shaped ligature was carried out externally to the skin through the ipsilateral zygomatic arch. Ligatures were removed within 2 months. At the postsurgical follow-up examination, 14 days after surgery, all dogs were found to be ambulatory. Atlanto-occipital stability was assessed by clinical examination with an average of 24 months of follow-up. The positive outcomes in this case series suggest that atlanto-occipital dislocation may be surgically treated with this novel technique, irrespective of the severity of the clinical presentation and associated lesions observed on MRI.

KEY WORDS: atlanto-occipital dislocation, dog

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Injuries to the upper cervical spine commonly include fractures or combinations of fractures and luxations of the first and second cervical vertebrae [12]. Atlanto-occipital luxation is a rare condition in dogs and cats, because of the means of stability that prevent dislocation. Luxation and subluxation can occur in dogs and cats following trauma [2, 4, 5, 10, 11, 14, 17, 18]. The stability of the atlanto-occipital joint is attributable to the multiple, strong ligaments associated with it [18]. The ligaments of the atlanto-occipital joint are shared with the atlantoaxial joint; therefore, this anatomical region should be considered as a unique functional entity, that is, the occipito-atlanto-axial unit, also defined as the craniocervical junction [2, 6].

The dens of the axis is maintained in the fovea dentis of the atlas by the transverse ligament of the atlas [6, 7]. The single apical ligament extends between the tip of the dens of the axis and the basion, defined as the most caudal point of the clivus that corresponds to the portion of the basioccipital bone in contact with the brain stem. The paired alar ligaments course between the tip of the dens of the axis and the ventral portions of the lateral margins of the foramen magnum [6, 7, 20]. Additional lateral stability for the atlanto-occipital joint is provided by the paired lateral atlanto-occipital ligaments that connect the lateral part of the dorsal arch of the atlas to the jugular process of the occipital bone [6, 7, 20]. The dorsal atlanto-occipital membrane connects the dorsal edge of the foramen magnum with the cranial border of the dorsal arch of the atlas [6, 7, 20].

Successful treatment outcomes for atlanto-occipital luxation after trauma have previously been reported in 4 dogs and 1 cat [2, 4, 5, 10, 11, 14, 17, 18]. Non-surgical treatment approaches may not provide adequate stabilization of the extensive joint instability [6, 20]. Various surgical techniques have been proposed, sometimes with disappointing results [4, 5, 10, 11, 14, 17, 18]. The aim of the current study was to present a novel minimally invasive surgical stabilization technique for canine atlanto-occipital dislocation and to report the associated magnetic resonance imaging (MRI) findings.

MATERIALS AND METHODS

This case series includes 5 dogs that developed atlanto-occipital dislocation. The clinical presentation and diagnostic procedures including high-field MRI are described for each case. For diagnostic imaging procedures, general anesthesia was induced with intravenous propofol (Proposure, Merial Italia SpA., Milano, Italy) and, after orotracheal intubation, anesthesia was maintained with a mixture of isoflurane (Vetflurane, Virbac Italia s.r.l., Milano, Italy) in oxygen and medical air.

The MRI examinations were performed with a 1.5 T scanner (Intera 1.5 T, Philips Medical Systems, Eindhoven, The Netherlands) that was equipped with a phased array spine coil. The dogs were placed in lateral recumbency to avoid the chances of further spinal cord injury, with supports to prevent rotation away from true lateral. The following scans were performed: a fluid-only thick slab sagittal scan (repetition time [TR] 8,000 msec, echo time [TE] 900 msec, slice thickness 40 mm, matrix 512, number of excitations

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[NEX] 1, field of view [FOV] 450 mm and acquisition time 0.13 min); a turbo spin-echo (TSE) T2-weighted (T2-W) two-dimensional (2D) sagittal scan (TR 3500 msec, TE 130 msec, slice thickness 2 mm, matrix 1024, NEX 2, FOV 530 mm and acquisition time 4.5 min); a fast field echo (FFE) T1-weighted (T1-W) 2D transverse scan (TR 340 msec, TE 3.5 msec, slice thickness 3 mm, matrix 512, NEX 3, FOV 120 mm and acquisition time 3.5 min); and a TSE T2-W 2D transverse scan (TR 3500 msec, TE 130 msec, slice thickness 2 mm, matrix 512, NEX 2, FOV 200 mm and acquisition time 3.8 min), of the head and cervical spine.

When additional computed tomography (CT) examinations were performed, the respective findings are described for each patient. CT examinations were conducted with a multidetector (MDCT) scanner (Brilliance 64 Slice, Philips Medical Systems). Patients were placed in lateral recumbency with supports. Isotropic voxels of 0.67 mm were used to perform multiplanar reconstructions and to obtain transverse images of the atlanto-occipital region with a perpendicular orientation. Scan parameters were: 200 mAs, 120 Kv, pitch 0.625, rotation 1 sec and slice thickness 0.67 mm.

All dogs underwent closed surgery. The novel surgical stabilization technique that was developed is described separately in the following text.

