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Challenging elbow fractures

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INTRODUCTION

The elbow joint is a ginglymoid (hinge-like) joint that includes three articulations with a common joint cavity: the humero-radial articulation, the humero-ulnar articulation, and the radio-ulnar articulation. The distal humerus forms a bony triangle comprised of a medial and lateral ramus (crest), and a condyle that is comprised of the trochlea medially and the capitulum laterally. The humero-radial articulation exists between the radial head and the humeral capitulum. The trochlea humeri articulates with the troclidean notch of the ulna and the medial aspect of the coronoid process.

Fractures of the humeral component of the elbow are the most common type of elbow fractures encountered in clinical practice and can be either unicondylar (more commonly affecting the capitulum in comparison to the trochlea), or bicondylar (affecting both portions of the humeral condyle). All humeral elbow fractures have an intra-articular (intercondylar) and a juxta-articular (supracondylar) component. Radial head, troclidean notch and coronoid fractures are far less common. Sixty per cent of distal humeral fractures involving the condyle in dogs. Ninety percent of unicondylar fractures of the distal humerus are reported to occur in association with minor trauma. Eighty percent of bicondylar fractures occur in association with severe trauma. A report on distribution of distal humeral fractures found 53% of condylar fractures involved the lateral aspect of the condyle, 10% the medial aspect of the condyle, and 37% were bicondylar. One study reported a peak incidence of unicondylar fractures after minor trauma at 4 months of age.

The presence of incomplete ossification of the humeral condyle (IOHC) is considered an important predisposing factor in the development of unicondylar humeral fracture and the disparate sizes of the medial and lateral rami predisposes the capitulum to detachment from the humerus by comparison with the troclidean. The role of the radial head in increasing the force that the capitulum sustains in a traumatic incident is postulated but not proven.

IOHC may be a subclinical condition, and has been reported as an uncommon cause of forelimb lameness in dogs. Lameness may be mild and intermittent to non-weight bearing in nature and may precede complete humeral condylar fracture. IOHC may decrease stability of the humeral condyle predisposing to complete fracture often after a minimally traumatic event.

IOHC may be diagnosed radiographically as a linear sagittal radiolucency in the humeral condyle in the region of the developmental cartilage zone separating the two condylar centers of ossification. Bone scintigraphy and arthroscopic examination have been reported useful in establishing a diagnosis but it is now appreciated that diagnosis may prove elusive using these modalities. Magnetic resonance imaging (MRI) or computed tomography (CT) may be necessary for definitive diagnosis. The author has found that both modalities are sensitive and accurate. The author has also found that cases which are clinically affected by lameness generally tend to have intercondylar fissures propagated into the joint itself, and are readily seen arthroscopically, with relative motion of the two condylar segments on pronation and supination.

GENERAL PRINCIPLES OF ELBOW FRACTURE REPAIR

Maintenance of a healthy bone articulation is dependent on joint motion and repetitive loading. Disruption of any component of the joint can result in fibrosis and osteoarthritis. Displaced intra-articular fractures can affect joint stability, cause pain, and disrupt effective joint motion. Gaps in the articular surface can fill with fibrocartilage, but this repair tissue has inferior mechanical properties and durability in comparison to articular cartilage.

Accepted guidelines for joint fracture management include anatomical reduction and rigid fracture fixation. Decreased range of elbow joint motion is a common complication associated with elbow fracture repair and minimizing the degree of periarticular fibrosis by utilizing optimal surgical technique and early post-operative mobilization of joint movement including active and passive physical therapy is imperative.
PREOPERATIVE PATIENT ASSESSMENT AND PLANNING

Thorough evaluation of the cardiovascular, respiratory, urinary, gastrointestinal and neurologic systems prior to fracture fixation is imperative. The presence of concurrent injury, particularly in patients that have sustained major trauma is common. Undiagnosed, the presence of pulmonary injury, myocardial dysfunction, intestinal rupture, urinary tract trauma and neurological deficits will adversely affect patient safety and surgical outcome and the clinician must initially prioritize the complete assessment of these organ systems and continue to re-assess their function during the post-operative period.

