Tips and Techniques in Elbow Surgery

A Practical Approach

Joshua S. Dines
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Preface

As our knowledge and understanding of the elbow continues to grow, we have garnered new insights into the injuries that can occur in this relatively complex joint. This insight has led to a rapid expansion of surgical treatment options for a wide variety of elbow pathologies. Many injuries that were once treated with large, open surgical approaches are now being addressed through minimally invasive techniques with improved patient outcomes. Similarly, some pathologies that historically did not have reliable surgical solutions can now reliably be addressed through surgical means. These treatment options have been developed, refined, and optimized by a multitude of thought leaders all over the world. In this book, we bring together the collective wisdom of the global community of elbow surgeons to provide you with the most up-to-date surgical treatment options for elbow fractures, arthritis, cartilage injuries, ligament injuries, tendon pathologies, nerve-related issues, and more. This book is designed for the busy elbow surgeon looking to stay informed on the latest surgical techniques as explained by the leaders who have helped pioneer them. The focus is on practical "Tips and Techniques" to ensure a high yield, and efficient learning experience that combines the real-world operative experience with the evidence-based practices of these esteemed authors from around the globe.

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Part IV Sports Conditions of the Elbow

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Part I

Elbow Trauma

1 Open Reduction Internal Fixation (ORIF) for Radial Head and Neck Fractures

Matthew Patrick, Jacob Murphree, and Bradley S. Schoch

1.1 Introduction

- Radial head and neck fractures typically occur following a fall onto outstretched arm.
- Accounts for 1–4% of all fractures and up to 1/3 of elbow fractures [1].

1.2 Associated Injuries

- Although radial head fractures can occur in isolation, up to 30–40% of radial head fractures present with an associated osseous or ligamentous injury.
- Radial head/neck fractures frequently occur during elbow dislocations and are a component of the injury constellation known as a "terrible triad" (Radial head fracture, coronoid fracture, lateral ulnar collateral ligament injury).
- Additionally, radial head/neck injuries can also result in an injury to the ulnar collateral ligament due to a valgus load or in conjunction with an interosseous membrane disruption (Essex-Lopresti Injury).

1.3 Imaging

- An anteroposterior (AP) and lateral view X-ray of the elbow should be obtained. Additionally, a Greenspan view may also be beneficial to assess the osseous anatomy of the radial head and radiocapitellar articulation. This view allows for visualization of the entire radial head profile without overlap of the coronoid.
- Anteroposterior and lateral radiographs of the forearm and wrist of the ipsilateral upper extremity are also recommended to evaluate for associated injuries. Pay close attention to the distal radio-ulnar joint (DRUJ) articulation. Dislocation/subluxation of the DRUJ can indicate a concomitant Essex-Lopresti injury.
- Computed tomography (CT) of the elbow may be used to further assess the fracture morphology for surgical planning in isolated radial head fractures depending on fracture complexity.

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1.4 Initial Evaluation/Examination

- Assess both active and passive elbow range of motion (ROM), including flexion, extension, pronation, and supination. Assess for a mechanical block to ROM. In the setting of an elbow dislocation, the examiner should also assess for elbow stability following reduction, especially during extension. If patients are unable to participate in an examination due to pain, consider injecting the elbow joint with local anesthetic.
- After assessing ROM, the examiner should assess varus/valgus stability of the elbow joint.

1.5 Classification

- The most commonly used classification system is the Mason classification, later modified by Hotchkiss [2, 3].
- Modified Mason Classification is outlined in Table 1.1.

1.6 Treatment Algorithm

- Type I Fractures—Isolated radial head fracture can be managed nonoperatively.
- Type II Fractures—Isolated displaced radial head fractures with no mechanical block may be treated nonoperatively. However, if there is significant displacement, mechanical block to motion, or an associated elbow injury (Terrible Triad) open reduction internal fixation (ORIF) is recommended.

Table 1.1 Modified Mason classification

Type I	Nondisplaced or minimally displaced (<2 mm), no mechanical block to forearm rotation
Type II	Fracture displaced >2 mm or angulated, possible mechanical block to forearm rotation
Type III	Severely comminuted fracture, mechanical block to forearm rotation
Type IV	Radial head fracture with associated elbow dislocation

- Type III Fractures—ORIF when feasible. However, if >3 fracture fragments consider radial head arthroplasty (RHA) as worse outcomes are common after ORIF of radial head when >3 fragments are involved [4].
- Type IV Fracture—RIF vs. RHA depending on the fracture pattern (similar to Type III) as well as addressing other associated injuries involved with the elbow dislocation.

1.7 Surgical Treatment

1.7.1 Implants and Equipment

- Small point-to-point reduction clamps.
- Dental pick.
- Small periosteal elevators or a freer elevator.
- Small k-wires or Steinmann pins (1 mm or smaller).
- Mini-fragment screws (1.5 mm) or headless-compression screws.
- Mini-fragment plate and/or pre-contoured proximal radius plates.
- Radial head arthroplasty system available if unable to perform ORIF.

1.7.2 Positioning

- Supine position with the arm abducted and placed radiolucent hand table. We prefer to keep patients positioned on the hospital gurney rather than transferring them to a traditional operating room table.
- In the setting of limited shoulder ROM, the patient can be placed in the sloppy lateral position with a bump under the ipsilateral shoulder. The operative elbow is then placed on patient's chest for dissection.
- In the setting of complex elbow injuries, patients can also be placed in the lateral decubitus/prone position with arm over a bone-foam block. This allows for utilization of a posterior utilitarian approach and allows for simultaneous access to the medial aspect of the elbow.

1.7.3 Surgical Approach

1.7.3.1 Kocher Approach

The incision is made from the lateral epicondyle extending distally 5–6 cm directed towards the ulnar shaft aiming for a point 10 cm distal to the olecranon tip. The interval between the anconeus and extensor carpal ulnaris identified and dissected. The interval is more easily identified along the distal aspect of the approach and is often accompanied by a visible fat stripe. The deep fascia of the interval is incised and the anconeus muscle is retracted dorsally. The ECU is elevated off the underlying capsule and LUCL complex anteriorly . During the deep dissection and exposure of the radial head, pronate the forearm to help prevent PIN injury. Pronating the forearm will move the PIN away from the radial neck and further from the surgical field. If the LUCL-capsular complex is still intact, make an incision along the anterior boarder of the LUCL from the lateral epicondyle towards the ulna. Avoid dissection over the anterior radial neck to avoid PIN injury. Proximally the anterior capsular flap can be released from the epicondyle and extended proximally along the distal humerus to improve exposure. However, in the setting of an elbow dislocation, the LUCL-capsular complex is usually disrupted. In these cases, the surgeon may work through the traumatic arthrotomy and repair the LUCL-capsular complex at the conclusion of the case. Small Hohmann retractors can be placed posterior to the radial neck and an Army-Navy retractor used to retract anteriorly. We generally try to avoid placing Homan retractors anteriorly due to the risk of traction on the PIN. However, if needed, make sure the retractor is directly on bone and take care to not retract too vigorously due to close proximity to and risk of injuring the PIN.