RESULTS

Case series: Clinical information regarding signalment, clinical history, chief concern, and MRI findings for the 5 dogs included in the report is summarized in Table 1.

Case 1 −An 18-month-old male German Shepherd was admitted to our center 12 hr after meeting with a traumatic accident in which he was pressed down and dragged away by a car. Plain laterolateral radiographs showed a slight increase in the width of the atlanto-occipital articular space with the atlas shifted dorsally (Fig. 1A). MRI of the head and neck showed atlanto-occipital luxation with dorsal dislocation of the atlas. Spinal cord compression was evident, and associated findings of spinal cord hyperintensity and hydromyelia on long TR sequences were observed. Atlanto-occipital and occipital-axial ligaments were judged to be disrupted with the exception of the dorsal atlanto-occipital ligament. Confirmatory subsequent CT examination was performed. Dorsal displacement of the atlanto-occipital joint was clearly visualized on sagittal images. No fractures were detected on axial or reconstructed images.

Case 2 −An 8-year-old male mongrel, 21 kg, was admitted with a history of having been hit by a car 12 hr earlier. The owners reported that the car had run over the patient in a caudocranial direction in the neck region. The left laterolateral projection chest and neck radiographs were within normal limits, while the ventrodorsal projection showed a slight widening in the articular interline between the left occipital condyle and the articular surface of the atlas. MRI scans showed widening of the atlanto-occipital joint space, swelling of periarticular soft tissue structures and intra-articular effusion. The atlas was displaced caudally and dorsally with respect to the occiput, while the skull was subluxated ventrally, resulting in a moderate dorsal compression of the spinal cord at the level of the craniospinal junction.

Case 3 −A 6-year-old female Collie, 16 kg, was referred following the occurrence of a distraction injury 6 hr earlier in which the dog, after having the head stuck in a car window, attempted to pull it back with force. Radiological examination of the cervical spine revealed no abnormalities, and blood cell count and biochemistry profile results were within normal limits. The 1.5 T MRI of the head and neck showed atlanto-occipital subluxation consisting of ventrolateral asymmetric displacement of the atlas and loss of contact between the right and left articular surfaces of C1 and the occipital condyles (Fig. 2). The spinal cord was compressed bilaterally on its ventral aspect, but the signal intensity was homogeneous. Further CT examination revealed no fractures or bony malformation of the entire craniocervical junction.

Case 4 −An 8-year-old male mongrel, 24 kg, was referred after meeting with a car accident the day before. Plain radiographs of the first cervical vertebra had been performed earlier by the local veterinarian. On the ventrodorsal view, the skull and the atlas appeared aligned with subtle decreased articular space (Fig. 3). Dorsal dislocation of the atlas was evident on sagittal MRI scans, and the report stated that moderate spinal cord compression was present with the maximum degree at the point corresponding to the cranial aspect of the atlas (Fig. 3A). On T2-W sequences, the apical ligament appeared irregular, and the transverse odontoid ligaments appeared disconnected. A retropharyngeal bulging was observed on T2-W TSE transverse scan, caused by a homogeneous swelling of the longus capitis muscle, hypointense with respect to the muscle and isointense to fluid (Fig. 3C). CT was performed in succession; no evidence of bony fractures was present, and the loss of contact was evident on reconstructed images.

Case 5 −A 5 year-old male Rottweiler, 35 kg, was presented after having its head stuck in a metal gate one day previously. The owners reported that the dog was trying to escape by retracting the head from the gate with force when they became aware of the accident. Plain radiographs that had been obtained by the local veterinarian were not available. MRI of the head and neck confirmed monolateral left-sided atlanto-occipital dislocation with lateral left-sided atlanto-occipital ligament disruption, as well as partial disruption of the ventral atlanto-occipital and apical ligament (Fig. 4). Dislocation in this case consisted of unilateral loss of contact and distraction without displacement in the dorsal or ventral planes. In addition, a marginal hematoma and a faint medullary hyperintensity between the bulb and the C2 segment on long TR sequences were suggestive of a light intramedullary edema.

Surgery: Surgery was performed subsequently to diagnostic imaging, taking advantage of the general anesthesia that was induced for MRI and CT exams. Before the animals underwent surgery, atlanto-occipital dislocation was manually reduced and verified using fluoroscopy (GE Stenoscope, GE Healthcare Italia, Milano, Italy). Although we were able to obtain a correct anatomical relationship between the condyles and the atlas, persistent and clinically perceptible

Table 1. Summary of signalment, clinical outcomes, and MRI findings of dogs treated

Case	Signalment (Breed, age, sex)	Clinical history	Chief concerns	MRI findings
1	German Shepherd, 18 m, m	HBC	DP, tetraplegia, propioceptive ataxia, cervical hyperesthesia and AO instability	Increased AO space and dorsal dislocation of the atlas
2	Mongrel, 8 y, m	HBC	Ecchymosis, TP, tetraplegia, cervical hyperesthesia and AO instability	Increased AO space and dorsal dislocation of the atlas
3	Collie, 6 y, f	Distraction injury	TP, cervical hyperesthesia, paraparesis and AO instability	AO ventrolateral subluxation
4	Mongrel, 8 y, m	HBC	DP, cyanosis, ecchymosis, tetraplegia, cervical hyperesthesia and AO instability	Dorsal atlas dislocation and capsular laceration
5	Rottweiler, 5 y, m	Distraction injury	Hyperthermia, DP, cervical hyperesthesia, paraparesis and AO instability	Left-sided AO dislocation

MRI: Magnetic resonance imaging. HBC: Hit by a car. DP: Dyspnea. AO: Atlanto-occipital. TP: Tachypnea.

