Review article

Articular fractures of the distal humerus

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ABSTRACT

Distal humeral fractures represent 2% of all adult elbow fractures. Injury mechanisms include high-energy trauma with skin involvement, and low energy trauma in osteoporotic bone. Treatment goals are anatomical restoration in young, high-demand patients and quick recovery of activities of daily living in the elderly. Complete fractures are relatively easy to diagnose, but partial intra-articular fractures are not. The clinical diagnosis must take into account potential complications such as open injuries and ulnar nerve trauma. Standard X-rays with additional distraction series in the operating room are sufficient in complete articular fracture cases. Partial intra-articular fractures will need CT scan and 3D reconstruc-tion to fully evaluate the involved fragments. SOFCOT, AO/OTA and Dubberley classifications are the most useful for describing fractures and selecting treatment. Surgery is the optimal treatment and planning is based on fracture type. Complete fractures are treated using a posterior approach. Triceps management is a function of fracture lines and type of fixation planned. Constructs using two plates at 90° or 180° are the most stable, with additional frontal screw for intercondylar fractures. Elbow arthroplasty may be indi-cated in selected patients, having severely comminuted distal humerus fractures and osteoporotic bone. Open fractures make fixation and wound management more challenging and unfortunately have poorer outcomes. Other complications are elbow stiffness, non-union, malunion and heterotopic ossification.

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1. Introduction

Articular fractures of the distal humerus in adults are difficult to treat because of their epiphyseal location. Although not a common fracture [1], approximately 3000 distal humerus fractures in adults and children are treated surgically every year in France [2]. An orthopaedic surgeon in France sees an average of five distal humerus fractures per year. Because these fractures are fairly rare, proposing a routine but specific management scheme is challenging.

The treatment process consists of determining the injury mechanism, defining the diagnostic modalities and developing a treatment algorithm to allow the patient to completely regain full mobility of this complex joint. Normal function is hard to restore if the joint is deformed by malunion and/or stiffened by heterotopic ossifications or capsular and ligament contractures.

2. Anatomy

In the frontal plane, the distal humerus has a triangular shape, is empty in the middle and is made up of a horizontal capitellum-trochlea segment inserted between the medial and lateral columns [3]. The interposed segment extends more distally than the columns, thereby resembling a cylinder pinched between the tips of the index finger and thumb [4]. The central area comprises a coronoid fossa and an olecranon fossa. This area is quite thin, which allows extensive range of flexion and extension, but also generates weak point contributing to complex fractures, especially in the elderly.

The medial column holds the medial epicondyle and medial portion of the humeral trochlea. When viewed from the side, this medial column appears continuous with the humeral shaft axis. Conversely, the lateral column is flexed relative to the humeral shaft, placing the capitellum ahead of the trochlea. The epiphy-seal section of the distal humerus containing the trochlear and capitellum articular surfaces is in 4–8° valgus relative to the shaft, externally rotated by 3–8° relative to the metaphysis and flexed 40° relative to the shaft [5], resulting in the distal humerus being projected in front of the humeral shaft.

3. Fracture mechanism

Complete fractures result from impaction of the proximal ulna onto the articular part (trochlea, capitellum) of the distal humerus. The impact can occur with the elbow flexed or extended. If the elbow was flexed at impact, the articular fragments move forward; if the elbow was extended, they typically move backwards [3]. Some believe that contre-coup impaction towards the lower end of the humeral shaft results in separation of the medial and lateral
columns. Because of the complexity of the injury mechanisms, comminuted fractures are quite common, especially in the elderly.

Partial sagittal fractures of the lateral or medial condyle are the result of indirect trauma in valgus or varus while in full or nearly full extension. These fractures are accompanied by capsular and ligament injuries on the opposite side of the joint. The elbow will be acutely unstable.

Isolated capitellum fractures are the result of compression of the articular surface by the radial head (as if the radial head gave the capitellum an upercut) \[6\], either during the injury event with the elbow nearly in full extension or as a result of direct trauma to a highly flexed elbow. The position of the capitellum fragment on X-rays can help determine the position of the elbow during the injury \[3\].

4. Diagnosis

The clinical diagnosis is made when the patient presents a painfully swollen and deformed elbow. Because of the articular nature of the fracture, anatomical landmarks are disrupted. In complete bicondylar fractures, the two condyles can be moved independently of each other. In partial sagittal fractures, one of the condyles will be detached from the remainder of the humerus and moving freely. The forearm will be shorter because of proximal ulna migration and show either valgus or varus deformity. There is complete functional disability.