- Pros.
  - Less risk to PIN injury compared to Kaplan.
- Cons.
  - High risk of instability of the elbow if dissection/capsulotomy is too posterior and violates the LUCL.

1.7.3.2 Kaplan Approach

The incision is made from the lateral epicondyle and extended distally 4–5 cm directed toward Lister's tubercle. The plane between ECRB and EDC is then identified and bluntly dissected. As a general rule, distal extension of this split should be limited to two finger breadths to protect the PIN. The ECRB is retracted radially and EDC is retracted ulnarly. Once the interval is fully developed, the underlying supinator muscle will be exposed. The forearm is then maximally pronated to the move the PIN away from the surgical field. The humeral and ulnar attachments of the supinator are released and the supinator is mobilized expose the underlying elbow capsule and annular ligament. The capsule is then incised in line with the muscular split, extending this proximally to the distal capitellum. Care is taken to stay anterior to the LUCL origin, which is located at the center of the capitellum laterally. Similar to the Kocher approach, the anterior capsule can be elevated superiorly along the distal humerus to aid in exposure of the radial head.

- Pros.
  - Less risk of injuring LUCL due to more anterior approach.
  - Better visualization of coronoid.
  - Better visualization of anterior/ulnar sided radial head fractures.
- Cons.
  - Technically more difficult exposure.
  - Increased risk of PIN injury.

1.7.4 Reduction and Fixation

Fixation technique is based on fracture pattern. A simple partial articular fracture that does not extend into the radial neck can be managed with screw fixation alone with good results. Under direct visualization a dental pick and small point-to-point reduction clamps can be utilized to secure the reduction. Once reduced, small K-wires (0.035 in.) or Steinmann pins (1 mm) can be placed to provide provisional fixation of the fracture. Intraoperative fluoroscopy is recommended to confirm reduction. Countersunk mini-fragment screws (1.5 mm) or headless compression screws can then be placed to achieve definitive fixation (Fig. 1.1a, b).

However, if the fracture extends into the radial neck or if the radial neck is compromised, additional plate fixation is needed to provide adequate stability. A mini-fragment plate or pre-contoured proximal radius plate can be utilized. The radial neck is often impacted in these fracture patterns (Fig. 1.2a). Use a small elevator to carefully disimpact the radial head. There is often intact cortex or periosteum on the far side of the fracture that acts as a hinge and can assist with the reduction (Fig. 1.2b). Take extreme care not to disrupt the hinge or the reduction will become significantly more difficult. The void created by the impaction zone can be backfilled with cancellous allograft to assist with maintenance of reduction and add biomechanical stability. Provisional stability can be achieved by placing a small K-wire obliquely from radial head to the radial neck until plate fixation is complete.

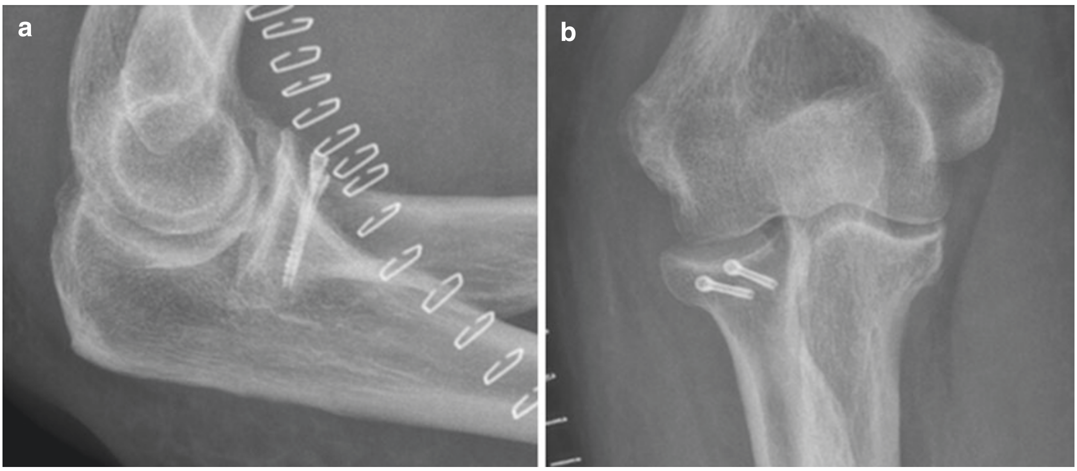

Fig. 1.1 (**a**) Lateral and (**b**) AP of elbow demonstrating the use of a headless compression screw for fixation of Mason II partial articular fracture of a radial head

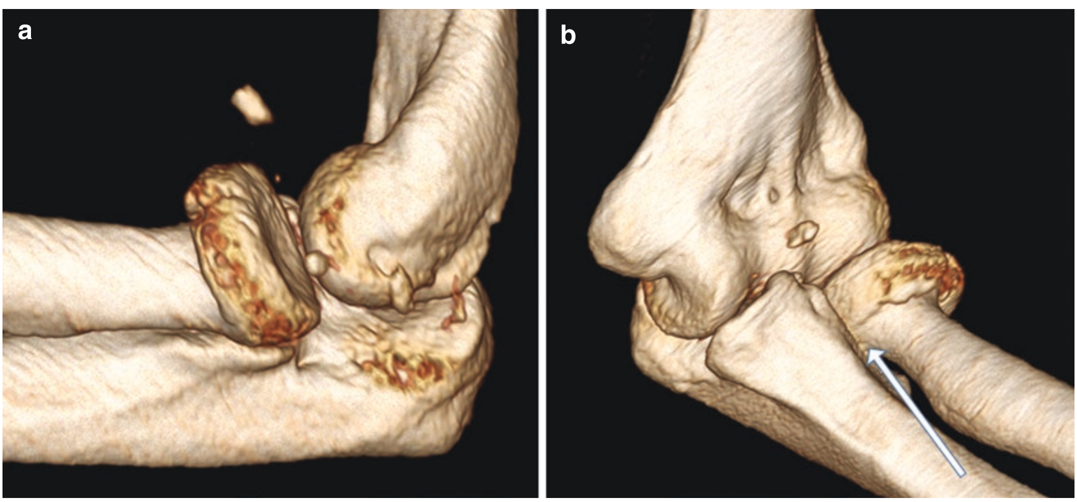

Fig. 1.2 (**a**) 3D CT image demonstrating radial head fracture with extension into radial neck and frequently associated impaction of the metaphyseal neck. (**b**) Arrow highlights the intact cortical hinge of impacted radial head/neck fracture

The plate is sized and contoured to fit the proximal radius. The plate should be placed in the "safe zone," a 110° area free of impingement between the radius and ulna. This area is located opposite of the radial tuberosity or in the area between the radial styloid and Lister's tubercle. This area can be easily identified on fluoroscopy, as it is opposite the where the biceps tuberosity profile appears largest in maximal supination [5]. Once the plate is provisionally secured, the forearm should be pronated and supinated to confirm no impingement occurs. At least two screws need to be placed into the radial head and two screws in the radial shaft. One screw should be placed from distal in the plate in a retrograde manner to engage the opposite cortex of the radial head (Fig. 1.3a). This screw acts a "kickstand" to support the radial head and improves the biomechanical strength of the construct.