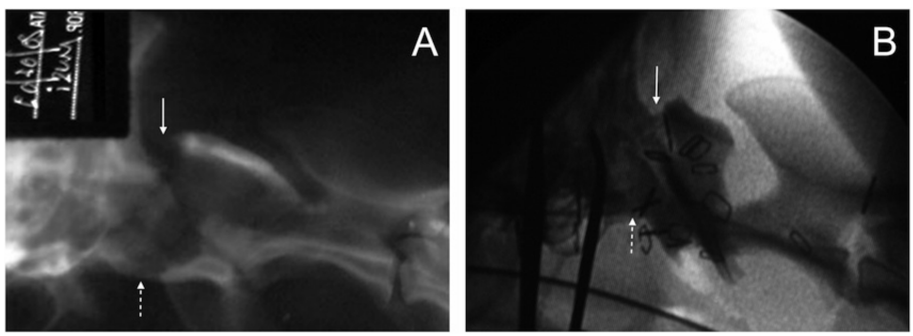

Fig. 1. Presurgical radiogram (A) and intraoperative fluoroscopic images (B) in Dog #5. The reductions of the intervals are evident in the spaces between the basion (within the occipital bone) and the odontoid tip (within the atlas) (dashed arrow), and between the opisthion (within the occipital bone) and the dorsal arch (within the atlas) in panel B.

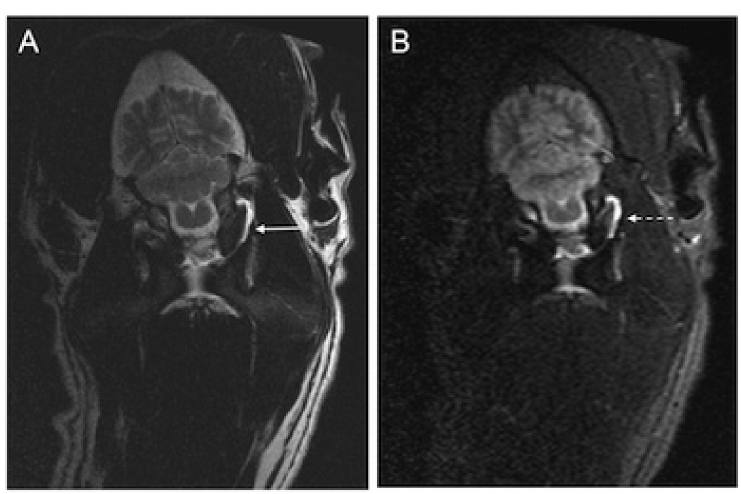

Fig. 2. The dorsal planes of T2-weighted (A) and short tau inversion recovery (STIR) (B) images showing the head and neck in Dog #3. The atlanto-occipital dislocation is evident with a widening of the joint space (arrow) as the atlas is caudally dislocated with respect to the occiput. A deviation to the right of the head is evident. The capsular laceration and the joint effusion are imaged in panel B (dashed arrow).

Fig. 3. The sagittal (A), dorsal (B) and axial (C) planes of the T2-weighted images showing the head and neck in Dog #4. (A) The atlas is dorsally displaced, and edema is evident within the retropharyngeal region (star). The apical ligament is disrupted (arrow), and the tectorial membrane is stretched (a). (B) The dislocation of the atlas is evident (arrows), and the alar ligaments are likely disrupted. (C) The spinal cord is imaged as hyperintense, and the dorsal dislocation of the atlas is visible with respect to the foramen magnum (arrow).

