Article published online: 2024-06-14

Long-Term Clinical Outcome of Medial Shoulder Instability in a Dog Treated with Synthetic Implant, Cortical Button, and Interference Screw

Julien Letesson[1] Antonin Crumière[2] Bastien Goin[2,3,4]

[1] Clinique Vétérinaire Lameilhé, Castres, France
[2] Novetech Surgery, Nice, France
[3] Université de Lyon, VetAgro Sup, Interactions Cellules Environnement, Marcy l'Etoile, France
[4] Univ Lyon, Univ Gustave Eiffel, Univ Claude Bernard Lyon 1, Laboratoire de Biomécanique et Mécanique des Chocs, Lyon, France

Address for correspondence Julien Letesson, DVM, DESV Chirurgie, CES d'Orthopédie, DU Microchirurgie, Clinique vétérinaire Lameilhé, 36 Rue François Couperin, 81100 Castres, France (e-mail: julien.letesson@vetocastres.fr).

VCOT Open 2024;7:e59–e68.

Abstract

Objective The objective of this study was to describe the surgical procedure and long-term outcome of traumatic medial shoulder instability in one dog treated with an ultra-high molecular weight polyethylene implant.

A Fox Terrier had traumatic medial shoulder instability caused by the disruption of the subscapularis muscle and medial glenohumeral ligament. The joint was stabilized through a medial approach with an ultra-high molecular weight polyethylene implant secured on the glenoid by a cortical button and on the humerus by an interference screw. Postoperative and follow-up examinations were performed at 1, 2, 4.5 months, and 2.5 years.

Results The patient bore weight after surgery and resumed normal gait after 2 months. Both the scapular and humeral tunnels had widened, essentially at their medial entrance, at 1 month postoperatively.

Entrance diameter increased for 2 months and remained unchanged thereafter. An increase of 35 degrees in the abduction angle was observed in the long term at the 2.5-year control with minor osteoarthritis. No implant loosening, medial laxity, excessive abduction angle, inflammation, or septic reaction were observed.

Conclusion The treatment of this case resulted in a satisfactory clinical outcome despite tunnel widening. This modified method using an interference screw could thus be considered as an alternative treatment of medial shoulder instability.

Keywords
- dog
- interference screw
- medial glenohumeral ligament
- medial shoulder instability
- synthetic ligament reconstruction

Introduction

Medial shoulder instability (MSI) can cause pain and forelimb lameness in dogs.[1–4] It may be of traumatic origin when a single event results in tearing or laxity of the shoulder's active and/or passive stabilizers that protect the joint.[1,5]

The medial glenohumeral ligament (MGHL) acts as passive stabilizer through its cranial and caudal branches inserting on the glenoid and the third branch on the humeral head, respectively.[1,6] Active stabilizers like the subscapularis muscle (SM) press the humeral head into the glenoid fossa.[1] Their

received August 4, 2023
accepted after revision May 5, 2024

DOI https://doi.org/10.1055/s-0044-1787563.
ISSN 2625-2325.

disruption causes dysfunction of the joint with medial shoulder luxation and increased external rotation and abduction angle.[1,5] Grading of MSI depends on the degree of impairment of the structures involved.[7]

Manipulation of the joint and measurement of the abduction angle are essential for the diagnosis of shoulder instability.[2] This test has good sensitivity but low specificity.[5,8] Other examinations like stress radiography may be required to assess pathological joint laxity.[9] Magnetic resonance imaging (MRI),[10] computed tomography (CT),[11] and arthroscopy[8] allow to assess integrity of the stabilizers and cartilage.

Surgical management is particularly recommended to treat acute traumatic affection with moderately to severely affected MGHL causing medial or multidirectional shoulder instability.[3,7] Treatments include, among others, the imbrication of the SM[12] and prosthetic MGHL repair using synthetic implants fixed by suture anchors,[13] screws with spiked washers,[14] toggle sutures,[4,7] or knotless anchors.[15] Although interference screws (IS) associated with synthetic implants have already been used in various ligament reconstructions,[16,17] they have never been explored to treat MSI. We thus report the surgical management and long-term outcome of traumatic MSI in a small-breed dog treated by imbrication of the SM and extra-articular stabilization using a synthetic implant and an IS.

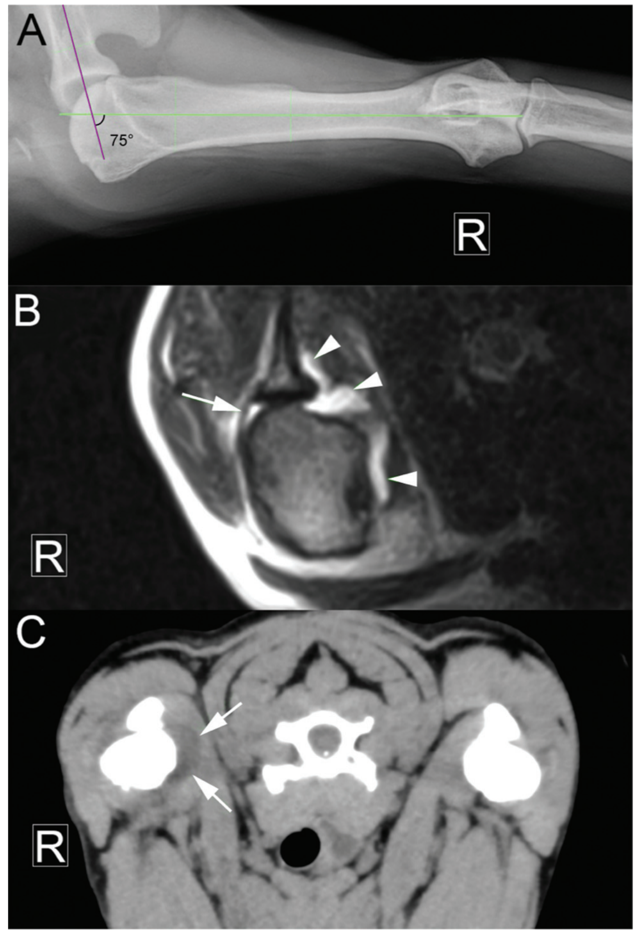

Fig. 1 Preoperative diagnostic imaging. (**A**) Caudocranial stress radiograph of right shoulder showing a 75-degree abduction angle. (**B**) Dorsal T2-weighted magnetic resonance imaging (MRI) showing lateral glenohumeral ligament (arrow). Medial glenohumeral ligament and distal part of subscapularis muscle are not visible (arrowheads). (**C**) Postcontrast transverse computed tomography showing swelling on medial aspect of right shoulder (arrows). Complete examination of the right shoulder using MRI included sagittal and transverse high-resolution turbo spin echo T2-weighted images, sagittal and transverse spin echo T1-weighted images, transverse turbo 3D T1-weighted images, and sagittal gradient echo T2-weighted images.