When exposing more distally for placement of a plate, pay close attention for the PIN. The nerve will cross over the anterior cortex of the radius 4–5 cm distal to the radiocapitellar joint from anterior to posterior in an oblique direction. If a longer plate is required for fixation, the PIN will need to be carefully dissected and mobilized for safe placement of the plate.

At the conclusion of the procedure, assess ROM of the elbow to confirm no mechanical blocks to motion and visualize the radiocapitellar joint to confirm no intraarticular placement of hardware. Finally, assess the elbow for varus/valgus stability as well as postero-lateral rotary instability.

1.7.5 Bailout

If the surgeon is unable to achieve adequate fixation or deems the fracture too comminuted for fixation, there are two bailout options. If the fracture fragment is less than 25% of the articular surface and there is no evidence of instability, the fracture fragment may be excised. However, if the fragment is greater than 25% of the articular surface or there is evidence of instability after fragment excision, a radial head arthroplasty (RHA) must be performed.

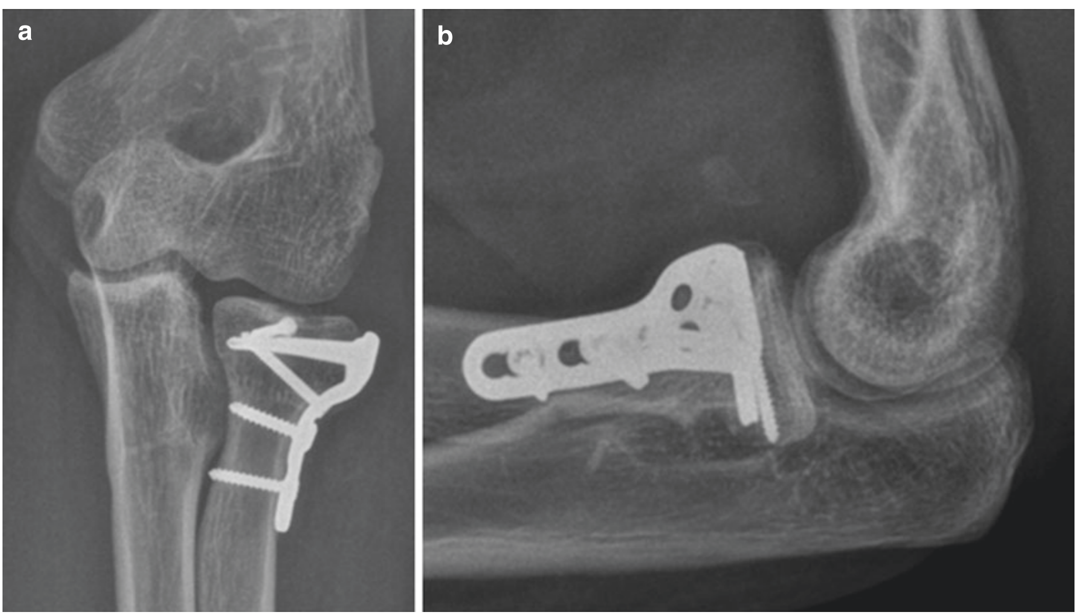

Fig. 1.3 (**a**) AP and (**b**) lateral radiograph illustrating appropriate position of proximal radial plate. Note plate is opposite the radial tuberosity indicating placement in the "safe zone." Arrow in (**a**) highlights placement of "kickstand" screw

1.8 Take Away Points

- Radial head fractures are frequently associate with other osseous and ligamentous injuries. Surgeons must evaluate for these associated injuries and address them at time of surgery to prevent poor outcomes.
- The PIN is at risk during exposure and instrumentation of radial head/neck fractures. Careful dissection and retractor placement is warranted. Additionally, the forearm should be placed in maximum pronation to move the PIN away from the surgical field.
- If plate fixation is utilized, the plate should be positioned in the "safe zone" to prevent radio-ulnar impingement.
- Have a RHA available for all procedures as a bailout if unable to perform ORIF.

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2 Open Reduction and Internal Fixation (ORIF) for Distal Humerus Fractures

Jonathan Barlow and Katherine E. Mallett

2.1 Background and Key Principles

Successful open reduction internal fixation of distal humerus fractures requires careful preoperative planning and principle based fixation. Distal humerus fractures account for 30% of elbow fractures. The complex anatomy of the distal humerus and the demand for early mobilization presents unique technical challenges when considering fixation. The goal of distal humerus reconstruction is to provide a construct rigid enough to allow for early motion, while also restoring the articular surface and anatomic geometry. In order to achieve these goals, fixation of each distal fragment must contribute to maximizing stability between the distal fragment and the humeral shaft. Eight technical objectives were initially described in order to guide fixation such that every fixation effort maximizes stability [1]:

1. All screws used in fixation should pass through a plate.
2. Each screw should engage fragments that are also part of a plated construct.
3. Fixation should include as many screws as possible.
4. All screws should be the maximum length possible.
5. Every screw should engage as many articular fragments as possible.
6. The distal most screws should interdigitate, locking together.
7. Supracondylar compression should be applied via plating in both columns.
8. Plates themselves must be applied in a rigid enough construct for union, specifically at the supracondylar level, which is at highest risk for nonunion.

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2.2 Indications

The indications for ORIF of distal humerus fractures includes most displaced distal humerus fractures. We group them into extra-articular fractures (transcondylar fractures, supracondylar fractures, and epicondyle fractures) and intraarticular fractures (intercondylar fractures and purely articular fractures [coronal shear]).

2.3 Contraindications

Nonsurgical management can be considered for nondisplaced fractures and for infirm patients, but remains rare. Total elbow arthroplasty is considered for elderly patients with commi-

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nuted fractures. TEA is also preferable in patients with inflammatory arthritis such as rheumatoid arthritis [2].

2.4 Special Considerations

Preoperative imaging is critical for surgical planning, and should include plain films (anterior–posterior (AP) and lateral) and computed tomography (CT) with three-dimensional reconstruction (Fig. 2.1). These reconstructions allow for detailed evaluation of the articular fragments for pre-operative planning. The ideal position for CT is with the patient's arm over their head for maximum radiographic clarity. A careful preoperative neurologic and vascular exam is also key, as many patients will have nerve mediated symptoms, most commonly involving the ulnar nerve.