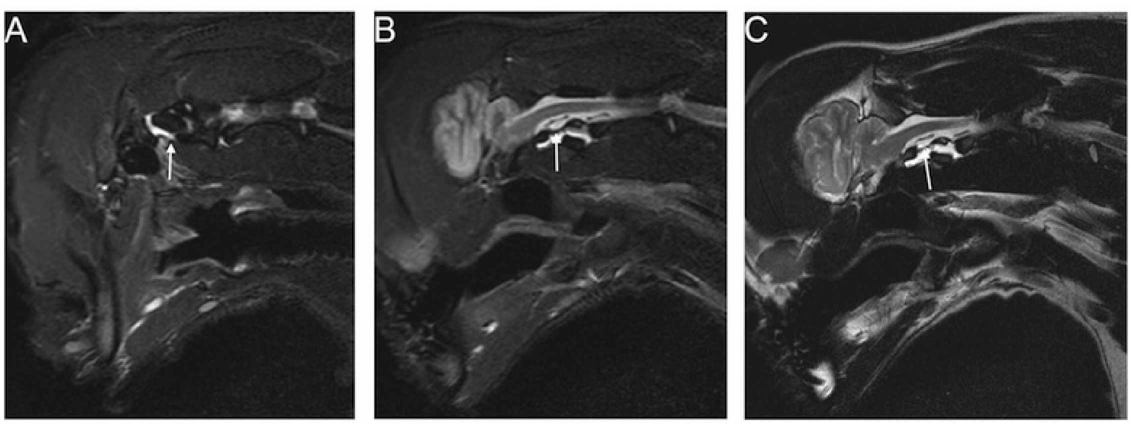

Fig. 4. The sagittal plane of the short tau inversion recovery (STIR) (A and B), and T2-weighted (C) images showing the head and neck in Dog #5. The capsular partial laceration is evident (arrow) in panel A, and the partial rupture of the annular ligament is evident (arrows) in panels B and C.

instability was still present. In all of the dogs in the case series, the degree of instability following manual reduction was severe and not amenable to management using an external collar. The main inclusion criteria were MRI findings consistent with atlanto-occipital dislocation with increased joint space between the occipital condyles and the atlas. In contrast, the exclusion criteria were the presence of both musculoskeletal malformation and fractures of the atlas, condyles and/or zygomatic arch.

The dogs were placed in sternal recumbency with the head maintained horizontal by a head-support frame. The surgical technique consisted of 2 ligatures (Fig. 5), developed as follows. Four surgical accesses were carried out, at the zygomatic processes (Fig. 6A) and at the atlas wings on each side, respectively. Once these structures had been exposed, a 2 mm diameter hole was drilled in each atlas wing 5 mm caudal to the cranial margin and 10 mm medial to the lateral margin (Fig. 6B). A nylon monofilament (1 mm diameter) was inserted in the hole, and an O-shaped ligature was carried out externally to the skin through the ipsilateral zygomatic arch (Fig. 6C). When the ligatures were tightened, the joint space narrowed so the dislocation was reduced and the joint was stabilized at the same time. Once the anatomical reduction of the dislocation was verified through fluoroscopic imaging (Fig. 1B), the surgical wounds were closed in multiple layers (Fig. 6D). The mean surgical time was 25 min (range: 18–32 min).

Pre- and postoperative care: Perioperative antibiotic prophylaxis with cefazolin (30 mg/kg i.v.) (Cefazolina Teva, Teva Italia, Milano, Italy) was administered to each patient. Dogs were premedicated with a combined protocol of dexmedetomidine (3 μg/kg) and methadone (100 μg/kg). Anesthesia was induced using propofol dosed to effect and, after endotracheal intubation, anesthesia was maintained by isoflurane in oxygen administered by volume-controlled ventilation. Perioperative analgesia was provided using

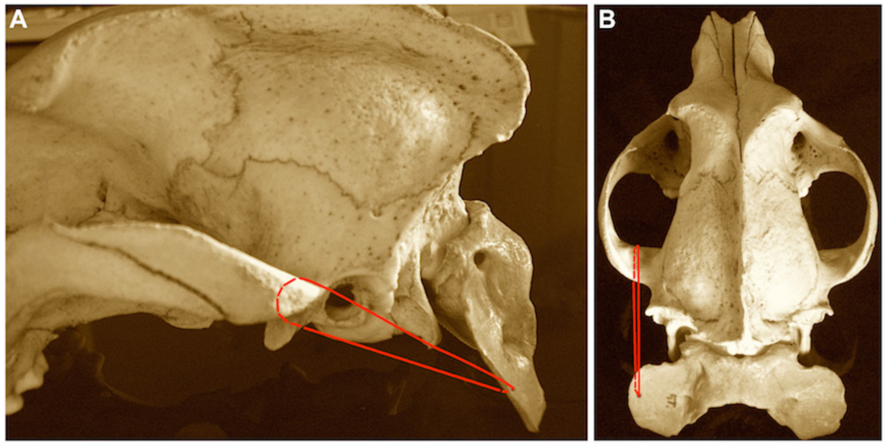

Fig. 5. Schematic representation of the surgical technique in lateral (A) and dorsal (B) views of an anatomical specimen. The prominent occipital condyles and the favorable alignment of the zygomatic arches with the atlas wings allow a stable reduction that is performed with application of the tension band principle.