Case Description

Clinical History

A 13-kg, 10-year-old sterilized female Fox Terrier was presented with a 1-month history of nonweight-bearing right forelimb lameness following a fight with another dog.

Clinical Examination

The general examination and complete haematological and biochemical assessment were normal.

Orthopaedic Examination

Severe muscle atrophy of the right shoulder was evident. The flexion of the shoulder was painful. Shoulder dislocation could be elicited by humeral abduction and external rotation, suggesting high-grade MSI. The neurological examination was normal. A complementary orthopaedic examination was performed under anesthesia, during which an excessive abduction angle of the shoulder joint compared with the contralateral limb was noted.

Diagnostic Imaging

All diagnostic imaging procedures were performed during a single session in anesthesia. First, orthogonal radiographs (flat screen detector, Ibis, Italy) of the right forelimb revealed mild new bone formation on the medial aspect of the neck of the scapula without major signs of osteoarthritis. No fracture was identified. Stress radiographs confirmed MSI with a 75-degree abduction angle at the intersection of the scapular and humeral anatomical axes[9] (►**Fig. 1A**).

Second, an MRI (VetMR, 0.18T, Esaote, Italy) examination of the right shoulder highlighted an increase in synovial fluid volume. The MGHL and the insertion of the SM were not clearly identified. The lateral glenohumeral ligament, the insertion of the infraspinatus and supraspinatus muscles, and the biceps tendon appeared normal (►**Fig. 1B**).

Third, CT (Canon Aquilion Lightning 32, 120 KVp, 120 mAs, $0.430 \times 0.430 \times 0.5\,mm^3$ voxel size) of the right forelimb and cervicothoracic spine (C5 to Th3) was performed before and after an intravenous injection of 600 mg I/kg of iodixanol (Visipaque, GE, United States). Radiographic findings were confirmed as there was mild bone production on the medial aspect of the scapular neck without fractures. Articular swelling was present, particularly on the medial side of the shoulder (►**Fig. 1C**).

Clinical and imaging findings (i.e., traumatic origin, absence of substantial radiographic signs of osteoarthritis, disruption of two unique medial stabilizers of the shoulder) indicated a grade 3 MSI[7] and the need for surgical stabilization.

Surgical Treatment

The patient received premedication and analgesia with 0.1 mg/kg/SC of morphine (morphine chlorhydrate, Aguettant) and 0.1 mg/kg IV of meloxicam (Metacam, Boehringer Ingelheim). Antibiotic prophylaxis consisted of 30 mg/kg/IV of cefazolin every 2 hours (Cefazolin, Panpharma). Anesthesia was induced with 0.5 mg/kg/IV of diazepam (Valium, Roche) combined with 2 mg/kg/IV of alfaxalone (Alfaxan, Dechra). After intubation, anesthesia was maintained with isoflurane (Isoflurin, Axience).

The dog was positioned in dorsal recumbency. The procedure was performed through a single craniomedial approach to the shoulder.[18] A remnant of the SM, the torn medial capsule, and a complete tear of the MGHL from its glenoid insertion were identified. The optimal positioning of the two bone tunnels was preplanned by CT scan. The entry point of the first tunnel was drilled at the center of an estimated line connecting the insertions of the cranial and caudal branches of the MGHL on the glenoid, near the articular surface (►**Fig. 2A–C**).[6] A Kirschner wire secured the entry point of the tunnel. The tunnel was given an oblique craniodorsal direction (i.e., the lateral exit was more cranial and dorsal than the medial entry point). This increased its length, thus maximizing bone stock to optimize anchorage, and avoided glenoid effraction. The orientation was validated by subjective assessment. A 4.0-mm cannulated drill-bit was used for slow medial to lateral drilling with constant irrigation. A second 3.5-mm tunnel was drilled perpendicular to the axis of the humerus with a medial entrance close to the joint line and just posterior to the lesser tubercle, to respect the insertion of the physiological MGHL (►**Fig. 2A–C**).[6] This tunnel aimed to be bicortical to maximize screw purchase in the bone and increase the surface in contact with the implant (►**Fig. 2E**). After drilling, the entrances of the tunnels were flushed to avoid any bone debris. Bone edges at tunnel entrances were smoothened with a countersink driver (DePuy Synthes) to avoid damaging implant fibers. The humeral tunnel was pretapped.

An ultra-high molecular weight polyethylene (UHMWPE) implant (Novalig 4000 Platine, Novetech Surgery, France) with a preassembled cortical button was used to maintain the reduction.

First, the cortical button was inserted blindly from the medial to the lateral side of the scapula through the bone tunnel, using a Mayo–Hegar needle holder (►**Fig. 2F**). It was gently pushed through the tunnel using a passing tube (Novetech Surgery, France), ensuring that it fully exited the tunnel laterally and trying to avoid penetrating overlying fascia or muscle. To secure the button in contact with the lateral cortex of the scapula, it was flipped like a toggle by exerting tension on the implant. A suture passer was used to push the implant through the humeral tunnel in a medial to lateral direction. The implant was maintained in a flat position. The suture passer was retrieved laterally without any additional approach. The implant was grabbed at the lateral side (►**Fig. 2D**) using a Mayo–Hegar needle holder and brought back cranially to the humerus medial side where tension was applied (►**Fig. 2G**). The latter was adjusted and temporarily secured by pulling the implant and rolling it around the Mayo–Hegar needle holder (►**Fig. 2G**). Restrained abduction, maintenance of joint coaptation, and normal range of motion in all plans were the criteria for validating optimal tension. Final fixation was achieved with a 4.5×20-mm titanium IS placed medially to laterally in the humeral tunnel (►**Fig. 2E, G**). We reconstructed the remnants of the joint capsule and reattached the SM by imbrication with a horizontal mattress suture pattern of 2–0 polydiaxonones.[12] The implant was positioned under the SM and outside the joint capsule. Owing to capsular tear, its complete reconstruction was unachievable, and part of the implant was in contact with humeral head cartilage. Rinsing and plane-by-plane closure were performed.

