Linear-circular external skeletal fixation of intra-condylar humeral fractures with supracondylar comminution in four cats

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Keywords
Hybrid external skeletal fixator, intra-condylar humeral fracture, supracondylar comminuted humeral fracture, feline

Summary
Objectives: Intra-condylar humeral fracture with supracondylar comminution in cats is rare, and the stabilisation for such fractures is challenging. The purpose of our study was to describe the use of a hybrid external skeletal fixator, and to report the complications and outcomes of this surgical technique.

Methods: A retrospective review was performed of clinical, radiographic and surgical records of all cats with intra-condylar humeral fractures and non-reconstructable supracondylar comminution stabilized by linear-circular external skeletal fixator in two institutions between January 2005 and March 2010.

Results: Four cats met the inclusion criteria of the study. All cases achieved fracture union and clinical outcome was considered excellent at the time of the final assessment (11 – 24 weeks).

Clinical significance: This study demonstrates that a linear-circular fixator system can be used successfully in the management of intra-condylar humeral fractures with non-reconstructable supracondylar comminution in cats.

Introduction
Intra-condylar humeral fractures are rare in cats and are usually the result of high-energy trauma, including vehicular trauma and high-rise injuries (1, 2). These fractures are often associated with significant comminution of the supracondylar region (1, 2). Consequently, these fractures represent a particular surgical challenge, both from a biological and mechanical standpoint. The relatively low incidence of humeral condylar fractures in cats, when compared with dogs, is thought to result from inter-species anatomical differences, including the absence of a supratrochlear foramen, the presence of a supracondylar foramen and the presence of straighter and wider epicondylar ridges in cats (1, 3).

Intra-condylar humeral fractures require accurate anatomical reduction to restore joint congruity (4, 5). Reconstruction of a comminuted supracondylar fracture may not be possible and, at best, involves intricate surgical manipulation, which can have a negative impact on fracture biology and subsequent bone healing (4, 6). Management of the supracondylar component by internal fixation has been described in a series of cats. Macias and others describe the use of a transcondylar compression screw and paired supracondylar neutralisation plates to treat this fracture configuration in five cats (2). Major complications were reported in two of the four cats which had non-reconstructable fractures. These included early implant failure and loss of elbow range-of-motion, resulting in significant lameness and debilitation. Early implant failure was thought to be a result of the limited number of cortices that could be engaged in the distal fracture segment (2). Persistent stiffness following exercise was also reported in a third case (2).

A more biological approach has also been described, through the use of linear-circular external skeletal fixator systems to treat juxta-articular fracture configurations (7). Two of the cats reported in this study were treated for intra-condylar humeral fractures and non-reconstructable supracondylar comminution with linear-circular external skeletal fixator constructs comprised of multiple linear rods and two 1.6 mm transcondylar wires (7). The outcome of one case was excellent and the outcome in the second case was fair, with the fixation removed at 11 and 31 weeks post-operatively in each case, respectively.

In this case report, we describe the clinical application of a simplified linear-circular external skeletal fixator comprised of linear fixation elements and small (1.0 mm or 1.3 mm) transcondylar olive wires for stabilization of feline intra-condylar humeral fractures with supracondylar comminution, and report the clinical and radiographic outcome in four cases.
Materials and methods

Inclusion criteria

Clinical, radiographic and surgical records of all cats with intra-condylar humeral fractures and non-reconstructable supracondylar comminution stabilized by linear-circular external skeletal fixator in two institutions (The Small Animal Hospital at the Royal Dick School of Veterinary Studies, University of Edinburgh, and Fitzpatrick Referrals) between January 2005 and March 2010 were reviewed.

Retrieved data

Data recorded included signalment, fracture configuration, cause of injury, time from injury to surgical repair, physical examination findings (including neurological examination), surgical technique (including implants used), postoperative complications, and the time from operation to radiographic union and implant removal.

Surgical technique

Surgical intervention was performed in all cats. Cats underwent routine general anaesthesia, followed by aseptic preparation of the entire thoracic limb and positioning in dorsal recumbency. For all cases, a lateral approach to the distal humerus was performed (8). In three cases, this was combined with an approach to the medial aspect of the distal humerus to improve exposure to the medial portion of the humeral condyle (9).