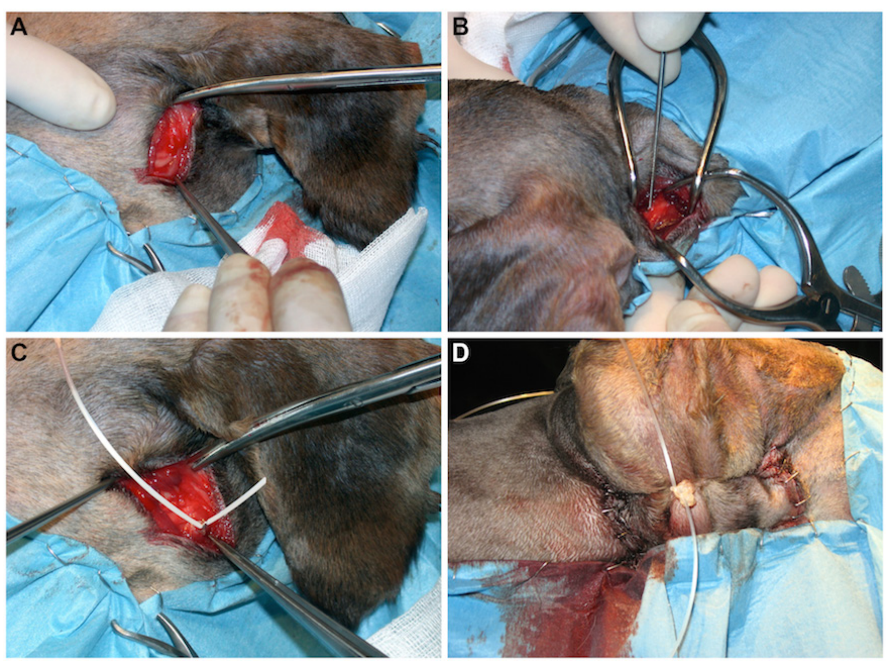

Fig. 6. Steps of zygomatic arch-atlas wing stabilization. (A) The left zygomatic arch is exposed by blunt resection. (B) Drilling of the left wing of the atlas makes a hole. (C) The nylon monofilament suture is passed under the left zygomatic arch. (D) The suture passing both the left zygomatic arch and the hole within the left wing of the atlas is knotted over the skin.

methadone (0.2 mg/kg) (Semfortan, Ati s.r.l., Ozzano Emilia, Bologna, Italy). Postoperative care for the first week consisted of 30 mg/kg cefazolin every 12 hr by intramuscular injection and 2–3 mg/kg tramadol every 6 hr administered orally or by intramuscular injection. Over the following 15 days, amoxicillin/clavulanic acid was administered at a dose of 12 mg/kg every 8 hr, orally. An antiseptic ointment was applied to the 4 skin emergences of the 2 ligatures on a daily basis until their removal

Postoperative outcomes: Clinical examination 2 weeks after the surgical treatment revealed that all patients had regained the ability to walk. At that time, the neurological examination of all of the dogs was within normal limits. Gentle manipulations were performed to assess atlanto-occipital stability; the absence of rotational movements of the atlas on the occipital condyles in all of the dogs that had undergone surgery was interpreted as successful stabilization. A slight reduction in the physiological excursion in flexion and extension was observed. Ligatures and external collars were removed after 2 months. Follow-up periods ranged from 12 to 36 months, with an average of 24 months, and consisted of clinical and radiological examinations. Radiological examinations revealed reductions of the space between the occipital basion and the odontoid tip of the axis and between the occipital opisthion and the dorsal arch of the atlas. All of the dogs had normal findings during the follow-up period.

DISCUSSION

Traumatic injuries that involve the occipito-atlanto-axial joint are characterized by peculiar clinical signs and variable severity and course. A thorough understanding of the clinical presentation, radiographic assessment and mechanisms of injury can minimize morbidity and enhance treatment effectiveness for the more common upper cervical ligamentous and bony injuries [9]. Successful conservation of the integrity of the neurological functions is strictly linked to prompt diagnosis and immediate stabilization [9]. In contrast, delayed recognition can result in significant mortality both in humans and in canine patients [6]. The high mortality associated with these injuries is probably due to medullary trauma, which may cause bradycardia, hypertension and cardiopulmonary instability [9].

In human medicine, atlanto-occipital dislocation occurs rarely [1, 9, 15, 19], and-excluding malformation and congenital pathologies [9], it is mainly caused by car or cycle accidents, falls, dives and firearm injuries [1, 9, 15]. The complex regional anatomy and overlying structures make plain radiographic images difficult to interpret. MRI is actually considered the most suitable diagnostic imaging modality [9], because of its capability for soft tissue visualization: the atlanto-occipital membranes, tectorial membrane, alar ligaments and apical ligament are identifiable on direct and post-contrast scans [1, 9, 15]. Moreover, visualization of the neural structures helps to define the prognosis and the best surgical options [1, 8, 9, 15, 19]. The experience accrued in human medicine was merged into a CT/MRI classification with 3 grades of atlanto-occipital dislocation with therapeutic implications [19]. Type I injuries are the most common and are described as anterior subluxation or dislocation of the occiput in relation to the atlas [19]. Type II injuries are a distraction injury without evidence of dislocation [19]. Type III injuries are posterior dislocation of the occiput in relation to the atlas [19]. It is interesting to note that 3 of our cases are comparable to the human Type I category, and 1 of each of the 2 remaining cases can be considered Type II and Type III, respectively. In the authors' opinion, if a prevalence of Type I injuries is confirmed in the future, the hypothesis of a biomechanical influence attributable to the heavy head of dogs should be considered.

