COMPANION OR PET ANIMALS

Minimally invasive osteosynthesis of a distal humeral Salter-Harris type II fracture by percutaneous pinning

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SUMMARY
A 13.2-kg, skeletally immature German shepherd dog presented with acute onset non-weight-bearing right forelimb lameness. A mildly displaced, distal humeral Salter-Harris type II fracture was diagnosed using radiographs and CT scan which demonstrated a characteristic ‘corner’ sign. Closed reduction was achieved using ligamentotaxis and stabilisation was performed via percutaneous pinning under fluoroscopic guidance. Physical examination and diagnostic imaging were repeated at 1 month postoperatively with telephone communication and Canine Brief Pain Inventory being completed 12 months postoperatively. Clinical union was documented radiographically 4 weeks postoperatively. Minimal lameness was noted clinically, reported to have resolved 2 weeks thereafter. Long-term outcome was excellent with both pain severity score and pain interference score being zero. This is the first detailed report of a distal humeral Salter-Harris type II fracture in the veterinary literature. Principles of minimally invasive osteosynthesis were applied to achieve closed reduction and stabilisation with excellent long-term clinical outcome.

BACKGROUND
Open reduction and internal fixation (ORIF) has traditionally been considered the standard-of-care for physeal fractures which are categorised using the Salter-Harris classification. While an open approach is reported to facilitate fracture reduction, restoration of anatomical alignment and accurate implant placement, surgeons must remain aware of the importance of preserving the surrounding soft tissue and blood supply.

As an alternative to ORIF, minimally invasive osteosynthesis (MIO) has grown in popularity in veterinary medicine since its recognition as a new standard-of-care for various fracture types in humans. MIO emphasises soft-tissue preservation over anatomical reduction and absolute mechanical stability. Advanced imaging technologies such as arthroscopy and fluoroscopy may be used to facilitate reduction and guide implant placement. When fracture reduction and stabilisation are achieved via a closed approach, potential advantages include reduced soft-tissue damage, preservation of periosteal blood supply and fracture haematoma, reduced infection risks and an earlier return to function.

The most commonly encountered type of distal humeral physeal fracture is the Salter Harris type IV of the lateral humeral condyle (LHC). These are traditionally repaired via open reduction and transcondylar lag screw placement, with or without the addition of an anti-rotational K-wire. Type III fractures of the medial humeral condyle have also been reported to be stabilised with fixation that mirrors that of the traditional type IV LHC fracture repair. A technique for fluoroscopically guided closed reduction with internal fixation of LHC fractures has been described and determined to be an effective technique with all dogs regaining 90–100 per cent of full function.

To the authors’ knowledge, descriptions of Salter-Harris type II humeral condylar fractures (HCFs) are limited to brief remarks within case series. While one case series reports that 16 per cent of HCFs in skeletally immature dogs are of this type, there are no comprehensive reports detailing the imaging findings, stabilisation techniques and outcome following these fractures in the veterinary literature. In addition, despite these fractures arguably representing ideal cases for a minimally invasive approach, the use of MIO to stabilise type II HCFs has never been reported. The objective of this report therefore is twofold: to describe a case of this unusual injury and detail the minimally invasive approach used for stabilisation along with the long-term outcome.

CASE PRESENTATION
A 3-month-old intact female German shepherd dog weighing 13.2 kg was presented to the emergency service 24 hours after sustaining vehicular trauma. Initial evaluation revealed a non-weight-bearing right forelimb lameness. There was pronounced soft-tissue swelling associated with the distal humerus with a marked pain response and crepitus elicited on right elbow manipulation.

INVESTIGATIONS
Orthogonal radiographs of the both humeri were performed. A mildly displaced Salter-Harris type II fracture of the right, distal humerus was noted (figure 1). The dog was hospitalised and maintained on a continuous rate infusion (CRI) of sufentanil (Sufenta; Janssen Pharmaceuticals) at 0.4 µg/kg/h intravenously overnight. A CT scan was performed the following day which confirmed the radiographic findings (figure 2).