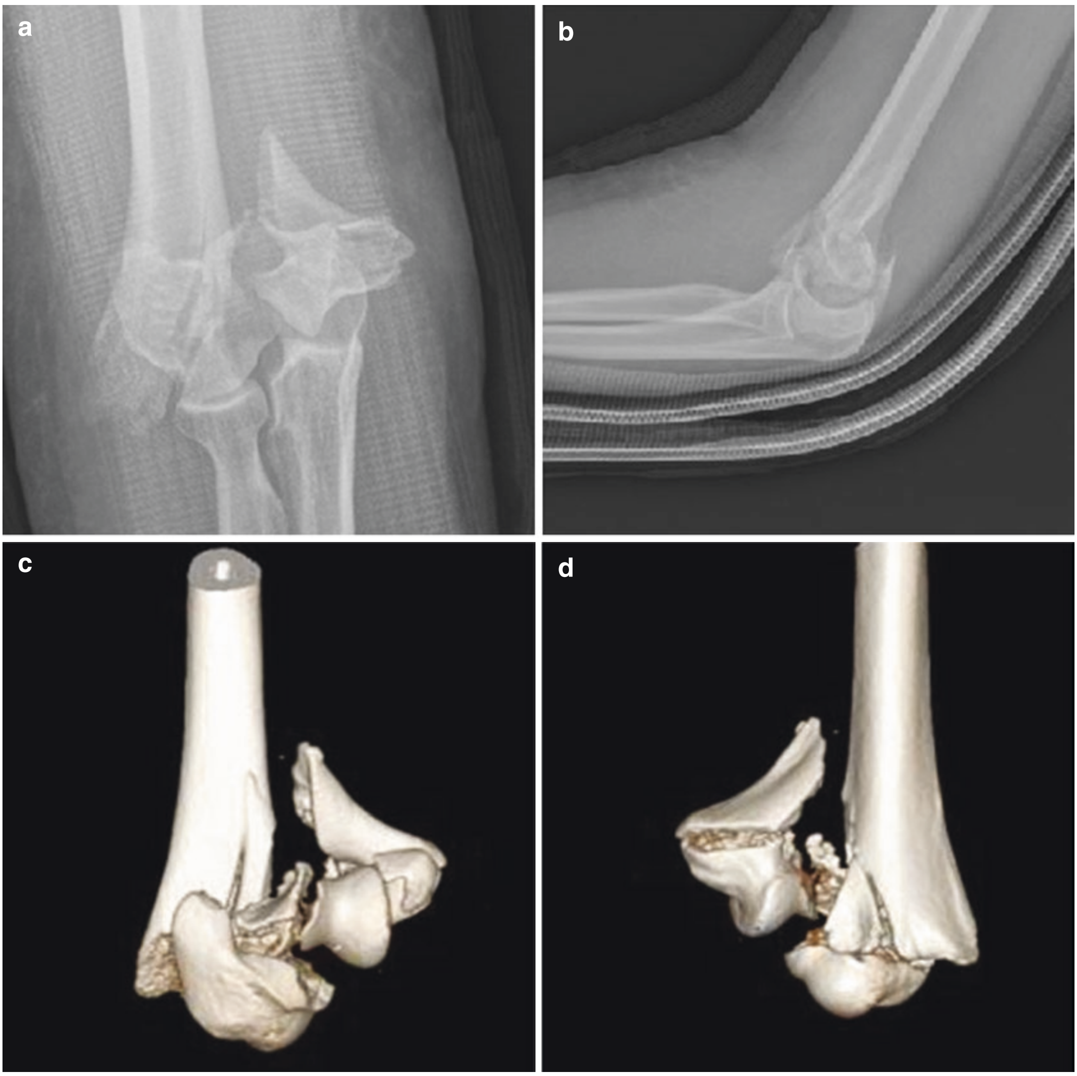

Fig. 2.1 (**a**) Anterior–posterior (AP) and (**b**) lateral plain films of a bicolumnar distal humerus fracture with intraarticular involvement. (**c**) Anterior view computed tomography (CT) three-dimensional reconstruction of the same fracture, demonstrating articular comminution and columnar displacement. (**d**) Posterior CT reconstruction of the same fracture