In human medicine, transarticular screw fixation and fusion of the occiput to multiple cervical segments is the standard treatment for atlanto-occipital dislocation [8]. Arthrodesis of more cervical levels, however, decreases the cervical range of motion.

In the authors' knowledge, only a handful of cases of atlanto-occipital dislocation have been reported in dogs, and there has been 1 case reported involving a cat [2, 4, 10, 11, 14, 17, 18]. Four of the published cases were treated with a manual closed reduction followed by the application of a rigid collar [2, 10, 14, 18], while a surgical approach was reported in the other four cases [2, 4, 5, 17] using 3 different techniques: open reduction [5], dorsal laminectomy [4, 17] and ventral fixation [2].

In the conservative approach through the closed reduction technique, the patient is maintained under general anesthesia and positioned in lateral recumbency. While an assistant extends the neck and head in order to apply traction to the atlanto-occipital joint, the head is carefully rotated to allow the condyles to snap back into the cranial articular fovea of the atlas, producing a "popping" sound. Then, a U-shaped cast is applied to the ventral aspect of the neck from the manubrium to the mandible, in order to limit dorsal-ventral flexion of the neck. This technique was performed successfully in 4 cases in the literature, but failed in 2 other cases [2, 17], in which it was chosen as the first approach. Moreover, the results were completely positive in 2 cases [10, 14], while 2 other cases presented problematic postoperative outcomes: reluxation and persistent anisocoria in 1 case [10] and ataxia, left-sided hemiparesis and pain in the second one, so that cage confinement was necessary [18].

Comparing our technique with conservative medical treatment, the main difference is the effective stability of the reduction of the atlanto-occipital joint that we obtained. In fact, a collar may not be sufficient to neutralize the forces acting on this joint, resulting in a possible therapeutic failure. Moreover, surgical stabilization may be more appropriate than conservative treatment in patients with chronic or severe dislocations resulting in high-grade instability.

Regarding the surgical approach, the open reduction is described in a dog [5] and consists of a surgical dorsal approach with manual reduction of the luxation. After curettage of the articular cartilage, a 2.7 mm cortical screw is inserted in lag fashion through the cranial edge of the atlas and occipital bone. In addition, a dorsal tension band is constructed with 2 sutures of #5 braided polyester through holes drilled through the occipital protuberance and the dorsal process of the axis. Finally, a heavily padded bivalve fiberglass cast with a nose bar is applied to the patient from midcranium to thoracic limb in order to provide more stability. In the single case reported in the literature, although an improvement in neurological function occurred, the patient showed urinary incontinence, *Pseudomonas aeruginosa* urinary tract infection and slight proprioceptive deficits in both hind limbs during the follow-up period.

Dorsal laminectomy of C1 has been performed in 2 cases of chronic luxation due to the failure of repeated attempts at both open and closed reduction, because of the presence of chronic inflammation and fibrous tissue [17]. In this technique, the dog is placed in sternal recumbency with a flexed neck. Through a dorsal approach, the atlanto-occipital joint is exposed. In chronic cases, a large amount of scar tissue is present at this level; this tissue should remain *in situ* to avoid joint instability. Instead, the dorsal atlanto-occipital ligament and the compressive portion of the occipital bone are removed through the performance of a 1 cm-diameter craniectomy above the foramen magnum with a high-speed burr. The result is an enlargement of the foramen magnum with decompression of the spinal cord. Although the technique was found to result in a good long-term prognosis, both patients had complicated postoperative outcomes, with intermittent obtundation, ataxia, left head tilt and mild tetraparesis until 6 months after surgery in 1 case [17] and head tilt for 25 days in the second [4]. Moreover, this technique is advised only in chronic cases, where fibrosis prevents dislocation.

The ventral screw fixation technique has been described in a case report in which there was a successful outcome and the patient regained ambulation in 12 weeks [2]. A manual closed reduction under fluoroscopy was initially attempted with an unsuccessful outcome, likely due to the fibrosis that had already occurred, leading to the need for an open surgical technique.

Through a ventral approach, first the atlanto-occipital joint capsule is exposed and excised, and then, the exposed cartilage is removed. A temporary reduction and stabilization of the atlanto-occipital joint is obtained using a self-retaining pointed bone reduction forceps, allowing the placement of two 2.7-mm cortical bone screws in each occipital condyle and 4 additional 2.7-mm cortical screws in the body of C1. Although screws placed in that manner stabilize the atlanto-occipital joint, they also protrude into the spinal canal, leading to a high risk of iatrogenic spinal trauma. No spinal trauma was identified in the follow-up of the work mentioned, but in the authors' opinion, the risk of spinal cord damage should be considered and estimated in more than 1 single treated patient.