The clinical diagnosis of complete or partial sagittal fractures is not particularly difficult. However, partial frontal fractures of the capitellum or trochlea can go unrecognized. The functional loss is hard to detect, but will reveal itself as either a passive or active flexion or extension deficit. The elbow shape is normal. Anatomical landmarks are in their usual location. Hemarthrosis with filling of the posterolateral recess of the elbow is a sign of intra-articular injury \[6\]. The clinical appearance can be summarized as a painful swollen elbow after an injury event, which may explain the high number of delayed diagnoses for these fractures.

Skin lesions may occur posteriorly, where bone is located right under the skin. Open wounds add complexity when choosing the surgical approach \[7\]. Vascular complications are most common in supracondylar fractures. Fractures displaying signs of ischemia must be treated urgently. Nerve injury occurs in 25% of cases and affects either the median or ulnar nerves \[8–11\]. It is important to determine if the ulnar nerve is injured, as it will need to be transposed during the fixation process. Ruan \[8\] and Chen \[10\] believe that transposition is only necessary if the patient displays clinical signs before the surgery. If none are present, transposition is associated with worse results. There is no demonstrated link between the occurrence of postoperative ulnar neuropathy and the type of fixation hardware used \[11\].

5. Radiological evaluation

Standard AP and lateral X-rays of the elbow are sufficient for detecting complete fractures \[12\]. The AP view must allow the distal humerus to be viewed from the front, which is difficult to achieve in a position that is pain free for the patient. Because of the patient’s pain and the displaced fragments, X-rays are often not sufficient to identify all the bone fragments, the degree of comminution, and allow for surgical planning. If the elbow is half-flexed, a CT scan is difficult to perform. We prefer taking X-rays with the arm in traction with the patient under general anaesthesia in the operating room; this allows us to align the fragments and get a good view of the distal humerus (Fig. 1).

CT scans are useful in partial or very distal fractures because the various fragments will be superimposed, which hinders precise analysis of the fracture on standard views. Three-dimensional reconstruction shows the shape and position of the bone fragments and is helpful in determining the appropriate surgical approach \[14\] (Fig. 2). A comparison of the diagnostic ability of 2D axial slices alone or in combination with 3D reconstruction was performed with partial distal fractures and complete fractures \[14,15\]. Inter-observer reproducibility was best with 3D reconstruction. In all fracture types, more bone fragments could be identified than when X-rays only were used. Others have found more limited benefits of 3D reconstruction, as it only improves intra-observer reproducibility \[16\]. Doornberg felt that CT scanning with 3D reconstruction was only truly useful during preoperative planning for distal humerus fracture treatment.

6. Classification systems

All of the proposed classification systems are based on determining the status of the columns and looking for sagittal or frontal fracture lines. The most used classification in France is the one put forward by Lecestre et al. \[17\] during the 1979 SOFCOT meeting. It effectively captures the various fracture types encountered. The AO/OTA classification system (Fig. 3) is a worldwide reference for published studies, but does not help the surgeon determine which treatment strategy is appropriate \[18,19\]. For distal humerus articular fractures, the Dubberley classification system \[20\] has the advantage of being able to differentiate between various fracture types involving the capitellum or trochlea and then suggesting a technique for treating each one (Fig. 4).

7. Treatment

7.1. Functional and conservative treatment

The elbow joint must be mobilized early on to avoid stiffening and heterotopic ossification. Because of axial loads, the joint cannot be moved without inducing secondary displacement. Immobilization is only feasible in cases of non-displaced fractures, or as a temporary treatment in the elderly before arthrolysis and arthroplasty \[1,21\]. Absolute non-surgical treatment can be justified in cases of hemiplegia sequelae involving the ipsilateral upper limb, advanced osteoporosis and fractures with extensive bone loss, but the functional result will always be unsatisfactory \[1\]. Functional treatment should only be considered in elderly patients when the fracture is located below the insertion of the collateral ligaments and muscles inserting on the epicondyles. The surgeon hopes for an ideal non-union, without risk of secondary displacement because the ligaments insert proximally to the fracture line \[1,21\].

7.2. Surgical treatment

Distal humerus fractures are primarily treated surgically. But partial and complete fractures require different treatment strategies. Techniques range from conservative surgical treatment using internal fixation in young patients to elbow joint replacement in older patients with comminuted fractures. Controversy exists as to the best was to position the plates on each column: 90° or 180° to each other. The availability of locking compression plates has changed how we plan internal fixation and can result in lower morbidity. The main goal of surgical treatment is to obtain fixation that is stable enough to allow immediate postoperative elbow mobilisation and prevent it from stiffening. If the distal humerus fracture is immobilized in order to avoid fixation failure, stiffening is almost assured and arthrolysis will have to be performed later on.