Immediate Postoperative Examination

A slightly reduced range of flexion of the shoulder with maintenance of joint coaptation was observed. Abduction was reduced due to the transfixation (►**Fig. 3**). The abduction angle was −11 degrees (indicating excessive adduction) owing to an inversion of the scapular and humeral anatomical axes at their intersection on stress radiographs (►**Fig. 4B**). Radiographs and CT confirmed the appropriate position of the implant and bone tunnels and correct restoration of the articulating surfaces (►**Fig. 3**).

Postoperative Management

Nonsteroidal anti-inflammatory drugs (Meloxicam, Metacam, Boehringer Ingelheim) were prescribed for 21 days. Hobbles were placed around the shoulder for 15 days. Gentle mobilization of the limb (passive range of motion of the shoulder three time a day) was thereafter prescribed with regular short walks for 1 month.

Long-Term Postoperative Examination

Postoperative examinations were performed at 1, 2, 4.5 months, and 2.5 years postoperatively. Each included orthogonal radiographs under sedation and CT.

The dog bore weight after surgery and resumed normal gait at 2 months postoperatively, while presenting increased joint amplitude with full recovery of shoulder flexion. At 2.5 years, the owner reported slight lameness after exercise, which spontaneously resolved with rest. Full restoration of the periscapular muscle mass was observed compared with the contralateral limb during the follow-up.

To evaluate the persistence of medial shoulder stability over time, the abduction angle was measured on stress radiographs.[9] The abduction angle was −4 degrees at 2 months (►**Fig. 4C**) and 31 degrees at 2.5 years (►**Fig. 4D**) postoperatively on the stress radiographs. Radiography at 1 month postoperatively did not allow comparable measurement. CT revealed a widening of the medial entrance of both the scapular and humeral tunnels after 1 month, which slightly increased up to the 2-month visit and then remained stable (►**Fig. 5**). Only mild bone remodeling of the lateral parts of the tunnels was observed during the entire follow-up, with no apparent signs of loosening of the IS and the cortical button (►**Fig. 5**). Comparable measurements were

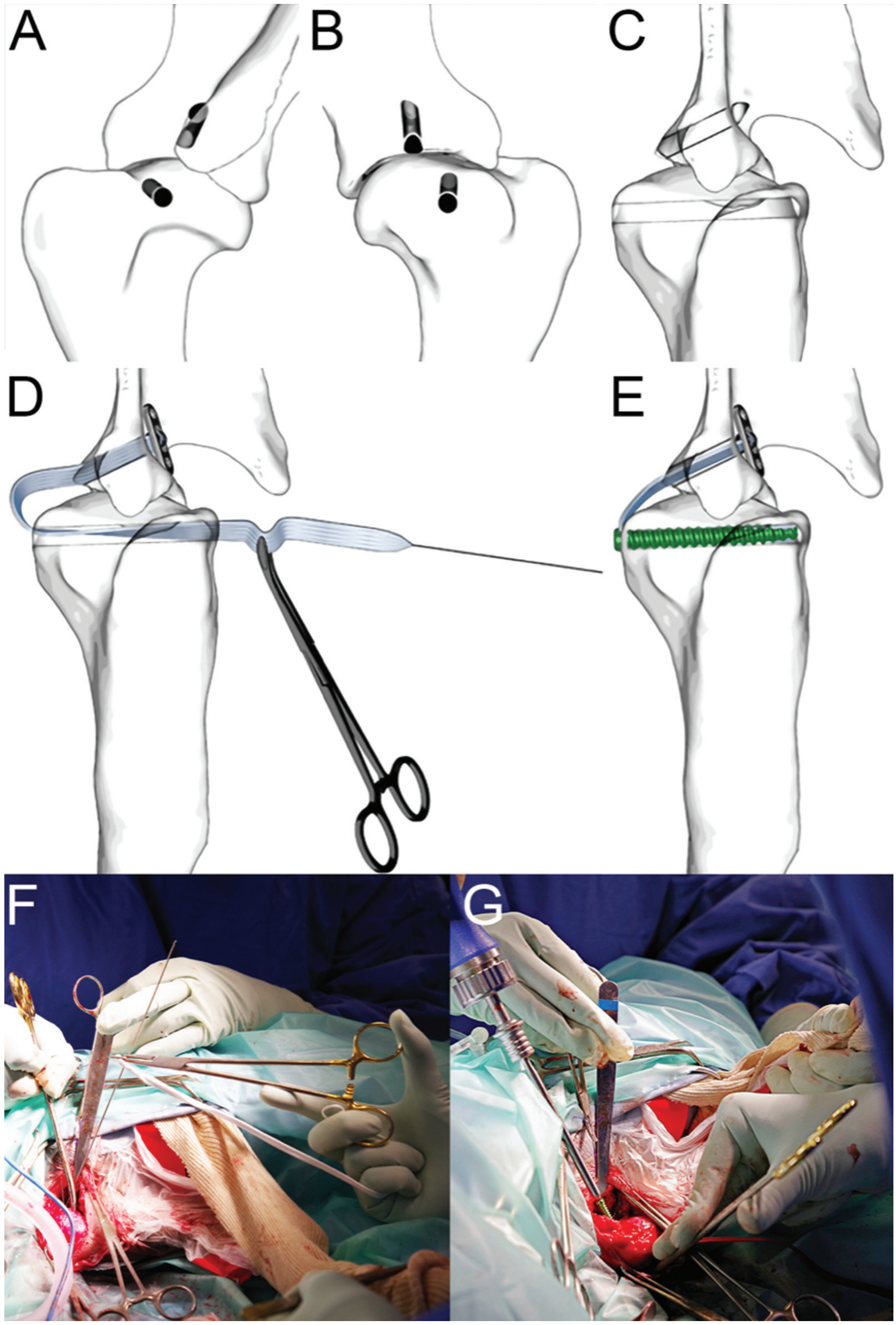

Fig. 2 Reconstruction technique and preoperative surgical views. (**A**) Lateral, (**B**) medial, and (**C–E**) frontal view of shoulder joint showing position of scapular and humeral tunnels. (**D**) Cortical button passed mediolaterally through scapular tunnel and flipped on lateral aspect of scapula cranially to acromion. Implant then passed mediolaterally through humeral tunnel, retrieved and tensioned with Mayo–Hegar needle holder. (**E**) Implant then secured by bicortical interference screw in humeral tunnel. (**F**) Placement of Novalig 4000 Platine implant. (**G**) Joint is held reduced (adduction and internal rotation) while implant is secured with interference screw in humerus.