A significant number of dogs and cats with humeral fractures have partial temporary or permanent nerve dysfunction. The ulnar, median and radial nerves are in close proximity to the distal humerus and a sound knowledge of their location and peripheral distribution is needed for a complete pre-surgical evaluation of the limb function. In cats this is especially relevant because the radial nerve passes through the supracondylar foramen. Partial temporary nerve injuries typically resolve quickly once the fracture is stabilized. The presence of cutaneous sensation and spontaneous motor function is commonly used as a positive predictive finding for intact neurological function.

Temporary stabilization and support of elbow fractures requires placement of a spica splint. In most cases, splinting is unnecessary prior to surgery unless a delay is anticipated before fracture repair. Incorrect bandage application may have significant consequences and should be carefully avoided. Patient confinement and appropriate analgesic administration is required.

Thorough preoperative planning is a prerequisite for successful management of elbow fractures. Preoperative imaging should include complete radiographic examination and computer tomography is indicated if available. The presence of small bone fragments and fissure lines in complex comminuted fractures can be difficult to identify with plain radiography alone. Failure to identify the anatomic characteristics of the fracture present will adversely affect surgical planning and may adversely affect the post-surgical results achieved. An added caveat is that acidulous attention should be paid to examination of radiographs for any evidence of neoplastic disease, particularly since pathologic fractures can be masked by proliferative new bone secondary to elbow arthrosis.

SURGICAL TECHNIQUE

On the lateral aspect of the distal one-third of the humerus, the radial nerve emerges from deep to the triceps muscle to lie superficial to the brachialis muscle. On the medial aspect of the distal humerus the median, musculocutaneous and ulnar nerves are present along with the brachial artery and vein. Meticulous anatomic dissection during the surgical approach is necessary to avoid damaging these important structures. Fractures of the lateral and medial aspect of the condyle are exposed by an approach to the lateral or medial aspect of the humeral condyle respectively. A tenotomy of the triceps tendon or osteotomy of the tuber olecrani may prove helpful in long-standing fractures that can be a challenge to reduce. The olecranon osteotomy approach has been associated with high morbidity and complication incidence and is rarely employed by the author.

Positioning the animal in dorsal recumbence with a mild tilt to the operated side facilitates exposure and reduces operating time. A transcervical screw and anti-rotational K-wires or screws are the principle means of unicervical fracture fixation. Reduction maintenance pre-implantation is achieved using appropriate bone holding forceps. A minimally invasive technique using fluoroscopy to reduce the fragments and position the implants has been previously described. A glide hole can be started from the fracture surface or from the epicondyle before fracture reduction or from the epicondyle after fracture reduction. Whatever method is chosen, the hole is drilled so that it exits or enters craniodistally to the epicondyle and in the centre of the fracture surface. These two points define the axis of the hole. After fracture reduction has been secured, a drill sleeve is typically inserted into the glide hole and a thread hole is drilled into the opposite part of the condyle. The author prefers to drill the fracture fragment from the condylar isthmus to the epicondyle, then reversing the drill bit through this fragment, reducing the fracture and driving the drill into the opposing aspect of the humeral condyle. In immature animals a washer can be used to prevent penetration of the head of the screw into the bone while tightening of the screw. In this patient group a bone clamp can be used to compress the fragments during insertion of a positional screw.