7.2.1. Surgical approaches to the distal humerus

The choice of surgical approaches for internal fixation of distal humerus fracture is a difficult one to make, which justifies the need
for comprehensive presurgical planning. In elderly patients, one has to choose between an approach best for fixation and one that would be best for arthroplasty. In the ideal scenario, the procedure could be chosen at the time of surgery and only one surgical approach would be needed.

7.2.1.1. Approaches for internal fixation. Use of a medial approach [22–24] provides only limited exposure of the entire distal humeral epiphysis. It exposes the anterior part of the distal quarter of the humerus and requires neurolysis of the ulnar nerve. By longitudinally splitting the fibres of muscles originating on the medial
The lateral approach is used most often with epiphysis fractures of the elbow. It starts centrally over the tip of the lateral epicondyle and then extends longitudinally, providing exposure of the lateral epicondyle, the front and back of the distal humerus and muscles on the lateral epicondyle. With a distal humerus fracture, the approach must not damage the proximal attachment of the muscles originating on the lateral epicondyle and the joint incision itself is performed on either side of these structures.

The posterior approach is the only route that allows both columns of the distal humerus to be viewed simultaneously through a single incision. A vertical skin incision is made centred over the superior mid-line of the triceps contour, with the olecranon bulge in the middle and the posterior crest of the ulna below. The ulnar nerve must be located and released (neurolysis). Either column can be viewed by moving the triceps muscle medially or laterally. At this stage of the exposure, various techniques can be used to better view the epiphysis. To provide the best view of the joint, the extensor mechanism must be cut and reflected. The posterior approach is then combined with a transarticular or extra-articular olecranon osteotomy, detachment of the terminal tendon or cutting of the triceps at the muscle-tendon joint (TRAP technique). We prefer using the TRAP technique, which has similar benefits as olecranon osteotomy, provides a reverse template for reconstructing the trochlea and allows rehabilitation to start immediately.

7.2.1.2. Approaches for primary total elbow arthroplasty. Various routes have been used for total elbow arthroplasty (TEA), but only specified implant must be chosen. Constrained, semi-constrained, unconstrained, and resurfacing implants all have different characteristics. The former can be used when the elbow's lateral stabilizing structures are not intact, while the latter require these structures to be preserved. The Bryan-Morrey and Gschwend approaches disassemble the elbow, which forces the surgeon to use a constrained (linked) implant. The TRAP approach preserves the lateral structures, which allows faster functional recovery after the extensor mechanism is reinserted.

7.2.2. Fixation of partial articular fractures

Displaced partial fractures must be fixed with 2.7 mm or smaller diameter screws, depending on the distance from the cartilage. The screw heads must be buried. The joint must be stable enough to allow immediate rehabilitation (Fig. 6). The types of injuries being treated determine the approach to use. Fractures of the capitellum alone, in combination with the lateral epicondyle and capitulotrochlear groove (Hahn-Steinthal fracture) and of the entire articular surface (Kocher diacondylar fracture) are best treated through a lateral or anterolateral route. Medial epicondyle fractures and trochlear fractures are treated through the medial approach. If the main fracture line has a sagittal path and extends to one of the columns, plate fixation will be required.
7.2.3. Fixation of complete articular (bicondylar) fractures

This is the “gold standard” of distal humerus fracture fixation. Because the elbow has two columns (medial and lateral), each can be used for fixation in the frontal plane, even if the columns are not completely solid. The aim is to achieve simultaneous bicortical purchase of the screws through both columns. Since the introduction of early-precontoured anatomical plates [17], various plates are now commercially available: pure lateral, posterolateral, pure medial and posteromedial. These can be used with conventional or locking screws. The main benefit of precontoured plates is that they provide an acceptable anatomical compromise, with the plate serving as a reference or support when reconstructing the anatomy of the distal humerus.

In bicondylar fractures, the most mechanically stable construct is the combination of a lateral plate with at least four bicortical screws above the fracture site and a medial plate with at least two bicortical screws on either side of the site. A construct with two parallel plates (180° placement) is the best in terms of biomechanics [30]. An additional posterior plate, placed on the lateral column to prevent rotation (three plates in all) is the most stable construct for comminuted fractures [3]. But construct stability is negatively affected by the rotation and moment arm induced by the upper arm and forearm segments. Published studies have compared 90° or 180° dual-plate constructs [31]. Randomized studies have shown 180° constructs to be superior [31–34].