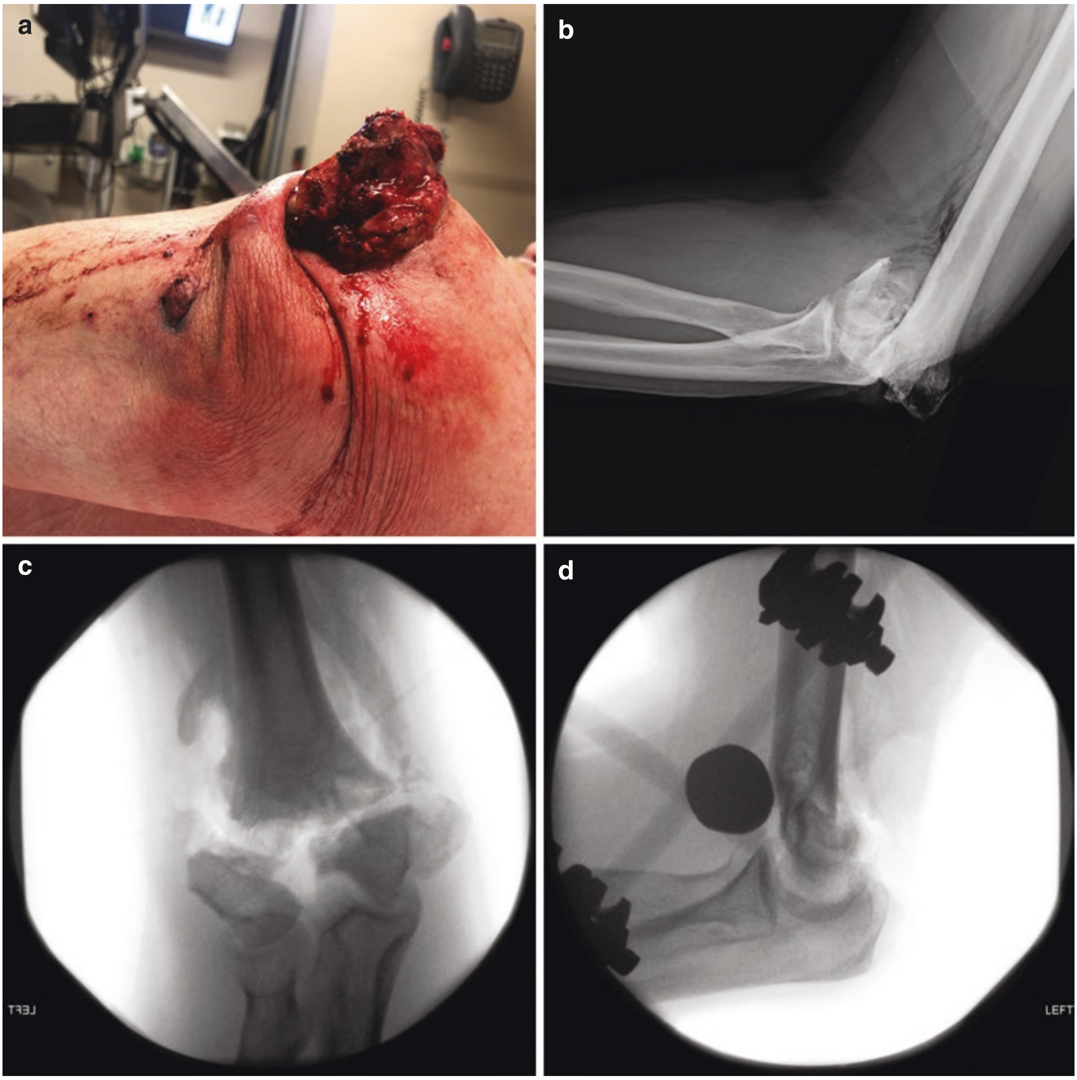

Fig. 2.2 (**a**) Photograph of an open distal humerus fracture. (**b**) Lateral plain film of the initial injury demonstrating open component of fracture. (**c**) AP intraoperative fluoroscopy of the same fracture. (**d**) Lateral intraoperative fluoroscopy after external fixator placement

Additionally, a careful assessment of the skin integrity around the injury is crucial for determining fixation timing, as open fractures or patients with acute threatened skin may benefit from application of external-fixation initially prior to definitive open reduction and internal fixation (Fig. 2.2). It is also vital to have a clear discussion with patients preoperatively, because these fractures are at high risk for nonunion, malunion, soft tissue complications, and hardware complications, and many patients require additional surgical intervention. Even patients who successfully avoid major complications can have persistent range of motion loss and/or post-traumatic arthritis.

2.5 Anesthesia and Positioning

Anesthesia is general and may include an interscalene or supraclavicular block, however, this may confound early postoperative examination and we do not use peripheral nerve blocks in patients with pre-operative nerve symptoms.

The patient is positioned lateral decubitus with the operative arm flexed over a radiolucent arm board (Fig. 2.3). This position allows for intraoperative flexion, extension, pronation, and supination as needed, while also stabilizing the proximal humerus.

Fluoroscopic imaging should be verified prior to prepping and draping to ensure the positioning is logistically conducive to intraoperative imaging during reduction and fixation. We typically use a plexiglass arm holder for the down (nonsurgical) arm to avoid interference with imaging.

Fig. 2.3 Patient in lateral decubitus with operative arm draped over an elevated radiolucent arm board stabilizes the humerus while allowing for intraoperative flexion, extension, pronation, and supination as needed

2.6 Tips, Pearls, and Lessons Learned

2.6.1 Olecranon Osteotomy

Using an olecranon osteotomy allows the most complete exposure to the articular surface, up to 57% of the surface, and therefore lends itself to complex intraarticular fractures. It is helpful to have a low threshold for this approach when preoperative CT reveals a complex fracture pattern with articular involvement. We prefer to use a cannulated 6.5 mm screw with a washer for fixation of the osteotomy. The guidewire can be placed and the screw may be tapped and placed until nearly down to confirm length and stability prior to osteotomy. Starting your pin slightly dorsally in the tip of the olecranon can avoid translation of the osteotomy dorsally (Fig. 2.4). The screw may then be removed and saved, which makes fixation straightforward at the end of the case.

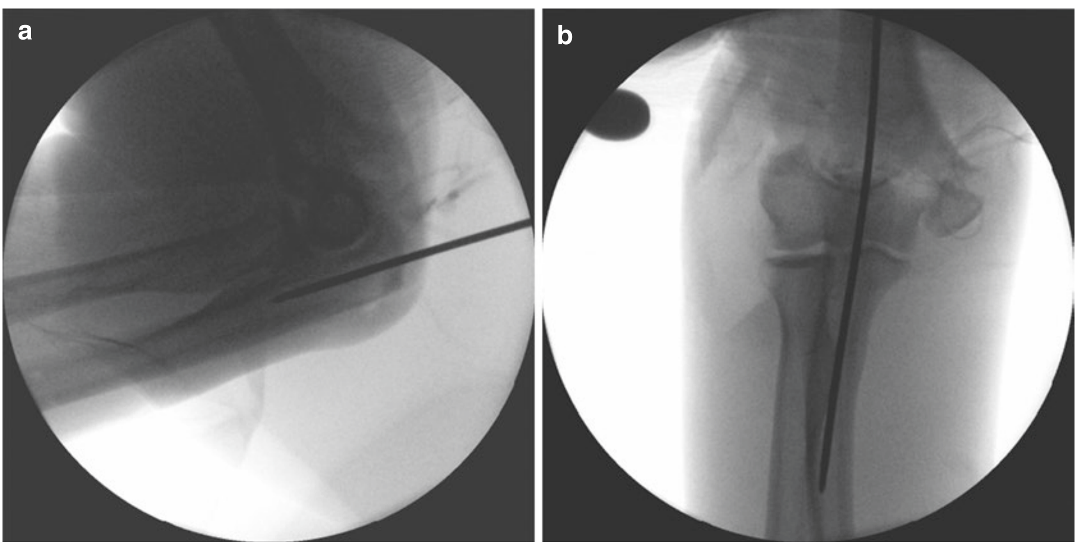

Fig. 2.4 (**a**) Lateral fluoroscopic view of predrilling for the olecranon osteotomy. A starting point at the dorsal aspect of the tip of the olecranon helps avoid dorsal translation of the fragment. (**b**) Confirmatory AP view during predrilling. The tip of the screw should begin to engage the radial cortex of the ulna