Partially threaded cancellous screws or fully threaded cortical screws can be used. Cannulated headless tapered screws can are also a valid implant option and have been successfully used in human, equine, canine and feline articular fracture cases. In small dogs a self-compressing threaded pin system has also been reported as successful. The author has employed headless screws in both canine and feline humeral condylar fractures, but generally reserves their use to parallel a transcervical bone dowel in fixation of cases of incomplete ossification of the humeral condyle.
Complications are not uncommon with unicondylar fracture repair but can be minimized with careful surgical dissection, appropriate placement of implants, excellent post-operative care and the early and judicious use of physical therapy. Particular attention must be applied to make sure that the epicondylar region is accurately reconstructed, otherwise mismatch at the intercondylar area is inevitable and fragments with short epicondylar segments are prone to rotate around the condylar screw and become malaligned. Augmentation of the medial epicondylar ridge using locking plates such as the 2.0 or 2.4 mm Synthes LC P™ or the 2.0 mm or 2.7 mm string-of-pearls SOP™ plate may be beneficial and as a general guideline, if the author feels that there is any possibility of aberrant healing or tenuous implant purchase, an epicondylar plate is applied. Bicondylar fractures can be exposed with a combined lateral and medial approach (favoured by the author) or with an approach to the caudal aspect of the elbow joint after an osteotomy of the tuber olecrani or a triceps tenotomy. The intercondylar component of the fracture is managed similarly to the unicondylar fractures. Two approaches are valid - either reconstruction of a uni-condylar fracture first, with subsequent repair of the opposing aspect of the condylar fracture; or repair of the humeral condyle first and then reconstruction of the humerus. The author favours the latter approach and frequently employs a fracture distractor to overcome muscle contracture prohibiting satisfactory reduction. Fixation can be applied using standard or locking plates or plate-rod techniques. The author previously used hybrid 3.5/2.7 pancarpal arthrodesis plates applied medially and laterally but now favours 2.7mm and 3.5mm SOP™ plates. Lag screws are a helpful adjunct, but rarely used in isolation by the author who favours more robust reconstruction support. An intramedullary pin placed in the medial epicondyline and exiting the proximal humerus via the subtubercular region can facilitate realignment and may obviate requirement for two plates, facilitating a plate-rod technique. Cerclage wire can be important or vital for re-apposition and stabilisation of spiral fragments, and can be used to sequentially realign long spiral fragments under guidance of a fracture distractor. Lateral bone plating with the transcondylar screw incorporated into the plate construct has been examined clinically and found to be a successful technique that limits micromotion of the fracture site more effectively in comparison to caudal plate position.

In case of severe comminution perfect reduction of the supracondylar fracture is not necessary as long as correct bone alignment and sufficient bone buttressing with two bone plates have been achieved. Commuted fragment recruitment can be facilitated using lassos of polydioxanone suture material. Accurate plate contouring is a pre-requisite for perfect reduction of the bone fragments as compressing the bone fragments onto the plate will lead to secondary loss of reduction if the shape of the plate and that of the bone are not an accurate match. Locking plate technology allows decreased dependence on plate contouring, as the fixation is not dependent on the friction between the bone and the plate, secondary loss of reduction is less of an issue compared with conventional plates.

Ensuring that no implants cross the intercondylar fossa is of vital importance and the surgeon must be alert ed when normal range of motion cannot be achieved or crepitus is apparent after reconstruction of the bone fragments. A technique utilizing trans-condylar implants incorporated in a modified Type I external fixation has been described but is not favoured by the author. Hybrid linear-arch fixators have also been described. In small fragments or comminuted juxtaarticular fractures of cats or dogs, external skeletal fixation may be very useful including application of small half-pins, self-compressing threaded pins or olive wires on arches distally to facilitate condylar reconstruction. Such arches and stretch-rings mounted with linear components further proximally and constituting hybrid fixation systems offer tangible advantages over conventional linear frames and where conventional circular frames cannot be mounted on the proximal thoracic limb. However, external skeletal fixation of the humerus in dogs is a high-maintenance technique in that pin tract discharge and prolonged healing times may be issues. Therefore the author prefers internal fixation unless there is very valid rationale to choose fixator constructs.

Although in each study regarding condylar fractures published to date, a different subjective means of clinical outcome has been used, it is generally accepted that unicondylar fractures enjoy a better prognosis than bicondylar fractures.

Where IOHC is present or fracture has yielded a paucity of bone stock for implant purchase, elbow fractures can be difficult to treat because of general inability to achieve osseous union at the intercondylar interface, such that epicondylar structural integrity is important. Non-union is common and can give rise to transcondylar implant loosening and resorption of bone around the implant. In recalcitrant cases this can be overcome using a transcondylar threaded rod and nuts on either side of the humeral condyle (Webb Bolt). Tissue glue may be applied to prevent nut loosening.