The medial and lateral aspects of the humeral condyle were identified and the intra-condylar fracture line was cleared of soft tissue and debris. One pilot hole was drilled in the medial and a second one in the lateral parts of the humeral condyle (0.8 mm and 1.1 mm holes for 1.0 mm and 1.3 mm diameter fixation wires respectively) in an ‘inside-to-out’ fashion to facilitate placement of each transcondylar fixation olive wire in the humeral condyle without violating the articular surface (10). The small size of the humeral condyle necessitated parallel or near-parallel orientation of the fixation wires. All fixation pins and wires were placed through separate stab skin incisions using a number 11 scalpel blade, rather than via the surgical approach to the fracture. The humeral condyle was then reduced using small single-pointed fragment forceps and the olive wires were placed through the pre-drilled holes, one from medial-to-lateral, and one from lateral-to-medial. Since the epicondylar region of the humerus was comminuted in all cases, fracture reduction was visually assessed as far as possible at the articular surfaces of the humerus. Intra-condylar compression was achieved by mounting the olive wires on a circular external skeletal fixation ring component, and applying tension until the stopper for each wire firmly engaged the cortical bone of the humeral epicondyle and the intercondylar fracture line appeared compressed. Fixation wires were attached to the ring using wire fixation bolts with or without slotted washers. Fixation rings were either a half-ring, a 5/8th ring or a stretch ring, 45 or 50 mm in diameter depending on the size of the patient limb, and the longest ring which still facilitated a full range–of–movement of the elbow without impingement of the antebrachium on the cranial ‘open’ aspect of the ring was used.

The hybrid rod was attached to the fixation ring directly with four fixation bolts (Case 1), or laterally or cranio-laterally using a hybrid connecting bar with variable dimensions, depending on the length of the humerus. The hybrid rod was further stabilised with additional struts (Cases 2, 3, 4) placed between the ring component and the linear frame component, typically comprised of either 2.4 to 3.2 mm Steinmann pins mounted from pin fixation bolts and one-hole posts, or fixation clamps.

When required, ‘tied-in’ intramedullary pins placed in a normograde manner in the proximal fracture segments were mounted from the linear frame component. The transfixation pins were placed in the proximal fragment first, after pre-drilling pilot holes of an appropriate size, and attached to the linear rod. In cases 2 and 3, the distal transfixation pins were attached to a separate linear rod. The humerus was positioned to achieve appropriate spatial alignment of the shoulder and elbow joints, and to approximate humeral limb length prior to securing proximal fixation components. No attempt was made to accurately reduce or primarily reconstruct the supracondylar fracture segments; however in cases 2, 3 and 4 major butterfly fragments were loosely recruited towards the fracture site using circumferential polydioxanone sutures.

Perioperative management

Perioperative analgesia included meloxicam (0.1 mg/kg subcutaneous, continued at 0.05 mg/kg orally once daily) for two weeks postoperatively and methadone (0.2 mg/kg intramuscular at 0.2 mg/kg every 4–6 hours) for one to three days postoperatively as determined by individual requirements. Cefuroxime sodium (22 mg/kg) or clavulanate-potentiated amoxicillin (20 mg/kg) were administered perioperatively and repeated every 90 minutes for the duration of surgery. Strict cage rest was enforced until the time of removal of external fixation in all cases.

Clinical outcome assessment

Long-term clinical outcome was assessed by physical and radiographic examination. Function of the affected limb was graded retrospectively and extrapolated from the clinical notes using a previously established classification system (11): excellent = normal limb function; good = mild, intermittent lameness; fair = mild to moderate lameness; and poor = non-weight-bearing lameness.

References

1. PDSII®, Ethicon, Gargrave, UK
2. Metacam®: Boehringer Ingelheim, Bracknell, UK
3. Synastone Injection: SNS Pharmaceuticals Ltd., Middlesex UK
4. Zinacef®: GlaxoSmithKline, Middlesex, UK
5. Augmentin®: GlaxoSmithKline, Middlesex, UK
Results

Four cats met the inclusion criteria of the study. Signalment, fracture aetiology, time elapsed from injury to surgery, time to radiographic union and implant removal, and outcome are detailed in Table 1. All humeral fractures had severe supracondylar comminution (Fig. 1). None of the cats had sustained any significant additional systemic or orthopaedic injuries, and fractures were closed in all cases. Radial neurapraxia was a feature in Cases 3 and 4.

Technical details regarding surgical technique and external skeletal fixator configuration are detailed in Table 2. While frame configuration and specific fixation components varied slightly between cases, all external skeletal fixator configurations featured a single ring component distally with two transcondylar stopper fixation olive wires, tensioned to achieve intercondylar compression, and a single major lateral or cranio-lateral linear external skeletal fixator component from which fixation elements for the proximal fracture segment were mounted. ‘Tied-in’ intramedullary pins were used in Cases 2, 3 and 4.

There were not any significant intraoperative complications encountered in any case. All fractures ultimately proceeded to osseous union. In Case 3, loosening of several fixation pins was noted during reassessment 14 weeks postoperatively. Radiographic assessment of this case confirmed progression of osseous union, including near-complete union of the distal fracture lines including the intra-condylar fracture, but the more proximal comminuted supracondylar region had not yet united. A Type 1A linear external skeletal fixator was applied for a further five weeks, during which time complete osseous union occurred. No other complications were encountered in any other case, and removal of the entire external skeletal fixator was performed at the time of fracture union in all cats.