available only for the medial entrance of the glenoid tunnel and indicated 4.1 mm immediately after the operation (►**Fig. 5I**), 5.6 mm at 1 month (►**Fig. 5J**), 6.2 mm at 2 months (►**Fig. 5K**), 6.1 mm at 4.5 months (►**Fig. 5L**), and 6.7 mm at 2.5 years (►**Fig. 5M**) postoperatively. At the 2.5-year visit, no contrast enhancement of the joint capsule or regional lymph node enlargement was observed on CT. The humeral screw seemed covered by bone (►**Fig. 3**) and no signs of screw

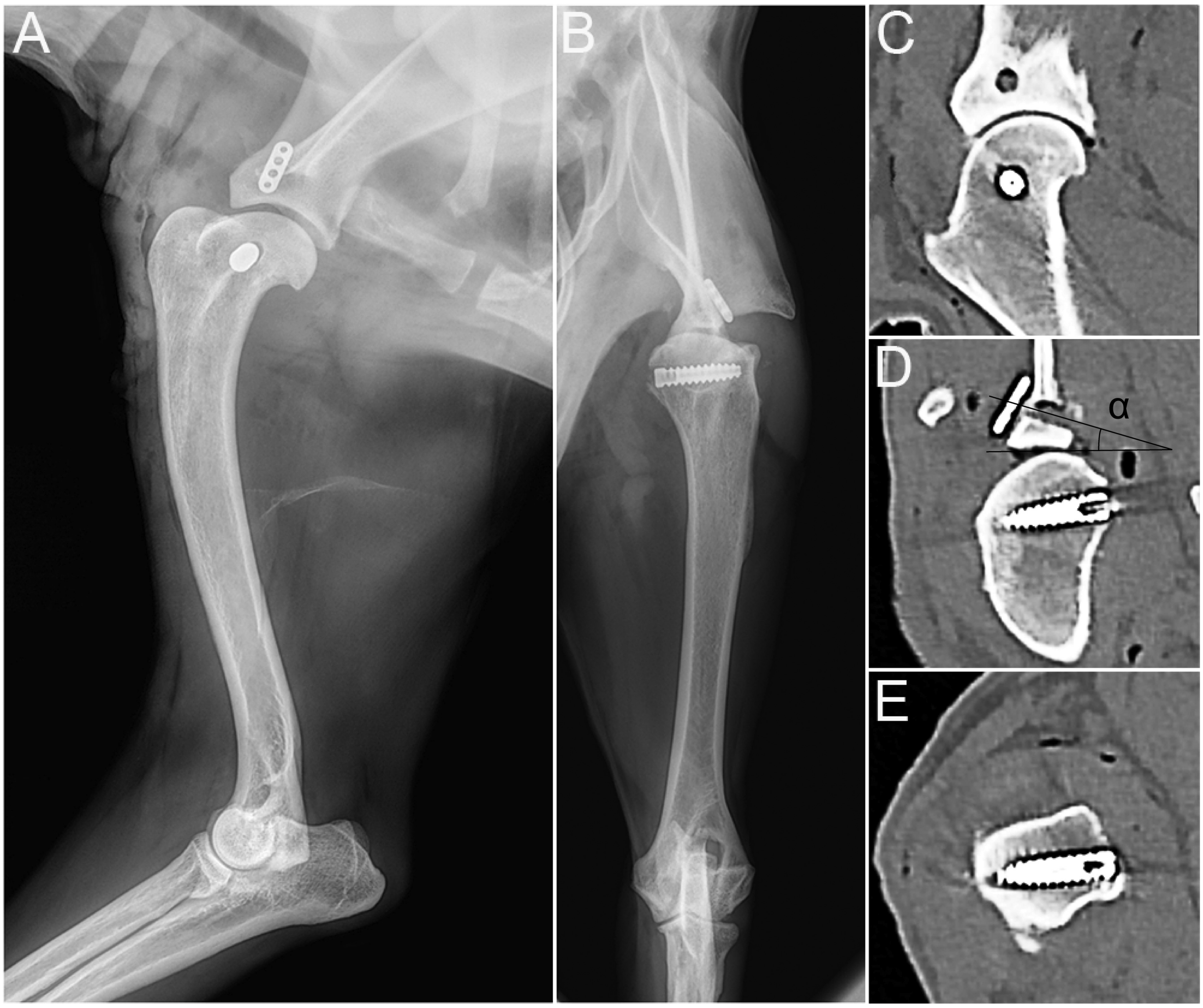

Fig. 3 Immediate postoperative imaging. (**A**) Mediolateral and (**B**) caudocranial radiographs of right shoulder. Multiplanar computed tomography reconstructions ([**C**] Sagittal, [**D**] dorsal, and [**E**] transverse) of right shoulder showing position of implant, interference screw, and tunnels. The angulation of the scapular tunnel (α) was 19 degrees from the glenoid surface on the sagittal plan.

intolerance were observed. Minor signs of osteoarthritis were present on the radiographs at 2.5 years.

A cytopathological analysis of the synovial fluid (microscopic observation of three smears) was performed at 2.5 years postoperatively. The paucicellular smears showed 90% of mononuclear cells of synoviocyte type and no granulocyte cells.

Discussion

Medial shoulder instability is a diagnostic[1,2,8] and therapeutic[7,12,14,15] challenge. In this traumatic case, painful shoulder instability was associated with excessive abduction of the shoulder along with major amyotrophy. A 75-degree abduction angle on stress radiography confirmed MSI.[9] This test seems to be sensitive for values above 53 degrees and correlated with shoulder abduction angles measured clinically under sedation.[9] However, it remains unspecific,[8,9,19] especially in the event of severe amyotrophy.

Magnetic resonance imaging and normal neurological examination confirmed the anatomical structures involved in the MSI[10] and excluded other major causes of neurological shoulder amyotrophy inducing “root signature” (i.e., plexus sheath tumor, brachial plexus avulsion).[20,21] It confirmed the disruption of the MGHL and the SM, with joint effusion compatible with a traumatic injury.

Computed tomography completed the evaluation of the joint[11] and confirmed the absence of fractures. It provided a 3D reconstruction of the joint, which helped to plan tunnel drilling for a safe placement of the implant. During the follow-up, CT helped to monitor and measure the enlargement of the tunnels.

However, we did not perform an arthroscopic evaluation of the joint, which could have provided information on cartilage integrity and intra-articular stabilizers. The small size of the joint and its disruption could have been risk factors for damage or fluid extravasation around it.