Comparing our surgical technique with the others described in the literature, it is much simpler, minimally invasive, easy to perform, respectful of the soft tissues, does not require expensive special implants and, in particular, does not involve any risk of damage to the spinal cord by the instrumentation. In the cases reported in the literature, no attempt at classification of the type of dislocation was made. In our group of patients, all 3 kinds of dislocation described in the Traynelis classification occurred [19]. Our technique provided good stability for all 3 types of dislocation in our patients. The results that we obtained were consistently successful; consequently, we strongly recommend this surgical technique as a valid alternative to all the types of conservative and surgical approaches described in the previous literature.

This case series describes the MRI findings for 5 dogs affected by atlanto-occipital dislocation. In all of the cases, the presumptive diagnosis of atlanto-occipital dislocation had been clinically formulated, but the MRI evaluation contributed substantially in defining the type of luxation as well as depicting the anatomical integrity of structures and associated lesions. A peculiar finding was represented by the retropharyngeal edema that was observed in patient number 4. This lesion has been described in human patients with atlantoaxial luxation and disruption of the craniocervical junction ligaments, and it is believed to be caused by bleeding and synovial fluid leakage [1, 9, 15].

Traumatic atlanto-occipital dislocation differs from another recently described pathological condition of the craniospinal junction, known as atlanto-occipital overlapping [3]. Atlanto-occipital overlapping consists of a "craniodorsal displacement of the atlas with its lamina overlapping the occipital bone" that occurs after a malformation or a traumatic fracture of the skeletal base. In contrast, the traumatic atlanto-occipital dislocation that we describe in the present paper is a caudodorsal (3 cases), ventrocaudal (1 case) or pure caudal (1 case) displacement of the atlas with an increase in width of the atlanto-occipital joint. The patients affected by atlanto-occipital overlapping in the study by Cerda-Gonzalez were small-sized purebred dogs, while the dogs in the present report were all middle/large-sized. Although the number of dogs is limited, the evidence suggests that atlanto-occipital traumatic dislocation and atlanto-occipital overlapping are two different diseases. Because the direction of dislocation is opposite, our surgical technique to correct atlanto-occipital traumatic dislocation is not applicable to correct atlanto-occipital overlapping. Additional contraindications to our technique include musculoskeletal malformations and fractures of the atlas, condyles and/or zygomatic arch.

The rationale for the novel stabilization technique that we developed was to neutralize distractive and rotational forces, taking into consideration the anatomical characteristics of the atlanto-occipital joint in the dog. The cranial articular processes of the atlas "cup" the occipital condyles so, under physiologic conditions, the atlanto-occipital joint allows only free up-and-down movement of the head [7]. Under normal conditions, each tensile force exerted mainly by muscles is converted into compressive forces. These anatomical considerations accord with the tension band surgical principles [16]. As in fractures, in which the muscle pull exerted on one side tends to distract the fragments on the opposite side, our technique involved the application of 2 ligatures aligned along the tension. The prominent occipital condyles together with the favorable alignment of the zygomatic arches with the atlas wings allowed a stable reduction in our patients and ensured rotational stability and flexion-extension ability at the same time. Our surgical technique limits abnormal motion of the traumatized joint within a physiological range of motion.

Since the sutures used intersect the path of the facial nerve, it was believed that positioning them externally to the skin better protected these nerves from possible mechanical damage due to friction or crushing. The dogs that underwent surgery did not show either maceration of the skin or septic phenomena.

After 2 months, once the sutures had been removed, all of the patients demonstrated clinical evidence of atlanto-occipital reduction. It can be assumed that the joint stability is due to the phenomena of normal fibrosis that occur in patients bearing articular dislocations treated by immobilization. The formation of a fibrous capsule and regeneration of the lateral atlanto-occipital ligaments provided adequate stability to the atlanto-occipital joint. The same findings occur in patients bearing articular dislocations treated by immobilization [13]. Indeed, no pathological joint movements have been reported in our patients through clinical examination or radiological imaging during the follow-up period.

To the authors' knowledge, there are no criteria in the literature to evaluate the reduction of an atlanto-occipital luxation. We considered the preoperative and postoperative distances between the basion (the most caudal anatomical point of the clivus, corresponding to the point where the skull base is in contact with the brain stem) and the odontoid tip of the axis, and between the opisthion (the dorsal midpoint on the caudal margin of the foramen magnum) and the dorsal arch of the atlas (Fig. 1). Decreases in both spaces subjectively evaluated by a radiologist after surgical stabilization and during follow-up have been considered to indicate a successful and effective joint reduction.

In conclusion, atlanto-occipital dislocation is easily diagnosed with MRI. Our surgical technique has yielded encouraging results and can be considered as a treatment option for this rare and serious injury. Due to the limited number of cases considered, further clinical studies with larger surgically treated populations are required.