All cases were able to bear weight on the surgically repaired limb within 48 hours postoperatively, although in Cases 3 and 4, weight bearing was abnormal due to radial neurapraxia for several weeks postoperatively.

Clinical outcome was considered excellent at the time of the final assessment (11–24 weeks) in all four cases, without any visible signs of lameness or apparent discomfort on elbow joint manipulation. Slight reduction in elbow joint range-of-motion by comparison with the contralateral limb was noted in Cases 2 and 3, but this complication was considered clinically unimportant.

Discussion

This retrospective study describes the use of a linear-circular fixator system to stabilize intra-condylar humeral fractures with non-reconstructable supracondylar comminution in four cats. In contrast to dogs, distal humeral fractures in mature cats are almost exclusively associated with severe trauma and are subject to a high degree of comminution (1). Incomplete ossification of the humeral condyle is a known predisposing factor for these fractures in dogs, but it has not been described in cats to date (12). In two cases, vehicular trauma was the known cause of the fracture, and in Case 1 the injury resulted from falling from the second floor of a building. Radial neurapraxia is a recognized concomitant injury in cats affected by humeral fractures, especially when the supracondylar region is

<table>
<thead>
<tr>
<th>Case</th>
<th>Signalment* (age, sex, bodyweight)</th>
<th>Aetiology</th>
<th>Concomitant injuries</th>
<th>Time elapse (injury to surgery)</th>
<th>Complications</th>
<th>Time to fixation removal</th>
<th>Outcome veterinary assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8-months-old Female entire 3.0 kg</td>
<td>Fall from height (2nd floor)</td>
<td>None</td>
<td>3 days</td>
<td>None</td>
<td>11 weeks</td>
<td>Excellent (11 weeks postoperative)</td>
</tr>
<tr>
<td>2</td>
<td>43-months-old Female spayed 3.3 kg</td>
<td>Road traffic accident</td>
<td>None</td>
<td>2 days</td>
<td>None</td>
<td>10 weeks</td>
<td>Excellent (18 weeks postoperative)</td>
</tr>
<tr>
<td>3</td>
<td>38-months-old Male neutered 6.3 kg</td>
<td>Road traffic accident</td>
<td>Radial neurapraxia (had resolved spontaneously by 6 weeks postoperative)</td>
<td>2 days</td>
<td>Loosening of pins in proximal segment 14 weeks postoperatively prior to complete supracondylar union - revised with linear ESF</td>
<td>14 weeks: Hybrid frame removed 19 weeks: Type 1A linear ESF removed</td>
<td>Excellent (24 weeks postoperative)</td>
</tr>
<tr>
<td>4</td>
<td>24-months-old Male neutered 4.8 kg</td>
<td>Unknown</td>
<td>Radial neurapraxia (had resolved spontaneously by 4 weeks postoperative)</td>
<td>1 days</td>
<td>None</td>
<td>10 weeks</td>
<td>Excellent (14 weeks postoperative)</td>
</tr>
</tbody>
</table>

**Table 1.** Patient data and outcome for four Domestic Shorthaired cats following fracture stabilisation.

*All patients were Domestic Shorthaired cats; ESF = external skeletal fixator; ROM = range-of-motion.
involved (13). The high-energy trauma, evidenced by the high degree of comminution, may explain the high incidence of this injury in this case series.

The use of a linear-circular external skeletal fixator has a significant advantage in allowing stabilisation of small juxta-articular fracture segments where limited bone stock is available (14, 15). This technique has been applied to distal and proximal antebraehial and crural fractures with fewer cases reports of its use in humeral fractures (7, 15–17). Incomplete ring configurations are significantly weaker when compared to those using complete rings that confer greater bending stiffness; however, complete rings severely restrict the range-of-movement of the elbow joint.

**Fig. 1** Medio-lateral (A, E and G) and cranio-caudal (B, F and H) radiographs, and reconstructed computed tomographic images (C and D) of case 4. **A-D** Preoperative images demonstrating severely comminuted humeral condyle fracture. **E-F** Immediately postoperative radiographs demonstrating external skeletal fixation (external skeletal fixator) in situ. **G-H** Ten weeks postoperative radiographs taken immediately after external skeletal fixator removal documenting radiographic fracture union.
(18). To compensate, configuration stiffness can be increased by the addition of a ‘tied-in’ intramedullary pin, a drop wire, or additional distal half-pins (18–20). In all but one case, further points of fixation were obtained in the distal fragment by placing one or two distal half-pins from the ring component. The biomechanical properties of the fixation were further enhanced in three cases (which were heavier cats) by placing a single or double tied-in intramedullary pin.