These findings justified surgical stabilization. The reconstruction and imbrication of the SM alone can be moderately effective to stabilize the shoulder.[12] Owing to the severe amyotrophy and grade 3 MSI in our case, we were concerned that SM imbrication might have been insufficient.

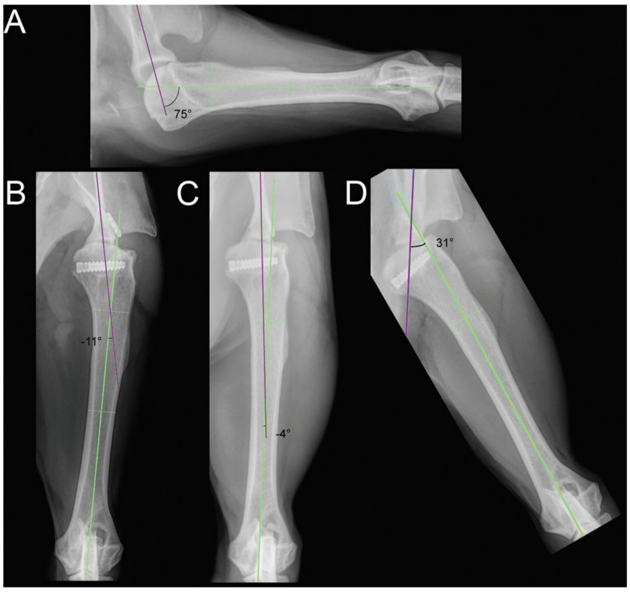

Fig. 4 Measurement of abduction angle. (**A**) Preoperative abduction angle of the right shoulder measured at 75 degrees, (**B**) at −11 degrees immediate postoperatively, (**C**) −4 degrees at 2 months, and (**D**) 31 degrees at 2.5 years postoperatively. The stress radiographs are oriented with the scapula in similar position to facilitate comparison. Abduction angles were measured at the intersection of the scapular and humeral anatomical axes as described in Livet methodology.[9] The measurement of abduction angle is subjected to approximation because of difficulty of scapula positioning. Negative values are due to the inversion of scapular (purple) and humeral (green) axis indicating excessive adduction.

The choice of a UHMWPE implant was based on the biocompatibility of its fibers[22] as well as the *ex vivo* biomechanical strength[23–25] and clinical versatility it demonstrated in various applications.[16,17] In the reported case, its flat and wide shape (compared with other implants[7]) helped to restore stability while reconstructing a single arm of the MGHL, previously shown to be sufficient for maintaining shoulder stability in young beagles.[26] Covering the joint with an implant fixed on a single point on the glenoid to stabilize MSI has previously been described with various implants and materials (spiked washers and screws, buttons and UHMWPE tape, anchors).[7,14,27] These reports seem to have obtained good clinical outcomes.[7,14]

The flat and wide section of the implant was expected to increase the contact area and the stability of the joint, especially by increasing stiffness.[28] A previous *ex vivo* study on hip stabilization has demonstrated the mechanical superiority of tape-type implants over string-like ones when using a toggle rod fixation to limit luxation.[28] In the shoulder, the TightRope system has shown 20% of reluxation (2/8 dogs presented with luxation or subluxation).[7]

The stiffness of the UHMWPE implant is close to that of the physiological ligament and joint capsule on feline hip cadaver models.[25] It seems to persist in the long-term follow-up, as suggested by the abduction angle, which remains below 53 degrees (i.e., the threshold value indicating an affected shoulder on stress radiographs).[9] However, these may be approximate measures as they depend on the reproducible orientation of the scapula during radiograph acquisitions. The implant is placed flush with the joint surface, thus limiting its working length and increasing its stiffness.[29] This was expected to limit an excessive range of motion of the joint.[29]

With the cortical button placed through a bone tunnel, it was possible to fix the implant on the scapula, which has limited bone stock. This positioning seemed appropriate to preserve the integrity of the glenoid rim, especially in a small dog. The safety implantation of anchors has only been studied in dogs above 20 kg,[30,31] whereas sutures with buttons have been used for scapular fixation in small dogs under 10 kg.[7,15] The wide flat implant required broad tunnels, which could be a limitation for the safety of the implantation and a risk for glenoid integrity. Using a cortical button avoided any concerns about the safety angle of the anchor or screw insertion and the associated risks of loosening.[15,27,30,31] Suture toggles have been suggested to have biomechanical advantages over knotless anchors, owing to the difficulty to implant and angulate anchors.[27,31] Indeed, reaching the optimal anchor insertion angle for the greatest pullout resistance (i.e., "deadman's angle") is difficult yet essential to achieve satisfactory implantation and decrease the risks of loosening.[31]

Medial implantation without a minimal lateral approach (as discussed in[7]) could be advantageous. In theory, careful implantation without penetrating the overlying soft tissues should limit the risk of entrapping the suprascapular nerve with the button.[7] It also helps to place the button tightly against the bone since it only needs to be flipped and pushed down just after having exited the scapular tunnel.[7] Finally, it limits the risk of seroma on the lateral part of the shoulder and the subsequent risk of sepsis on a pressure point when the patient lies down.[7] However, entrapping soft tissues is a risk in this procedure, which could lead to an early change in implant tensioning.

The IS placed in the humerus provided a fixation system with an important pull-out strength.[24] It avoided the use of a knot fixation that tends to slip with UHMWPE,[32] which might be a limitation of toggle pin implants. It also had the advantage of being totally embedded inside the bone allowing to fix the implant near the humeral insertion of the MGHL[6] and the articular space. It avoided any conflict with the joint or abrasion risks for the implant and surrounding tissues, unlike with eyelet anchors.[33] It avoided the use of screws associated with spiked washers, which have a tendency to loosen in this area.[14] The use of an IS could be an advantage over knotless anchors or spiked washers and screws as the tension can be preadjusted. In our case, tension was adjusted with a Mayo–Hegar needle holder. This surgical instrument provided an optimal grip of the implant due to the tungsten carbide, which prevented UHMWPE slipping,[32] when tensioning by rolling the implant around it. Joint mobility was then tested before securing the final tension with the IS.