TREATMENT
In preparation for surgery, the patient was pre-medicated with 1 µg/kg dexmedetomidine (Dexdomitor; Zoetis) and a 0.2 µg/kg bolus
sufentanil intravenously. Anaesthetic induction was performed with 1.6 mg/kg propofol (PropoFlo; Zoetis) and 1.6 mg/kg ketamine (Ketaset; Zoetis) intravenously, and the dog was maintained on isoflurane inhalant. A brachial plexus block was performed with 2 mg/kg ropivacaine (Naropin; Fresenius Kabi USA) perineurally.

The dog was placed in left dorsolateral recumbency, with the entire right forelimb prepared using a hanging limb technique. Using vacuum conforming bags (Olympic Medical, Seattle, WA), the chest was elevated from the surgical table to allow unrestricted manoeuvering of a Hologic Insight 2 Mini C-Arm (Hologic, Marlborough, MA) around the elbow. Before the final aseptic limb preparation, orthogonal fluoroscopic images of the right elbow were obtained to ensure that the fracture could be imaged throughout surgery. Using ligamentotaxis techniques, indirect closed reduction of the fracture was achieved via antebrachial traction, as well as forced abduction and supination either sequentially or simultaneously. Anatomical reduction was confirmed fluoroscopically. Twenty-five-gauge needles were inserted at the lateral and medial borders of the distal humeral physis to act as fiducial landmarks. Under fluoroscopic guidance, a 12G hypodermic needle was anchored distal and caudal to the lateral epicondyle at approximately 65 degrees to the physis to serve as both a tissue guard and a drill guide. A 2.0-mm K-wire was progressively advanced through the hypodermic needle using a handheld power drill. As the K-wire engaged the metaphyseal fracture fragment, appropriate placement was confirmed in two planes (figure 3). The K-wire was then driven through the trans cortex of the distal humeral diaphysis. A second, 12G hypodermic needle was placed similarly entering distal and caudal to the medial epicondyle. Again, appropriate placement was confirmed before driving a 2.0-mm K-wire through the needle to exit the trans cortex at the level of the greater tubercle. Intraoperative fluoroscopy was used to evaluate fracture reduction and implant placement; the K-wires crossed at the junction of the distal and middle thirds of the humerus, proximal to the fracture site (figure 4). Small stab incisions were made to allow the K-wires to be cut short. The stab incisions were closed with 2-0 Ethilon (Johnson and Johnson). Postoperative orthogonal radiographs were performed to confirm appropriate alignment, apposition and implant placement (figure 5). No external coaptation was applied.
Postoperatively, the intravenous sufentanil CRI was continued with the addition of carprofen (Rimadyl, Zoetis, 2.2 mg/kg subcutaneously) every 12 hours. On day 2 of hospitalisation, injectable carprofen and sufentanil were discontinued and oral analgesics instituted in preparation for discharge. Amantadine (Symmetrel, Sandoz, 4.0 mg/kg by mouth once daily), carprofen (Rimadyl, Zoetis, 1.85 mg/kg by mouth twice daily) and trazodone (Trazodone hydrochloride, Teva, 3.7 mg/kg by mouth once daily) were continued after discharge for 2 weeks. The dog was discharged from the hospital 24 hours after surgery with instructions to restrict activity to leash walks and return for clinical and radiographic follow-up at 4 weeks postoperatively.

OUTCOME AND FOLLOW-UP
At 1-month follow-up, mild forelimb lameness was apparent with no pain or crepitus elicited on right elbow manipulation. Orthogonal radiographs were repeated under sedation (butorphanol 0.2 mg/kg intravenously, dexmedetomidine 5 µg/kg intravenously) which showed clinical union and bony remodelling around the fracture site with no evidence of implant failure or growth deformity (figure 6).

One year postoperatively, telephone communication with the owner including completion of the Canine Brief Pain Inventory (CBPI)\textsuperscript{18} indicated an excellent long-term outcome. The pain severity score and pain interference scores were both zero and...
the quality of life was deemed excellent. Furthermore, the owner described that lameness had resolved approximately 2 weeks following the last appointment (6 weeks postoperatively).