Smaller fixation wires were used in this case series when compared with the previous report of this technique. This decreased wire strength results in a decreased stiffness of the construct, as stiffness is proportional to the diameter of the wire squared (21). However, the stiffness of the construct must only be of sufficient diameter to prevent plastic deformation when subjected to the weight bearing forces (21). Due to the variation of the constructs it is impossible to precisely calculate their stiffness and make a direct comparison with the two previously reported cases. The use of a single transcondylar pin of between 1.5 and 2.2 mm has been recommended for placement in the humeral condyle of cats with linear fixation, based on their anatomical diameter (22). Whilst similar recommendations have not been made for circular wires, it is prudent to place the smallest wires which provide adequate stiffness wherever possible to facilitate the ease of placement.

Pin tract discharge and loosening at the level of the proximal pins was recognized in one cat fourteen weeks postoperatively. This is a common complication associated with external skeletal fixator, particularly in areas where large muscle groups are present, such as the humerus where no safe corridors for pin insertion are present (22, 23). A safe area exists in the cranio-lateral aspect of the proximal humerus, but despite this, loosening of the proximal external skeletal fixator pin after humeral fracture stabilization in cats is reported to be more common when compared with the use of a similar technique to stabilise femoral fractures (22, 24, 25). This may be related to the relatively thin cortices in this region (25).

In Case 3, premature implant loosening occurred requiring implant revision and prolonged external fixation. This major complication did not impact on functional outcome in the long-term, which contrasts with a previous report using internal fixation for the treatment of intra-condylar humeral fractures in five cats (2). In this report, only a single case had an excellent outcome, with another having a good outcome and the remaining three cats having a poor outcome. This suggests that linear-circular external skeletal fixator may be preferable to internal fixation for this configuration of fracture.

This study demonstrates that a linear-circular fixator system can be used successfully in the management of intra-condylar humeral fractures with non-reconstruct-

<table>
<thead>
<tr>
<th>Case</th>
<th>Surgical approach</th>
<th>Internal fixation</th>
<th>Ring position</th>
<th>Configuration/ring diameter</th>
<th>Fixation elements on ring</th>
<th>Linear rod(s)</th>
<th>Linear fixation elements (proximal; distal fragment)</th>
<th>Bone graft</th>
<th>Support struts*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open lateral</td>
<td>None</td>
<td>Humeral condyle</td>
<td>5/8 ring / 50 mm</td>
<td>2x 1.0 mm olive wires</td>
<td>1x lateral (steel)</td>
<td>3x 1.6 mm PPET pins; 1x 1.6 mm NPET pin</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Open lateral and medial</td>
<td>1x 2 mm IM NTS pin tied-in to ESF</td>
<td>Humeral condyle ('vertical y'-orientated parallel with long axis of humerus)</td>
<td>Manually cut down half ring / miniature 45 mm</td>
<td>2x 1.3 mm olive wires</td>
<td>2x cranio-lateral (steel)</td>
<td>2x 1.6 mm NPET pins; 2x 1.1 mm NPET pins</td>
<td>Autogenous cortico-cancellous iliac crest plus freeze-dried ‘osteo-allograft’</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Open lateral and medial</td>
<td>1x 2 mm IM NTS pin tied-in to ESF</td>
<td>Humeral condyle</td>
<td>Half ring 50 mm</td>
<td>2x 1.3 mm olive wires; 1x 1.1 mm Kirschner wire</td>
<td>2x lateral (steel)</td>
<td>3x 1.6 mm NPET pins; 2x 1.1 mm NPET pins</td>
<td>Autogenous cortico-cancellous iliac crest</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Open lateral and medial</td>
<td>2x 2 mm IM NTS pins tied-in to ESF</td>
<td>Humeral condyle</td>
<td>Stretch ring 50 mm</td>
<td>2x 1.3 mm olive wires</td>
<td>1x cranio-lateral (steel)</td>
<td>3x 1.6 mm NPET pins; None</td>
<td>None</td>
<td>1</td>
</tr>
</tbody>
</table>

Key: *Support struts = Number of support struts required between the circular and linear frame components; ESF = external skeletal fixation; IM = intramedullary; NPET = negative profile end-threaded; NTS = non-threaded Steinmann; PPET = positive profile end-threaded.
able supracondylar comminution in cats. Further studies with a larger number of cases are required to determine if mechanically stronger configurations with additional fixation points in the small distal fragment or with additional internal fixation, such as a tied-in intramedullary pin, have any clinical benefit when compared with lower stiffness constructs.

Conflict of interest
None declared.

References