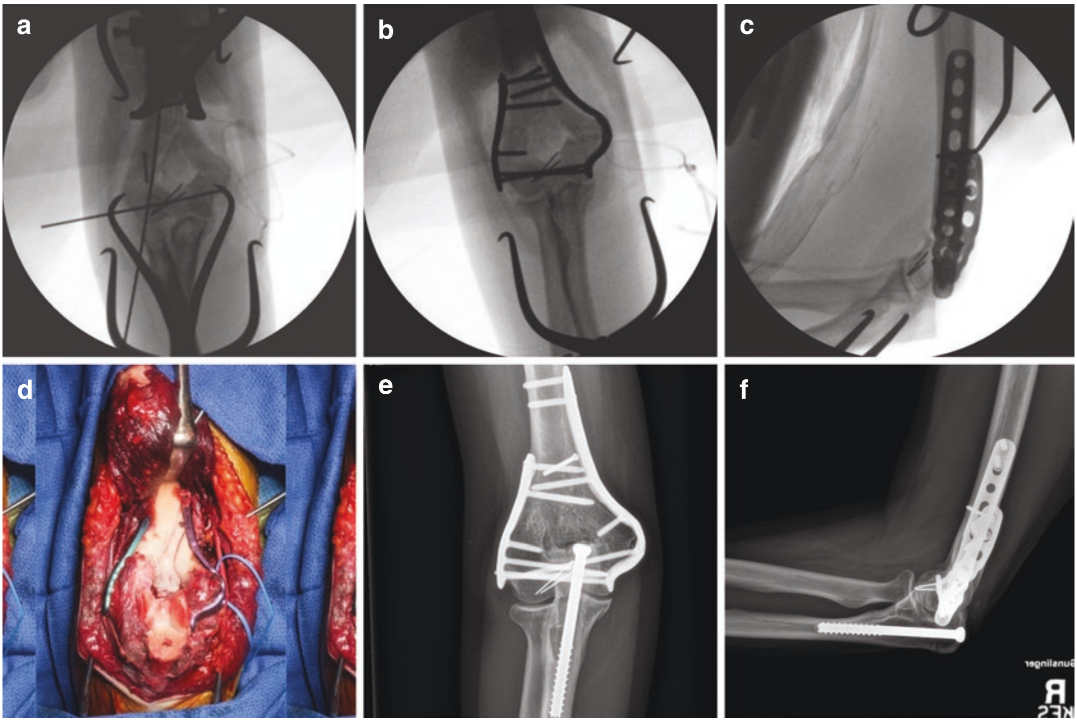

Fig. 2.5 (**a**) Reduction of articular fragments achieved with Kirschner wires and clamps. (**b**) AP intraoperative image of parallel plate fixation. (**c**) Lateral intraoperative fluoroscopy of parallel plate technique. (**d**) Intraoperative photograph. A vessel loop protects the transposed ulnar nerve. The olecranon is retracted superiorly with sutures, providing excellent visualization of the articular surface. (**e**) Postoperative AP image of the same fracture with final olecranon osteotomy screw fixation. (**f**) Lateral radiograph of final fracture fixation

2.6.2 Order of Reduction

In the majority of cases, reconstruction of the articular surface should be the first priority in fixation, using the intact radial head and ulna as a reference for articular alignment. Provisional fixation may be achieved with smooth Kirschner wires (Fig. 2.5a). In cases with severe articular comminution, the Kirschner wires may be used in addition to traditional plate and screws for definitive fixation (Fig. 2.5e).

2.6.3 Intraoperative Mobility Assessment

After reduction and before closing, range the elbow through full flexion, extension, pronation, and supination in order to assess the functional mobility of the joint after articular reconstruction. Many patients will go on to develop stiffness or face functional challenges, and ensuring appropriate alignment and restored joint mechanics intraoperatively is key for setting the patient up for functional success.

2.7 Difficulties Encountered

As stated above, reduction and fixation is best completed beginning with the articular surface distally, moving in a stepwise fashion towards the proximal fragments. The goal is to convert a complex articular fracture into a simple articular fracture by anchoring articular fragments to either the medial or lateral column before moving to proximal fixation. These distal fragments act like the keystone in an arch, providing intercondylar stability. Fragments that are too small may be removed. If the remaining articular surface is deficient, causing narrowing of the intercondylar width, autograft or allograft iliac crest bone graft may be used to bridge the gap and restore anatomic width.

In the setting of significant metaphyseal comminution, which may prevent supracondylar compression and anatomic reconstruction, a humeral shortening osteotomy maybe used to allow better bony apposition. It is key to ensure anatomic alignment, rotation, and geometry of the distal humerus are maintained when using a supracondylar osteotomy. It is helpful to mark rotation with electrocautery prior to the osteotomy. The distal humerus can tolerate up to 2 cm of shortening without sacrificing elbow biomechanics [3].

2.8 Key Procedural Steps

2.8.1 Exposure and Approach

Incision is midline posterior, which allows exposure of both columns via full-thickness fasciocutaneous flaps, dissecting to the triceps tendon. For rare single column injuries, a direct medial or lateral incision may be used. The single incision posterior approach has been shown to have better outcomes than a two-incision approach [4]. We typically begin by transposing the ulnar nerve. First, release the nerve from the cubital tunnel, ensuring you have about 6 cm mobilized both proximally and distally to the epicondyle. Tag the nerve with a vessel loop, and elevate a subcutaneous flap above the flexor pronator mass for transposition. Be sure to release Osborne's ligament and the fascia of the flexor carpi ulnaris, both areas of potential ulnar nerve impingement. A thorough decompression and transposition at that beginning of the case will allow the nerve to be protected through the remainder of the case (Fig. 2.5d).

In extra-articular fractures, or fractures with a simple articular split with extraarticular cortical reads, a paratricipital approach may be used. We do this by elevating the anconeus and triceps between the intermuscular septae, exposing the posterior humerus. If the fracture extends intraarticularly, windows on either side of the elevated triceps may be used.

For more complex intercondylar fractures of the distal humerus, we have a low threshold to perform an olecranon osteotomy. We begin by predrilling, tapping, and placing a 6.5 cannulated screw with a washer. This can be seated down until it is nearly contacting to ensure appropriate length. An anteroposterior (AP) fluoroscopy image will demonstrate the screw beginning to engage the radial cortex of the ulna (Fig. 2.4b). This gives outstanding fixation. By initiating a starting point that is on the dorsal aspect of the tip of the olecranon, dorsal translation of the fragment can be avoided.

Working through the medial and lateral windows of the triceps and posterior humerus, we visualize the bare area of the trochlea. This is the location where the osteotomy should exit, and should be visualized (rather than identified by fluoroscopy). A very small chevron osteotomy can be made with a thin saw, and the last 20% should be finished with an osteotome. Reflection of the osteotomy will allow excellent visualization of the distal humerus. We use sutures in the triceps to hold the osteotomy retracted proximally (Fig. 2.5d).

2.8.2 Fixation

Fixation follows the key principles listed in Sect. 2.1, beginning with the articular surface. Remove and save any fragments that are too small for Kirschner wire fixation, as these may be used for bone graft once stripped of cartilage. Kirschner wires may be used to fix articular fragments together until the articular surface is recreated. After pinning the articular surface, the distal construct including the articular surface can then be reduced to the shaft. In most cases, this is held in place with 0.062 K-wires, which can provisionally hold the reduction until plate application (Fig. 2.5a). We typically apply the plate to the most stable column first. Compression can be applied with pointed reduction clamps (and held compressed with locking screws) or with compression through the plate. Larger fragments, particularly extraarticular pieces, can be fixed together with lag screws.

In some cases of profound comminution or bone loss of one column, it may be advantageous to fix one column first, in order to restore alignment to the joint. Careful compression of the columns to ensure bone contact is critical if this technique is employed. We prefer to reduce the joint first, and compress to the supracondylar humerus.

When there is profound supracondylar comminution, supracondylar shortening can allow compression and stabilization of the articular segment. This can be done with minimal functional compromise to the arm. We have a low threshold for use of this technique, particularly in the elderly, or in open fractures. Steps are similar to those above, with removal of spikes of supracondylar bone to allow stable compression of the repaired articular surface to the distal humerus. The olecranon tip and coronoid tip should be inspected through an arc of motion to ensure they do not engage the humeral cortex. In most cases, recreation of the olecranon and coronoid fossa are necessary to ensure impingement free ROM.