**Surgical Treatment of IOHC**

Management of IOHC remains controversial. Conservative treatment of IOHC is associated with HCF. Marcelin-Little reported that 3/7 condyles (43%) with a partial radiolucent line and 1/12 condyles (8%) with...
a complete radiolucent line fractured 11 days to 18 months after diagnosis. The author has anecdotally observed high rates of fracture of untreated intercondylar fissures. Surgical treatment aims to prevent H.C.F., to encourage osseous fusion of the transcondylar fissure and to resolve lameness in the long-term. Current surgical treatment of I.O.H.C. generally involves use of a transcondylar screw, either fully or partially threaded, applied in either a position or in lag fashion. Screw placement may be combined with transcondylar bone tunnels created by drilling (forage) to allow vascular in-growth. A single case report prior to the author’s own work on transcondylar bone graft, suggested use of such a graft but this was not performed because of concerns about potential for the bone graft to communicate with the joint via the transcondylar fissure.

After transcondylar screw application, resolution of lameness usually occurs; however, complications include failure to achieve bone union, recurrence of lameness, fissure widening, loss of transcondylar compression, implant failure, and H.C.F. Failure to achieve bone union and condylar stability may result in cyclic loading of the screw with bending, stress fatigue, and failure. Some surgeons advocate changing the screw at regular intervals such as every other year and others advocate re-examination if lameness recurs, in an effort to prevent osseous fracture if the screw cycles to failure at the non-ossified interface. What is clear is that without biologic augmentation, union is never achieved. Some surgeons therefore advocate placement of screws of significantly large diameter (5.5 or even 6.5 mm).

Histologic features of the fissure site were consistent with atrophic non-union fracture in an English Pointer and were composed of fibrous tissue in two Cocker Spaniels with no evidence of chondrocytes or cartilage matrix. These findings may suggest that I.O.H.C might be approached similarly to treatment of atrophic non-union fractures, so treatment modalities promoting transcondylar bone osseous union are worthy of consideration. Autogenous cancellous bone graft application in the area of incomplete ossification has been proposed to optimize bone formation and remodeling by providing trabeculae necessary for bone conduction and osteoprogenitor cells, as well as cytokines and growth factors for osteoinduction and osteogenesis. No study has reported the effect of I.O.H.C on condylar stability but resultant instability may be in part or wholly responsible for observed lameness. In such cases, use of bone graft alone may not promote bone healing because of the effects of excessive movement at the fissure site inhibiting healing, similar to unstable atrophic non-unions where AO principles support the combination of a graft with rigid internal fixation to promote bony union.

The Acutrak™ bone screw (AT screw, Acutrak®TM, Acumed, Beaverton, OR) used since 1992 in human patients, is composed of titanium alloy (AST M F136), and is a cannulated, headless, tapered, variably-pitched, self tapping and fully threaded compression screw. The AT screw is inserted using a customized cannulated application system. The osteochondral autograft transfer system (OATS™, Arthrex, Naples, FL) has been used in humans for treatment of articular cartilage defects including osteochondritis dissecans. The author reasoned that both systems had features that might facilitate graft collection and treatment of I.O.H.C.