Follow-up examinations revealed a widening of the medial part of both tunnels at implant/tunnel interface, associated with recovery of normal flexion amplitude at the 2-month visit. Tunnel widening has been described after 1 month

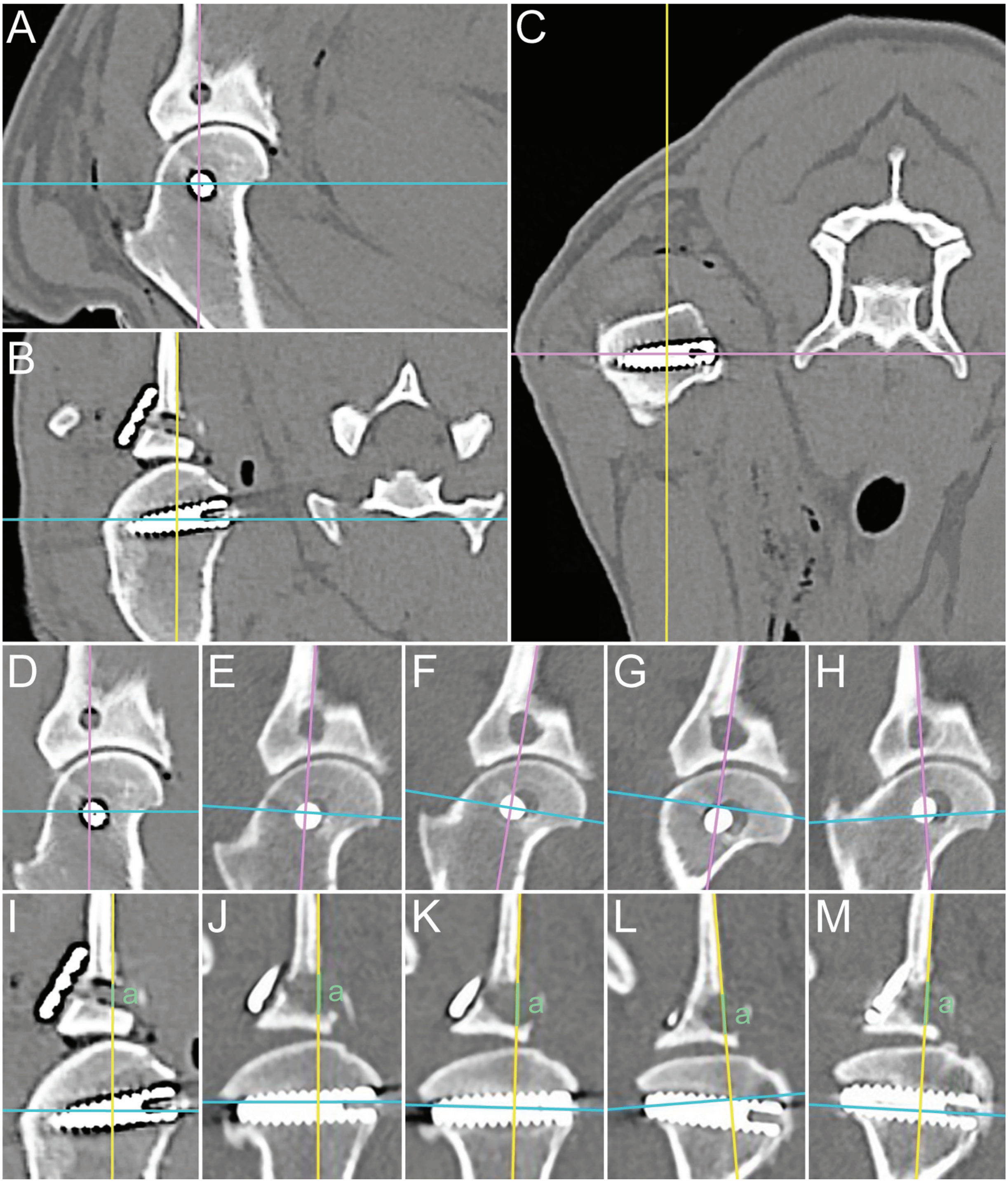

Fig. 5 Evolution of tunnels over time. Immediate postoperative computed tomography (CT) multiplanar reconstruction (MPR) ([**A**] sagittal, [**B**] frontal, and [**C**] transverse) of right shoulder. Sagittal CT imaging of right shoulder (**D**) immediate postoperatively, and at (**E**) 1 month, (**F**) 2 months, (**G**) 4.5 months, and (**H**) 2.5 years postoperatively. Frontal CT imaging of right shoulder (**I**) immediate postoperatively, and at (**J**) 1 month, (**K**) 2 months, (**L**) 4.5 months, and (**M**) 2.5 years postoperatively. MPR was used to acquire appropriate planes to perform standardized approximation of measurements of largest diameter of scapular tunnel during follow-up:

- Yellow line is parallel to medial cortex of scapula (**B**, **I–M**).
- Purple line passes through center of the two tunnels (**A**, **D–H**).
- Medial entrance of glenoid tunnel (green line symbolized by the letter “a” overlapping yellow line) was + 36.6% at 1 month (**J**), + 51.2% at 2 months (**K**), + 48.8% at 4.5 months (**L**), and + 63.4% at 2.5 years (**M**) postoperatively.

Deformation percentage expressed relatively to immediate postoperative measure. MPR did not provide satisfactory planes to measure humeral tunnel.

postoperatively in feline[34] and canine hip surgeries[35] after the use of a toggle rod and UHMWPE implant. In human knee surgery, the use of IS and cortical buttons with tendinous grafts can also be associated with bone tunnel widening.[36,37] Biological etiologies may explain this phenomenon, which includes thermal bone necrosis due to drilling,[38] immune response to UHMWPE,[39] and influx of synovial fluid containing cytokines into tunnels.[36]

A cannulated drill bit was used. It is known to produce more heat than regular drill bits.[40] Despite an appropriate drilling technique, potential thermal cell damage causing an enlargement of the bone tunnels cannot be completely excluded.

Biomechanical forces may also be a cause for tunnel deformation. A "bungy cord" effect due to excessive tension and/or micromovements of the implant during bone healing might cut into the bone.[36,41] The asymmetry of the tunnel deformation supports the biomechanical hypothesis.

The flat shape of the implant may have limited this deformation since it has lower risks of cutting into the bone than a round suture, as described in stifle surgery.[41] The orientation of the scapular tunnel might also have influenced the deformation. The angulation of the scapular tunnel was done at 19 degrees from the glenoid surface to avoid a sharp exit angle (►**Fig. 3D**). In stifle joint surgery, an angulation of 30 to 45 degrees was recommended to optimize implant transition, which could be an improvement of the technique.[41]

During surgery, the joint was held in excessive adduction when tensioning the implant to maintain joint coaptation and facilitate SM imbrication. On the one hand, this may have resulted in excessive tension on the implant, which may then have exerted pressure on the bone. Excessive tension could lead to immediate damage to the bone tunnel. On the other hand, potential initial overtensioning might have compensated for any subsequent loss of tension during recovery, as it did not negatively influence the outcome in terms of abduction angle, which remained in the physiological value range.[9] Overtensioning may help to protect the soft tissues during healing as the implant acts as a mechanical brace. Reconstructing the two arms of the MGHL could also help distribute the pressure exerted by a single implant and limit tunnel deformation.