REFERENCES

1. Bellabarba, C., Mirza, S. K., West, G. A., Mann, F. A., Dailey, A. T., Newell, D. W. and Chapman, J. R. 2006. Diagnosis and treatment of craniocervical dislocation in a series of 17 consecutive survivors during an 8-year period. *J. Neurosurg. Spine* **4**: 429–440. [Medline] [CrossRef]
2. Buks, Y., Snelling, S. R. and Yates, G. D. 2011. Ventral fixation of chronic atlanto-occipital luxation in a dog. *J. Small Anim. Pract.* **52**: 497–500. [Medline] [CrossRef]
3. Cerda-Gonzalez, S., Dewey, C. W., Scrivani, P. V. and Kline, K. L. 2009. Imaging features of atlanto-occipital overlapping in dogs. *Vet. Radiol. Ultrasound* **50**: 264–268. [Medline] [CrossRef]
4. Crane, S. W. 1978. Surgical management of traumatic atlanto-occipital instability in a dog. *Vet. Surg.* **7**: 39–42. [CrossRef]
5. DeCamp, C. E., Schirmer, R. G. and Stickle, R. L. 1991. Traumatic atlantooccipital luxation in a dog. *J. Am. Anim. Hosp. Assoc.* **27**: 415–418.
6. Dewey, C. W., Marino, D. J. and Loughin, C. A. 2013. Craniocervical junction abnormalities in dogs. *N. Z. Vet. J.* **61**: 202–211. [Medline] [CrossRef]
7. Evans, H. E. 1993. Arthrology-Atlantoaxial articulation. pp. 225–228. *In:* Miller's Anatomy of the dog, 3rd ed. (Evans, H. E. ed.), WB Saunders, Philadelphia.
8. Feiz-Erfan, I., Gonzalez, L. F. and Dickman, C. A. 2005. Atlantooccipital transarticular screw fixation for the treatment of traumatic occipitoatlantal dislocation. Technical note. *J. Neurosurg. Spine* **2**: 381–385. [Medline] [CrossRef]
9. Fisher, C. G., Sun, J. C. L. and Dvorak, M. 2001. Recognition and management of atlanto-occipital dislocation: improving survival from an often fatal condition. *Can. J. Surg.* **44**: 412–420. [Medline]
10. Greenwood, K. M. and Oliver, J. E. Jr. 1978. Traumatic atlanto-occipital dislocation in two dogs. *J. Am. Vet. Med. Assoc.* **173**: 1324–1327. [Medline]
11. Gross, W. R., Kimura, Y. M. and Fletcher, D. J. 2006. What is your diagnosis? Craniodorsal luxation of the atlas from its articulation with the occipital condyles. *J. Am. Vet. Med. Assoc.* **228**: 513–514. [Medline] [CrossRef]
12. Hawthorne, J. C., Blevins, W. E., Wallace, L. J., Glickman, N. and Waters, D. J. 1999. Cervical vertebral fractures in 56 dogs: a retrospective study. *J. Am. Anim. Hosp. Assoc.* **35**: 135–146. [Medline] [CrossRef]
13. Holsworth, I. G. and DeCamp, C. 2003. Coxofemoral Luxation. Treatment. p. 2003. *In:* Texbook of small animal surgery vol 2, 3rd ed. (Slatter, D. ed.), Saunders, Philadelphia.
14. Lappin, M. R. and Dow, S. W. 1983. Traumatic atlanto-occipital luxation in a cat. *Vet. Surg.* **12**: 30–32. [CrossRef]
15. MacDonald, R. L., Schwartz, M. L., Mirich, D., Sharkey, P. W. and Nelson, W. R. 1990. Diagnosis of cervical spine injury in motor vehicle crash victims: how many X-rays are enough? *J. Trauma* **30**: 392–397. [Medline] [CrossRef]
16. Ruedi, T. P., Buckley, R. E. and Moran, C. G. 2007. Tension Band Principle. pp. 249–254. *In:*AO Principles of Fracture Management vol 1. (Hak, D. J. and Stewart, R. L. eds.), AO Publishing, Swizerland.
17. Rylander, H. and Robles, J. C. 2007. Diagnosis and treatment of a chronic atlanto-occipital subluxation in a dog. *J. Am. Anim. Hosp. Assoc.* **43**: 173–178. [Medline] [CrossRef]
18. Steffen, F., Flueckiger, M. and Montavon, P. M. 2003. Traumatic atlanto-occipital luxation in a dog: associated hypoglossal nerve deficits and use of 3-dimensional computed tomography. *Vet. Surg.* **32**: 411–415. [Medline] [CrossRef]
19. Traynelis, V. C., Marano, G. D., Dunker, R. O. and Kaufman, H. H. 1986. Traumatic atlanto-occipital dislocation. Case report. *J. Neurosurg.* **65**: 863–870. [Medline] [CrossRef]
20. Watson, A. G., Evans, H. E. and de Lahunta, A. 1986. Gross morphology of the composite occipito-atlas-axis joint cavity in the dog. *Anat. Histol. Embryol.* **15**: 139–146. [Medline] [CrossRef]