Direct visibility of the cranial and caudal aspects of the humeral condyle is achieved and the narrowest isthmus of the articular surface is marked by 2 temporary 1.1mm Kirchner (K)-wires placed within the joint contiguous with the articular surface. A calibrated K-wire (Acumed, Beaverton, OR) is driven medial to lateral across the humeral condyle at its most distal extent, using an inverted AT screw placed over the K-wire as a spacing guide to ensure that the maximal diameter of the screw would not encroach on the articular cartilage at the narrowest part of the isthmus. When the wire has penetrated the trans cortex, bone depth is measured using the etch mark on the calibrated K-wire held against the scale on a customized depth gauge. The base of the inverted AT screw placed over the K-wire acts as a spacer allowing an OATS™ reamer (OATS™, Arthrex, Napes, FL) of maximal diameter to be centralized proximal to the AT screw on the medial aspect of the humeral condyle without encroaching on the intended screw position. The reamer position is maintained by advancing a guide drill across the condyle through the cannulated reamer. Parallelism of the drill guide/reamer and the wire/screw is desirable, but in some dogs with limited humeral condylar bone stock it is necessary to drive the screw parallel to the medial humeral joint surface rather than parallel to the transverse axis of the condyle. In these dogs, the screw passes obliquely from distomediaidal to proximolateral, craniodistal to the position of the intended bone core as marked by the guide drill. A hole is prepared for the AT screw using the customized AT insertion system (Acumed, Beaverton, OR). The guide K-wire is advanced through the trans cortex, soft tissues and skin and is secured with wire graspers on the lateral aspect of the condyle to minimize wire movement. A customized drill bit is advanced over the guide wire in increments of 3-4 mm and intermittently removed to allow removal of bone debris. External drill calibrated markings measured against the cis cortex allows advancement of the drill tip to within 2-6 mm of the trans-cortex. The reamer is then repositioned on the central guide drill. The intended socket depth is 75% of condylar width and is estimated from preoperative radiographs. Calibrated markings on the external barrel of the reamer allow socket depth measurement during reaming. An AT screw 2 mm shorter than the drill hole depth was threaded over the guide wire and inserted to finger tightness using a customized screw driver.
Challenging Fractures

N. Fitzpatrick

W V O C 2010, Bologna (Italy), 15th - 18th September • 390

Core socket depth and alignment are confirmed using a calibrated alignment rod before cancellous bone dowel collection. When free autogenous cancellous bone is used, it may be collected from the proximal aspect of the ipsilateral humerus through a small fenestration created using a bone curette. Corticocancellous bone dowels of appropriate length may also be collected from the proximal aspect of the tibia or distal femur using an OATS™ core harvesting chisel 1mm wider than the transcondylar recipient socket. The core harvester is a calibrated, cylindrical cutting chisel with louvered grooves at 4 equidistant points on the circumference. The louvers engage the bone core when hammer-tapped into the donor site and the bone dowel is extirpated by a twisting motion axial to the harvester, or by slight rocking ('toggling') whereupon the louvers engage the cancellous bone and break the dowel off at its base, which is subsequently removed within the chisel. Graft dowels are trimmed to fit recipient socket length where necessary. Grafts are transferred to the recipient socket by packing the free cancellous graft firmly with a tamp.

Bone dowel diameter is intrinsically limited by humeral condylar isthmus dimension and by the concurrent use of a transcondylar screw. Use of an AT screw allows placement of a mechanically robust but narrow implant whilst maximizing bone dowel diameter.

The cannulated system allows accurate insertion, using the guide wire of the screw and the reamer centralizer as trajectory guides for the screw and bone dowel respectively, without need for fluoroscopy, although fluoroscopic guidance may further facilitate accurate screw placement. The fully threaded, tapered nature of the screw provides constant new bone purchase as it is inserted, minimizing strip-out and maximizing pull-out strength, providing strong internal fixation. Where it is perceived that a transcondylar bone dowel of diameter 5mm or greater cannot be placed in an elbow, the author’s preference is to use a screw only as he does not perceive that a bone graft is necessary. Placement of a transcondylar screw allows retrieval of a mechanically robust but narrow implant whilst maximizing bone dowel diameter.

SALVAGE PROCEDURES

In cases of severe comminution or when fixation methods have failed resulting in severe osteoarthrosis and irreparable alteration of joint biomechanics, joint arthrodesis, replacement or limb amputation can provide a salvage choice. Elbow arthrodesis has in the author’s hands provided surprisingly satisfactory results in terms of pain-free functional ambulatory capability.
POST-OPERATIVE MANAGEMENT
Limiting postoperative limb swelling ensuring the surgical incisions are not interfered with, protecting the limb from excessive force, controlling post-operative pain and early ROM exercises are essential for establishing uninterrupted soft tissue and bone healing. Bicondylar fractures are more challenging and joint stiffness and reduced function is common in the absence of correct rehabilitation. Cryotherapy and pressure bandaging help limit early postoperative swelling. ROM and stretching exercises need to be initiated in the early post-operative period and excessive support bandage duration should be avoided particularly in juvenile patients. Swimming or underwater treadmill are particularly helpful as they provide patient buoyancy in combination with resistance to limb motion which is an effective technique to minimize peri-articular muscle atrophy and encourage re-establishment of adequate range of motion in the affected elbow joint. Early and ongoing adequate pain management is of vital importance for early limb usage and avoidance of reflex inhibition.