DISCUSSION

The novelty of the case described is twofold, both in the fracture configuration and the minimally invasive approach. It is a well-described phenomenon that young dogs are predisposed to Salter-Harris type IV lateral HCFs, with the most commonly affected age bracket being 3–4 months.2,11,15,19 The predictability of this injury is hypothesised to be both biomechanical20,21 and histological in nature.2,11,15,19 While the pathogenesis of type IV lateral HCFs is well understood, the events preceding other physial fracture configurations are less clear.

Recently, a report detailing Salter-Harris type III medial HCFs in dogs prompted new discussion into the proposed pathogenesis of these injuries, with no clear answer.14 To extrapolate from human literature, Salter-Harris III HCFs occur when the limb is forced into valgus causing an avulsion type injury to the epiphysis due to the firm attachment of the medial collateral ligament and flexor tendons.22

In the veterinary literature, there are currently no reports fully detailing a Salter-Harris type II distal humeral fracture as described in this case and therefore no suggested pathogenesis. Fracture separation of the distal humeral epiphysis (DHE) is a rare injury in young children.25 However, the cartilaginous distal aspect of the humerus is not visible on radiographs which complicates diagnosis; this may at least partially account for the low number of cases reported.24 In children, this injury has been postulated to be more likely secondary to rotatory shear forces than bending forces.24-26 The mechanism of injury may be a combination of rotation, angulation and hyperextension of the elbow with backward thrust on the forearm or rotatory force to the humerus.27-31 Birth injuries, child abuse, falling on to an outstretched hand, lifting an infant while grasping the forearm and motor vehicle accidents have been reported as causes of this injury.24,26,32-34 As this dog presented following vehicular trauma, one can only speculate what forces were encountered; however, given that abduction and supination were successful in reducing the fracture, the forces causing this injury may be similar to those reported in children.

The clinical findings in children with fracture separation of the DHE include marked swelling around the elbow with elbow manipulation resulting in a characteristic ‘muffled crepitus’. This distinctive feeling is described to occur between areas that are covered with cartilage in contrast to the crepitus that is present when motion occurs between ends of bone.24,35 The dog in this case report presented similarly with pronounced swelling and palpable crepitus.

In children, fracture separation of the DHE occurs as either a Salter-Harris type I or II injury.1,36 Type I injuries of the DHE in children represent a pure epiphysial separation with the fracture line confined to the hypertrophic zone while in the type II injuries the fracture line turns and extends into the metaphysis separating off a portion of its margin.26 Radiographically, this has been designated as the ‘corner sign’ and is considered the hallmark of a type II epiphysial separation.26 This ‘corner sign’ was also demonstrated in this case as can be seen on the craniocaudal views both preoperatively and postoperatively (figures 1 and 2). As the displacement of the epiphysis was minimal, the ‘corner sign’ was key in facilitating the diagnosis and may be a useful radiographic finding to look for in future cases.

Fracture separation of the DHE in children has been treated in a variety of ways including closed reduction and splinting or casting, closed reduction and percutaneous pin fixation and open reduction with pin fixation.36-38-40 Fracture separation of the DHE has been reported to lead to a higher rate of residual deformities than other elbow injuries in children37,38 with up to 30 per cent of children developing cubitus varus.31 The cause for this has been proposed to be avascular necrosis of the trochlea secondary to extensive soft-tissue dissection during open reduction.39 This has led to recommendations that closed reduction followed by percutaneous pin fixation may be preferable to open reduction.42,43 However, there is no consensus on the optimal treatment and in general, the outcome is good as long as an early diagnosis is made.34

This case represents the first report of a minimally invasive approach to a Salter-Harris type II HCF in a dog and mirrors the percutaneous pin fixation technique recommended by some authors in children. Benefits of a minimally invasive approach include reduced iatrogenic trauma to important structures such as the physis and joint capsule, minimised postoperative pain, a lower risk of infection, accelerated healing and an earlier return to normal function.16,17,40-42 However, there are several caveats of this approach such as insidious radiation exposure associated with use of fluoroscopy, lack of direct visualisation, difficulties achieving anatomical reduction, challenging learning curve and requirement for additional essential equipment.16,40,43