We use parallel plating for the vast majority of distal humerus fractures. This technique provides rigid support to the articular surface through interdigitating screws, while providing supracondylar compression. Precontoured periarticular plates designed with tightly grouped distal screw holes allow multiple long screws to pass through the articular fragments (Fig. 2.5e, f). All plates should ideally be slightly under contoured in order to compress across the metaphyseal fracture. Plate length should allow placement of at least three screws proximal to the metaphyseal fracture both medially and laterally, with the plates ending at different heights proximally to avoid stress riser creation [5].

Regarding plate orientation, parallel plating involves placing plates on the medial and lateral columns, with the screws oriented slightly anteriorly (Fig. 2.5). In orthogonal ("90–90" or perpendicular) plating, one plate is placed on the medial column, with a second plate on the posterolateral surface (Fig. 2.6). Biomechanical studies comparing both methods suggest parallel plating provides greater stiffness in extension, lateral bending, and torsion [6]. Ultimately fracture configuration will guide plate orientation, and both configurations have historically favorable outcomes. We use parallel plating in almost all cases, with the exception being certain supracondylar fractures with minimal intraarticular involvement.

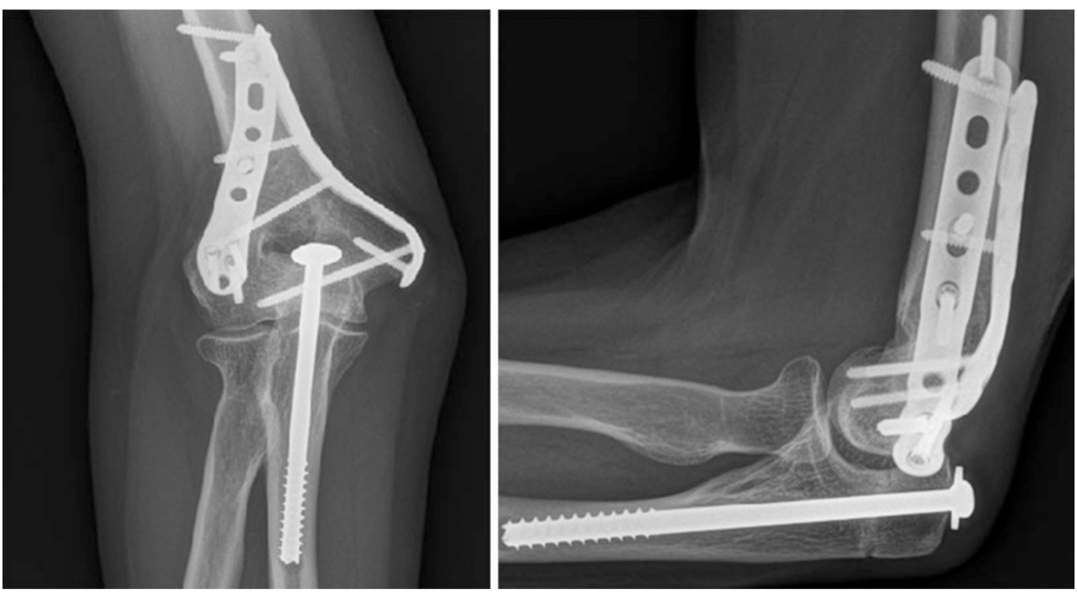

Fig. 2.6 AP and lateral plain radiographs demonstrating orthogonal, or "90–90" plating, with posterolateral precontoured plate and medial precountoured plate. This can be effective in simpler, mostly extraarticular fractures

2.9 Bailout, Rescue, and Salvage Procedures

In fractures that remain unstable despite dual plating, triple plating may be used to augment fixation in the coronal plane (Fig. 2.7) and provide a more rigid fixation construct in highly unstable or osteoporotic fractures. In cases where an anatomic reduction or stable construct may not be possible even with three plates, total elbow arthroplasty should be considered [7]. This is typically contemplated in elderly patients with intercondylar fractures. Total elbow arthroplasty (TEA) is also the gold standard in patients with inflammatory arthritis and elderly patients with poor bone quality due to osteoporosis (Fig. 2.8).

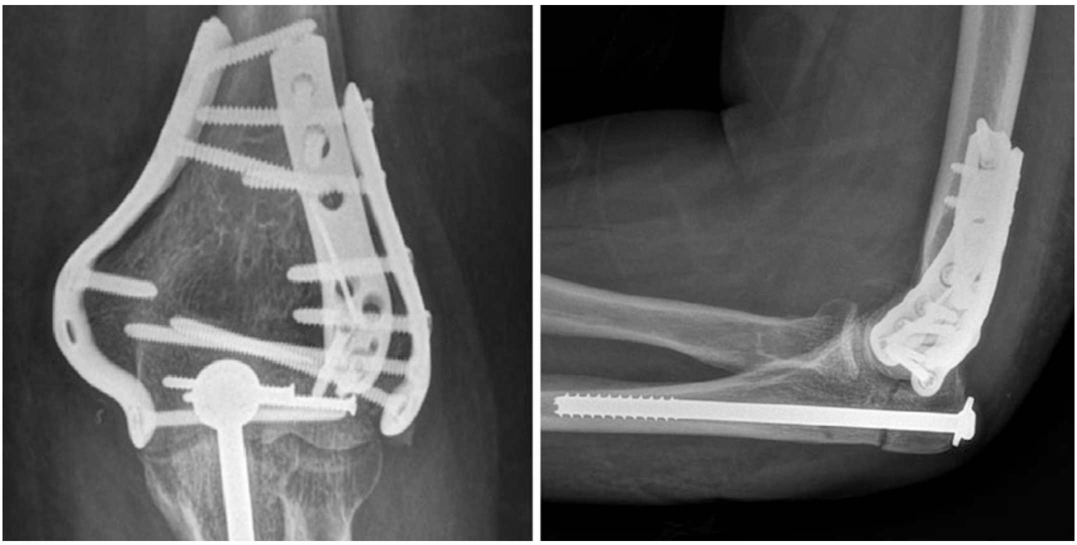

Fig. 2.7 AP and lateral views of triple plating technique, with two parallel plates and a third posterolateral plate placed perpendicular to the medial and lateral plates

Fig. 2.8 AP and lateral view of a primary total elbow arthroplasty (TEA) for distal humerus fracture in a 75-year-old woman with osteoporosis

Additionally, TEA outcomes after failed internal fixation are similar to those of primary TEA [8]. Finally, in very rare cases, elbow arthrodesis may be considered as a salvage procedure. Arthrodesis position is about 100° of flexion, neutral pronation [9].