SPECIAL CONSIDERATIONS FOR ELBOW FRACTURES IN CATS
Elbow fractures in cats are less commonly presented in the author's facility than canine elbow fractures with published data suggesting that humeral fractures generally represent 4.4% of all fractures in cats. Most are in the mid-shaft region (87%), approximately 70% of which are comminuted. Where fractures are simple, they are typically oblique or spiral in configuration and follow the “musculo-spiral groove” toward the supracondylar region. A range of fixation techniques are reported and selection largely depends on precise fracture configuration and availability of bone stock for implant placement. Presence of the supracondylar foramen which contains the radial nerve makes repair more challenging, not least because in most cats it renders introduction of an intramedullary pin into the medial epicondyle impossible. Where possible in this region, pin diameter has been reported as being limited to 1.6mm maximum. If the pin tip is left in the proximal supracondylar region, it has been suggested that up to 2.4mm pin diameter can be applied. However, additional fixation is always required to provide rotational and often compressional stability which may be compromised by inclusion of a large intramedullary device. Intramedullary nails up to 5mm in diameter have been reported but require specialist skills and inventory and may be inappropriate for many fracture configurations. Cerclage wire is seldom appropriate for common fracture configurations and since the humerus tends to taper toward the supracondylar region (and has the closely constrained radial nerve), wire placement is challenging to maintain safely.

Plate and screw fixation is commonly applicable although contouring to match the three-dimensional shape of the humerus may be challenging except for the most cranio-lateral portion, while the proximity of neurovascular structures, close association with musculature and variable fracture configuration distally makes surgical approach challenging. External fixation with or without a tied-in intramedullary pin may be applicable to the majority of fractures and hybrid circular/arch systems may optimize limited distal bone stock by allowing placement of fine wires or half-pins in the region of the humeral condyle. A significant proportion of other fractures involve the humeral condyle with the lateral condyle most commonly affected. Simple lateral or medial condylar fractures may be stabilized by transcondylar screw and anterotational epicondylar implant placement. An alternative to standard compression screw placement is the titanium Acutrak screw. Benefits include cannulation which increases reliability of placement within the relatively narrow humeral condyle and its headless design which minimizes soft tissue irritation and eliminates the risk of splitting small bone fragments during countersinking. The variably-pitched, tapered design means that the screw is self-compressing, while allowing for purchase in new bone for each rotation during insertion.

Y, T and comminuted elbow fracture configurations may necessitate either complex screw and double plate application or advanced external fixation techniques with circular or hybrid components and olive/stopper wire fixation to achieve intercondylar compression. Radius and ulna fractures are also common with wide variation in location and configuration although comminuted fractures appear overrepresented. It is rare for radial fractures to occur so far proximally as to compromise the elbow joint, but fractures of the ulnar notch and olecranon are more common. Anatomic reconstruction is essential and “drift” of the fracture interface during implant application can easily occur and careful attention is required in this regard. An intramedullary pin and tension band may be adequate or a compression plate with a hook fashioned from one of the plate holes over the olecranon may be applied for extra purchase in small olecranon segments.

Application of bone graft or biologic augmentation agents may be beneficial, particularly in more geriatric patients or where fracture configuration is anticipated to delay healing. The proximal humeri may provide small amounts of good quality graft, particularly in younger patients, but for more substantial quantities of autogenous graft material or in older patients, cortico-cancellous bone from the iliac crest may be harvested and morcellised. Freeze dried allograft feline bone chips (Veterinary Transplant Services®, Kent, WA) may
be highly advantageous in this circumstance, and are worthy of consideration in all circumstances where graft is required, including arthrodesis in cats. Elbow arthrodesis is a consideration for unreconstructable articular trauma in cats but indications are rare and it is worth mentioning that salvage joint replacement is now a reality including trabecular metal mesh reattachment of ligament avulsion, but again indications are rare and experience limited at this point.

REFERENCES