Appropriate case selection is critical when MIO with percutaneous pinning is considered. Pins counteract bending forces well but have limited capacity to counteract rotational and compressive forces, even when multiple pins are used.37 For this reason, Salter-Harris type I and II fractures have been considered the most amenable to this form of fixation as these configurations tend to have some inherent stability following reduction, limiting the forces which are placed on the pins. Pins also have limited ability to sustain long-term stability and therefore are generally used in young animals where rapid bone healing is anticipated. Ideally, fractures should be minimally displaced with a significant portion of periosteum remaining intact.17 Intact periosteum has the potential to contribute to stability by acting as a tension band if combined with appropriately placed pins.44 In Salter-Harris type II separations of the DHE in children, the periosteum, although stripped from the diaphysis, remains attached to the epiphysis on the side opposite the initial stress which created the injury.26 This periosteal hinge stabilises the fracture, and at the same time, prevents over-reduction. The authors consider it likely that the same is true in dogs with this injury which may make these fractures particularly suited to percutaneous pin fixation. Other characteristics of the fracture described in this report also made it an ideal case for MIO including the acute nature of the injury, which facilitates closed reduction and the absence of articular surface involvement.

Treatment of fractures via MIO often relies on indirect reduction techniques to obtain functional fracture reduction. The general principle is the use of the soft-tissue envelope to help stabilise and reduce the fracture fragments.45 While many different indirect reduction techniques have been described, these often require the use of additional instruments including pointed reduction clamps, distraction devices, external skeletal fixators or the plate planned for stabilisation.46 In skeletally immature animals such techniques may increase the risk of damage to the soft juvenile bone, the periosteum and the physes. In this case, no additional instruments were required.


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as indirect reduction was achieved through the use of ligamentotaxis; the indirect reposition of displaced osseous fragments via distraction on the ligaments attached to these fragments. The cranialateral displacement was resolved using a combination of traction, abduction and supination bringing the epiphysis into near-anatomical apposition. This may have been facilitated by the aforementioned periosteal hinge.

At 1-month follow-up, there was evidence of clinical union and only mild lameness was noted. As the dog was not available for evaluation of long-term outcome, the authors elected to use the CBPI, a validated assessment that could be performed by the owner remotely. The CBPI extrapolates subjective findings to a quantitative measurement of pain and reports pain in two dimensions based on owner-perceived severity and interference with daily activity. The CBPI has undergone systematic factor-analysis, reliability and validity testing before its adoption in veterinary medicine. At 1-year follow-up, CBPI results indicated no ongoing pain. The owner also reported that lameness had resolved and no complications were encountered representing an excellent clinical outcome.

This can be evaluated in comparison with the clinical outcomes of other distal humeral physeal fractures following both open and closed approaches. Reports detailing treatment of Salter-Harris type III injuries are limited but found similar clinical outcomes to that reported in this case with mild lameness and complete radiographic healing at 4 weeks following ORIF. Reports indicate that Salter-Harris IV fractures treated via ORIF have an unsatisfactory outcome in approximately 25% of cases, with complications detailed as persistent postoperative lameness, seroma formation, elbow arthrosis, non-union, fixation failure and infection. In contrast, the study evaluating Salter-Harris IV fractures repaired via MIO reported a return to normal limb function and radiographic healing with minimal lameness up to 21 months postoperatively. This Salter-Harris type II fracture repaired via MIO appears to demonstrate similar clinical progression based on 12-month follow-up.

In summary, this report describes a case of a Salter-Harris type II distal humeral fracture and details the minimally invasive reduction and stabilisation performed using percutaneous pinning. The radiographic ‘corner sign’ may facilitate diagnosis of these injuries. Given the positive outcome reported here, this therapeutic approach warrants consideration when faced with these uncommon injuries.

Learning points

► Although encountered less commonly than Salter-Harris type IV types, Salter-Harris type II fractures should be on the differential diagnosis list for skeletally immature patients presenting with elbow swelling, pain and crepitus.
► The radiographic ‘corner sign’ may facilitate diagnosis of Salter-Harris type II distal humeral fractures.
► Closed reduction using ligamentotaxis and minimally invasive stabilisation via percutaneous pinning warrants consideration for treatment of Salter-Harris type II distal humeral fractures.

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Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.
Competing interests None declared.
Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article.

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