Tunnel deformation might have contributed to a loss of tension of the implant, which may partly explain the increased abduction angle observed at 2.5 years postoperatively. However, since the abduction angle increased by 35 degrees between 2 months and 2.5 years postoperatively despite the stabilization of the scapular tunnel deformation, other causes such as loss of tension due to implant slippage at the IS/bone interface is possible. It is the most common mode of failure of this fixation system.[42] Alteration in the mechanical properties of the implant due to cyclic load is another possible cause.[24]

Determining the appropriate tension, tunnel angulation and rest period should limit the biomechanical stress exerted on the tunnel bone, thus limiting the widening effect.[41]

Two major differences between the reported procedure and human surgery should be highlighted. First, tunnel deformation seems uniform along the tunnel axis in humans, suggesting biological causes.[36,37] Second, fixation with a cortical button seems to be associated with lesser tunnel deformation than with IS in humans.[36,37] However, this comparison has limitations since the grafts, the IS material and the joints are different.[36,37]

Despite tunnel deformation that may compromise the mechanical integrity of the fixation,[41] the patient's long-term outcome was satisfactory from a clinical functional aspect (i.e., joint stability, muscle mass recovery). Long-term shoulder stability may result from the combination of the stabilization provided by the implant, SM imbrication, and partial capsular reconstruction. The procedure allowed the patient to quickly resume limb weight-bearing, thus leading to muscle mass and active stabilizers recovery, and to the development of periarticular healing structures.[14]

Further investigations are needed to determine whether this satisfactory outcome in one case is reproducible, to define the causes of tunnel widening and to determine the optimal tension of the implant. A cutoff tunnel deformation value that could affect clinical outcome should also be established.[37] Finally, since this outcome is in line with previously published results,[7,13–15] this modified stabilization method using an IS could be considered as a possible improvement for the treatment of MSI.

Author Contributions

J.L. examined the patient, diagnosed the pathology, performed surgery, performed follow-up visits, analysed data, and revised the manuscript. A.C. and B.G. analysed data, wrote and revised the manuscript.

Funding

This study received no external funding.

Conflict of Interest

A.C. and B.G. are employed by Novetech Surgery. The authors have no additional conflict to declare.

Acknowledgments

The authors thank Mrs Cooke-Martageix E. for copyediting and thank Pr. Paul Barthez, DVM, DACVR, DECVDI, for his advice in interpreting diagnostic imaging studies. The authors are grateful to Dr. Jérôme Abadie, DVM, PhD, DECVP, for cytopathological analysis and interpretation. The authors express their gratitude to Dr. Thibaut Cachon, DVM, PhD, DECVS, for his insightful contribution to the discussion.

References

1 Bardet JF. Diagnosis of shoulder instability in dogs and cats: a retrospective study. J Am Anim Hosp Assoc 1998;34(01):42–54
2 Cogar SM, Cook CR, Curry SL, Grandis A, Cook JL. Prospective evaluation of techniques for differentiating shoulder pathology as