In osteoporotic patients, screw hold in the diaphysis and epiphysis is precarious. In this group of patients, the primary treatment goal is bone union [22], even if some stiffness occurs. This can justify using a protective splint to immobilize the joint. A tricortical autologous bone graft can be added to the fixation hardware to help reconstruct the medial or lateral columns as needed [35].

The basic principles of internal fixation for reconstruction of the distal humerus anatomical triangle are the following:

- temporary fixation of bone fragments with K-wires;
- restoring the normal width along with aligning the trochlear groove with the anterior humeral cortex;
- fixation of articular fragments to the medial and lateral bone columns using shaped plates;
- intra-operative verification that the hardware does not encroach upon the articular surfaces and fossa, and allows for full range of motion;
- making sure the fixation construct is stable enough to allow early mobilization of the joint.

7.2.4. Advantages of LCP for fixation of distal humerus fractures

Locking compression plates (LCP) are particularly beneficial for partial distal humerus fractures. Monocortical fixation is sufficient since the diverging nature of the screws in the locked holes ensures good construct stability. These plates can rarely be used alone, but are often used with direct screw fixation. LCPs can also be used as a neutralization plate, resorting to shorter plate and one less screw per fragment.

The benefit of using LCP in complex distal humerus fractures was shown in an experimental model where two plate fixation positions were evaluated: two posterior plates or medial and lateral plates at 90° to each other [36]. In both types of constructs, conventional (non-locking) reconstruction plates were compared with locking compression plates. The differences between the different plate types were insignificant in torsional loading and anterior-posterior bending when applied in the same configuration. However, when a 90° construct was used, locking compression plates had 25–50%
better stiffness and strength relative to other constructs for the various movements tested (flexion, extension, rotation). Superiority of locking compression plates was evident when the plates were applied at 90° in supracondylar fractures, which would be most relevant in patients with reduced bone mass.

There is also clinical evidence of no secondary displacement or fixation failure occurring with LCP, especially in elderly patients with low-quality trabecular bone [32]. Complete fixation with two precontoured anatomical plates at 90 or 180°, allowing placement of totally angular stable locking screws and non-locking screws was felt to be the most suitable technique for these fractures. This type of construct is best suited for very distal fractures because the screws are locked into the plate. It was also pointed out that smaller diameter screws could be used because of the high angular stability of these constructs. Other groups [33,34] use 180° constructs with locking screws, in part because of the high fixation quality (more stable construct resembling a monoblock implant) and in part because smaller diameter screws can be used in the distal fragment, which is the keystone for construct stability (Fig. 1).

7.2.5. Total elbow arthroplasty and hemiarthroplasty

Total elbow arthroplasty has been proposed as an alternative treatment for distal humerus fractures in osteoporotic bone, especially in elderly patients, and for comminuted type C fractures. In cases where the surgeon does not want to disrupt the extensor mechanism, a posterior triceps sparing approach can be used [25,37]. After resecting the distal part of the fractured humerus and making a single cut perpendicular to the humerus, enough space is created to insert the two components of a constrained total elbow arthroplasty with its transverse axis. The implant itself provides stability, but there is no possibility of going back because the epiphysis bone, capsular and ligament structures have been removed. We prefer using the Triceps reflecting anconeus pedicle (TRAP) method described by O’Driscoll [13,22]. This method preserves the ligaments and olecranon and offers an axial view of the humerus, which guarantees proper rotational positioning of

Fig. 5. Management of extensor mechanism after posterior approach: a: triceps splitting; b: TRAP (triceps reflecting anconeus pedicle), → = drawing of periosteum and aponeurosis reflection; c: Bryan-Morrey approach; d: olecranon osteotomy; e: triceps sparing.

Fig. 6. Fracture of capitellum with countersunk screw head.
the humeral implant and ensures good postoperative functional results. The lateral columns are stabilized as needed (Fig. 7).

Total elbow arthroplasty provides good early outcomes when treating complex distal humerus fractures in elderly patients, with immediate postoperative mobilization and quick return to activities of daily living [26,37–40]. Implantation of a semi-constrained total elbow arthroplasty in patients having an average age of 81 years led to good results in 83% of patients [34]. Hemiarthroplasty (resurfacing) implants have been used more recently [26] but their true place in fracture treatment has not yet been established. In a randomized, multicentre study comparing total elbow arthroplasty with internal fixation (90 or 180° plates), the results were better with elbow replacement in osteoporotic subjects after at least two years of follow-up [41]. But the medium and long-term outcome of elbow replacement performed on an emergency basis for distal humerus fracture remains to be evaluated [42].