a source of forelimb lameness in medium and large breed dogs. Vet Surg 2008;37(02):132–141
3 Franklin SP, Devitt CM, Ogawa J, Ridge P, Cook JL. Outcomes associated with treatments for medial, lateral, and multidirectional shoulder instability in dogs. Vet Surg 2013;42(04):361–364
4 Woolley ELE, Collyer TA, Finch SJ, House AK. Medial shoulder instability: prevalence and treatment outcomes in 17 poodles and 31 dogs of other breeds. VCOT Open 2023;6(02):e107–e113
5 Cook JL, Renfro DC, Tomlinson JL, Sorensen JE. Measurement of angles of abduction for diagnosis of shoulder instability in dogs using goniometry and digital image analysis. Vet Surg 2005;34 (05):463–468
6 Diekmann C, Winkels P, Fehr M, von Freeden N, Harms O. Radiographische Lokalisation der Ansatz- und Ursprungspunkte des medialen glenohumeralen Bandes beim Hund. Tierarztl Prax Ausg K Klientiere Heimtiere 2016;44(06):389–396
7 O'Donnell EM, Canapp SO Jr, Cook JL, Pike F. Treatment of medial shoulder joint instability in dogs by extracapsular stabilization with a prosthetic ligament: 39 cases (2008-2013). J Am Vet Med Assoc 2017;251(09):1042–1052
8 Devitt CM, Neely MR, Vanvechten BJ. Relationship of physical examination test of shoulder instability to arthroscopic findings in dogs. Vet Surg 2007;36(07):661–668
9 Livet V, Harel M, Taroni M, et al. Stress radiography for the diagnosis of medial glenohumeral ligament rupture in canine shoulders. Vet Comp Orthop Traumatol 2019;32(06):433–439
10 Schaefer SL, Forrest LJ. Magnetic resonance imaging of the canine shoulder: an anatomic study. Vet Surg 2006;35(08):721–728
11 De Rycke LM, Gielen IM, Dingemanse W, Kromhout K, van Bree H. Computed tomographic and low-field magnetic resonance arthrography: a comparison of techniques for observing intra-articular structures of the normal canine shoulder. Vet Surg 2015;44(06):704–712
12 Pettitt RA, Clements DN, Guilliard MJ. Stabilisation of medial shoulder instability by imbrication of the subscapularis muscle tendon of insertion. J Small Anim Pract 2007;48(11):626–631
13 Fitch RB, Breshears L, Staatz A, Kudnig S. Clinical evaluation of prosthetic medial glenohumeral ligament repair in the dog (ten cases). Vet Comp Orthop Traumatol 2001;14(04):222–228
14 Hammer M, Grand JG. Inverted V-shaped extracapsular stabilisation technique and arthroscopic findings in six dogs with medial shoulder instability. J Small Anim Pract 2021;62(09):795–804
15 Penelas A, Pozzi A, Stańczyk E, Gutbrod A. Arthroskopisch-assistierte Stabilisation einer medialen Schulterinstabilität bei einem Zwergpudel. Schweiz Arch Tierheilkd 2018;160(09):533–538
16 Buttin P, Santoro V, Agbalé M, et al. Long-term outcome following synthetical reconstruction of the medial collateral tarsal ligament in a dog. Open Vet J 2022;12(03):375–382
17 Fauqueux F, Goin B, Agbalé M, et al. Intra-articular replacement of the caudal cruciate ligament using a UHMWPE ligament under arthroscopic guidance in a dog: a case report. Open Vet J 2023;13 (07):948–954
18 Hohn RB, Rosen H, Bohning RHJ Jr, Brown SG. Surgical stabilization of recurrent shoulder luxation. Vet Clin North Am 1971;1 (03):537–548
19 Cook JL, Tomlinson JL, Fox DB, Kenter K, Cook CR. Treatment of dogs diagnosed with medial shoulder instability using radiofrequency-induced thermal capsulorrhaphy. Vet Surg 2005;34 (05):469–475
20 Kerwin SC, Taylor AR. Neurologic causes of thoracic limb lameness. Vet Clin North Am Small Anim Pract 2021;51(02):357–364
21 King R. Advanced imaging of the forelimb: use of musculoskeletal ultrasound and MRI of the shoulder and brachial plexus. Vet Clin North Am Small Anim Pract 2021;51(02):383–399
22 Smith PA, Bozynski CC, Kuroki K, Henrich SM, Wijdicks CA, Cook JL. Intra-articular biocompatibility of multistranded, long-chain polyethylene suture tape in a canine ACL model. J Knee Surg 2019; 32(06):525–531
23 Buttin P, Goin B, Crumière AJJ, et al. *Ex-vivo* biomechanical analysis of an original repair of canine calcaneal tendon rupture using a synthetic implant as mechanical support fixed by sutures in the proximal tendinous part and by an interference screw in the bone distal part. Open Vet J 2023;13(05):645–653
24 Goin B, Buttin P, Lafon Y, Massenzio M, Viguier E, Cachon T. Biomechanical cyclic loading test of a synthetic ligament fixation system used for intra-articular stabilization of deficient canine stifles. Open Vet J 2022;12(03):341–350
25 Letesson J, Goin B, Viguier E, Cachon T. Validation of a biomechanical testing protocol of craniodorsal hip luxation in feline cadavers and comparison of two ultra-high molecular weight polyethylene materials used for extra-articular hip stabilisation. J Feline Med Surg 2022;24(10):e360–e369
26 Fujita Y, Yamaguchi S, Agnello KA, Muto M. Effects of transection of the cranial arm of the medial glenohumeral ligament on shoulder stability in adult Beagles. Vet Comp Orthop Traumatol 2013;26(02):94–99
27 Llido M, Livet V, Carozzo C, Viguier É, Cachon T. Treatment of medial shoulder joint instability by stabilization with an arthroscopically guided prosthetic ligament: a cadaveric feasibility study in dogs. Vet Comp Orthop Traumatol 2023;36(01):1–9
28 Baltzer WI, Schulz KS, Stover SM, Taylor KT, Kass PH. Biomechanical analysis of suture anchors and suture materials used for toggle pin stabilization of hip joint luxation in dogs. Am J Vet Res 2001;62(05):721–728
29 Scheffler SU, Südkamp NP, Göckenjan A, Hoffmann RFG, Weiler A. Biomechanical comparison of hamstring and patellar tendon graft anterior cruciate ligament reconstruction techniques: the impact of fixation level and fixation method under cyclic loading. Arthroscopy 2002;18(03):304–315
30 Penelas A, Gutbrod A, Kühn K, Pozzi A. Feasibility and safety of arthroscopic medial glenohumeral ligament and subscapularis tendon repair with knotless anchors: a cadaveric study in dogs. Vet Surg 2018;47(06):817–826
31 Rocheleau PJ, Holz KA, Peura AH. Ex vivo evaluation of arthroscopically assisted shoulder stabilization in dogs using an intraarticular aiming device. Vet Surg 2023;52(04):564–574
32 Barber FA, Herbert MA, Beavis RC. Cyclic load and failure behavior of arthroscopic knots and high strength sutures. Arthroscopy 2009;25(02):192–199
33 Kunkel KAR, Rusly RJ, Basinger RR, DesJardins JD, Gerard PD. In vitro acute load to failure and eyelet abrasion testing of a novel veterinary screw-type mini-anchor design. Vet Surg 2013;42(02): 217–222
34 Knell SC, Longo F, Wolfer N, Schmierer PA, Hermann A, Pozzi A. Outcome and complications following stabilization of coxofemoral luxations in cats using a modified hip toggle stabilization-a retrospective multicentre study. Vet Comp Orthop Traumatol 2023;36(04):218–224
35 Kieves NR, Lotsikas PJ, Schulz KS, Canapp SO. Hip toggle stabilization using the TightRope® system in 17 dogs: technique and long-term outcome. Vet Surg 2014;43(05):515–522
36 Buelow JU, Siebold R, Ellermann A. A prospective evaluation of tunnel enlargement in anterior cruciate ligament reconstruction with hamstrings: extracortical versus anatomical fixation. Knee Surg Sports Traumatol Arthrosc 2002;10(02):80–85
37 Mayr R, Smekal V, Koidl C, et al. ACL reconstruction with adjustable-length loop cortical button fixation results in less tibial tunnel widening compared with interference screw fixation. Knee Surg Sports Traumatol Arthrosc 2020;28(04):1036–1044
38 Mediouni M, Kucklick T, Poncet S, et al. An overview of thermal necrosis: present and future. Curr Med Res Opin 2019;35(09): 1555–1562
39 Kandahari AM, Yang X, Laroche KA, Dighe AS, Pan D, Cui Q. A review of UHMWPE wear-induced osteolysis: the role for early detection of the immune response. Bone Res 2016;4(01):16014

40 Palmisano AC, Tai BL, Belmont B, Irwin TA, Shih A, Holmes JR. Comparison of cortical bone drilling induced heat production among common drilling tools. J Orthop Trauma 2015;29(05): e188–e193
41 Corse M, Holsworth IG. Complications associated with extracapsular stabilization using multifilament material. In: Ben-Amotz R, Dycus DL, editors. Complications in Canine Cranial Cruciate Ligament Surgery. Hoboken:: Wiley-Blackwell;; 2022:121–143
42 Blanc Q, Goin B, Rafael P, et al. Effect of the number of interference screws for the fixation of an intra-articular cranial cruciate ligament prosthesis in dogs: biomechanical study. Comput Methods Biomech Biomed Engin 2019;22(01):S102–S104

Corrigendum: A corrigendum has been published for this article (DOI: 10.1055/s-0044-1788640).