8. Complications

8.1. Open fractures

Open distal humerus fractures are difficult to treat because of the need to simultaneously manage soft tissue injuries, often posterior and directly over the distal humerus, and also stabilize the fracture [7]. Use of two external fixators (one medial, one lateral) has been recommended to achieve epiphysis union and preserve humeral alignment [43]. A monolateralfixator can be used instead, as long as the distraction occurs in the humeral axis. The construct must span the humerus and ulna, with the distal anchorage point being in the proximal part of the ulna (i.e. olecranon area). Ligamentotaxis aligns the distal humeral epiphysis through traction forces. Long-term results of open fracture treatment are consistently worse than treatment of equivalent closed fractures, independent of the stabilization method chosen [3,4,7]. A hinged fixator can be used. The fixator would be locked initially and then released to provide secondary mobilization after the soft tissues have healed. But the drawback of using a fixator with fixed centre of rotation is that it will be impossible to regain the entire range of motion because of a cam effect during the last 30 degrees of extension.

8.2. Elbow stiffness

This is the most common complication of distal humerus fractures. If the stiffness is disabling, a full evaluation with thin CT slices and CT arthrography will help to identify osteophytes, radiolucent intra-articular foreign bodies and the volume of the joint cavity. The stiffness can be classified as either extrinsic or intrinsic, depending on if the joint is incongruent and the potential exists for loss of gliding between articular facets. Extrinsic causes of stiffness are anterior and/or posterior capsule adhesions, adhesions to the triceps or brachialis muscles, capsule contraction, intra- or extra-articular osteophytes, jutting out of fixation hardware. Mild stiffness (less than 30°) can be treated by arthroscopic arthrolysis [44] or limited open arthrolysis without hardware removal. Complex injuries must be treated by open arthrolysis [12] with hardware removal or total elbow arthroplasty in combination with arthrolysis in the older subjects [45].
8.3. Non-union and malunion

Distal humerus non-union is quite common in osteoporotic patients after partial articular fractures. In complex fractures, this can result in unattached or free floating fragments in the joint. CT scan and CT arthrography evaluations must be performed to identify intra-articular injuries that could be excised by arthroscopy or in an open procedure. Fragments of the entire trochlea or capitellum may also be present. In younger patients, the bone can be freshened and the fragment reattached with fully buried hardware [12]. In older patients, the involved fragments can be excised and a total joint replacement performed. In a small patient series [46], the outcome of total elbow replacement after failure of internal fixation was good in 11 of 14 cases, with no differences found relative to primary total elbow replacement performed on an emergency basis. However, the number of infection-type complications, ulnar nerve injuries or loosening seemed higher in secondary arthroplasty cases [46].

Two main types of malunion can be encountered:

- extra-articular ones that are easily treated with osteotomy and direct fixation after reduction;
- intra-articular ones due to lack of anatomical restoration of joint surfaced [12] that are harder to treat. These now have to be taken into consideration when managing joint stiffness.

8.4. Peri-articular osteomas

Osteomas or peri-articular ectopic ossifications contribute to posttraumatic elbow stiffening. The average published rate of heterotopic ossifications is 8.6% (range 0–21%) if preventative treatments are not used [5]. Although not statistically significant, there was a trend towards less heterotopic ossifications after indomethacin preventative treatment in high-energy distal humerus articular fractures. Known risk factors are an associated brain injury, delayed surgical management, and sequential surgery with secondary final treatment. Only a level C recommendation can be issued for adding peri-articular ossification preventative treatment in at-risk patients.

9. Conclusion

Distal humerus articular fractures are uncommon injuries requiring precise radiographic analysis for planning optimal treatment. In high-energy fractures in younger patients, the anatomy of the joint surfaces must be restored. CT scanning with 3D reconstruction helps the surgeon view all the fragments and choose the most suitable surgical approach for the injury in question. Fixation for complex fractures will consist of reconstruction plates or locking compression plates, with one plate being placed on each column to neutralize disassembly forces, especially rotational ones. We recommend using templates to put together the construct being implanted. The advent of monoaxial and polyaaxial locking screws has changed the indications and extended fixation options to fractures in osteoporotic or diseased bone. The primary objective of distal humerus fixation is a perfectly stable fracture; this will enable the early rehabilitation needed to regain normal mobility. With low-energy distal humerus fractures in older, osteoporotic patients, the degree of fracture comminution and the absolute need for fast return to activities of daily living may lead the surgeon to choose total elbow arthroplasty or hemiarthroplasty. Fracture complications such as stiffness, peri-articular ossification, non-union and malunion are quite common. Since fracture sequelae are challenging to treat, the optimal treatment must be performed right away.

Disclosure of interest

The author declares that he has no conflicts of interest concerning this article.

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