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3 Total Elbow Arthroplasty (TEA) for Distal Humerus Fractures

Nicholas Chang and Graham J. W. King

Key Points

- Total elbow arthroplasty is a good surgical option for low-demand, elderly, and medically unwell patients with comminuted intra-articular distal humerus fractures.
- Elderly patients receiving a total elbow arthroplasty have been shown to have better functional outcomes compared to open reduction internal fixation up to 2 years.
- Care should be taken to ensure appropriate implant position when bony anatomic landmarks are disrupted by fracture comminution.

3.1 Introduction

Total elbow arthroplasty is an accepted surgical option for older, low-demand, and medically unwell patients with comminuted, intra-articular fractures of the distal humerus. Indications include: non-reconstructable intra-articular fractures of the distal humerus due to comminution or poor bone quality, elderly, or medically unwell low-demand patients able to comply with lifelong activity restrictions, and patients with significant pre-existing elbow arthritis. Contraindications include: younger more active patients unable or unwilling to comply with lifting restrictions, active infection, high-grade open fracture, deficient soft tissue coverage, neuropathic or Charcot joint, and concomitant ulnar fracture not suitable for placement of an ulnar component.

3.2 Pre-Operative Assessment

A detailed history and physical examination, including the status of the ulnar nerve, should be performed pre-operatively. Evaluation of the skin is critical; if there are fracture blisters, surgery should be delayed until these are healed. Open fractures can be treated with a primary arthroplasty if the soft tissue injury and wound contamination is minimal and there is no delay to presentation. Higher grade open injuries should be debrided and treated with a delayed total elbow arthroplasty.

The elbow should be assessed for any pre-existing arthritis or deformities. Orthogonal radiographs of the elbow are essential. A CT scan (including 3D reconstructions) may be utilized to assess bone stock and comminution to assist in deciding if fixation of the fracture is likely to be successful. Patients should be asked about their baseline function and expectations for use after treatment. Surgeons should counsel patients on the lifelong activity restrictions with a total elbow

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arthroplasty. Patients should be medically optimized prior to surgery.

3.3 Patient Positioning

General anesthesia is preferred due to the proximity of the surgery to the airway. A regional block may be added as an adjunct to assist with pain control or as the definitive anesthesia in patients too ill to consider general anesthesia.

Patient positioning is left to the discretion of the surgeon, provided there is easy access to the medial/lateral sides of the elbow and adequate fluoroscopic images are obtainable. The authors' preferred position is supine with the arm draped over the body. Supine positioning is aided by a bump under the ipsilateral scapula. Lateral decubitus positioning involves draping the arm over a padded arm holder. A sterile tourniquet is recommended, and should be placed as proximal as possible on the arm. Tranexamic acid can be used topically or intravenously to reduce bleeding and lessen the risk of hematoma formation.

3.4 Surgical Approaches

In an acute fracture scenario, triceps-sparing approaches are preferred to allow early return of elbow function and to avoid residual weakness. The authors' preferred approach is the lateral para-olecranon approach. In this approach, the Boyd interval is extended proximally into a midline triceps split. It preserves the majority of the triceps insertion on the olecranon and enables good exposure for placement of the ulnar component. This preserves triceps strength and avoids any delay in post-operative rehabilitation. The paratricipital approach is another triceps-sparing approach, utilizing medial and lateral windows on either side of the triceps. However, visualization of the proximal ulna to prepare and insert the ulnar component can be problematic with this approach.

Approaches that detach the triceps provide improved exposure for placement of the ulnar component but delay post-operative rehabilitation due to the need to protect the triceps repair. It is challenging for older patients to be compliant with avoiding resisted active extension due to the need to use the arm to arise from a chair, move in bed, or use walking aids. If unsure pre-operatively whether to perform an ORIF or a TEA, it is advisable to initially avoid an olecranon osteotomy until an intraoperative decision is made to proceed with ORIF. Healing of an olecranon osteotomy may be problematic after an ulnar component is implanted, however, an olecranon osteotomy does not preclude proceeding with a TEA.

3.5 Key Technical Steps

3.5.1 Exposure of the Elbow

Place a longitudinal, midline posterior incision is placed medial to the olecranon. Elevate thick medial and lateral fasciocutaneous flaps. Identify, transpose, and protect the ulnar nerve throughout the case. Confirm whether ORIF, hemiarthroplasty, or TEA will be undertaken. Manage the triceps as per one of the strategies listed previously; the authors prefer the lateral para-olecranon approach due to the improved exposure for placement of the ulnar component and rapid rehabilitation [1] (see Fig. 3.1). If the humeral condyles are fractured, excise the condyles to improve exposure as they are not required for a linked total elbow arthroplasty. If the condyles are intact, release the collateral ligaments and tendinous origins to allow dislocation of the elbow.

3.5.2 Implant Sizing

Size the implants according to the technique guide for the chosen total elbow prosthesis; the Latitude EV (Wright Medical®) is illustrated in the current chapter. The width of the spool should match the width of the trochlea and capitellum; place the spool into the greater sigmoid notch and evaluate the alignment with the radial head as this

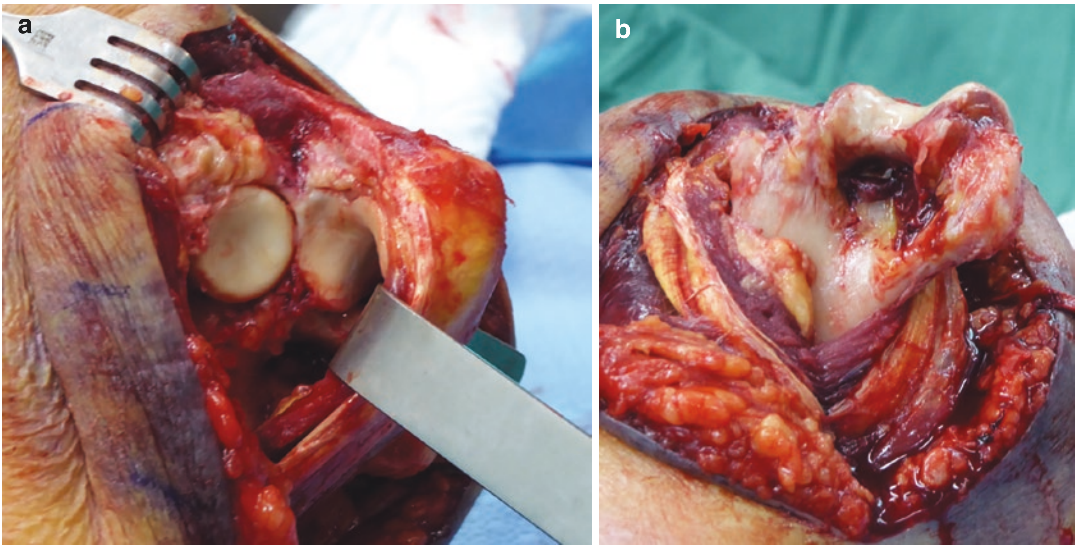

Fig. 3.1 (**a**, **b**) Exposure through a triceps-sparing lateral para-olecranon approach

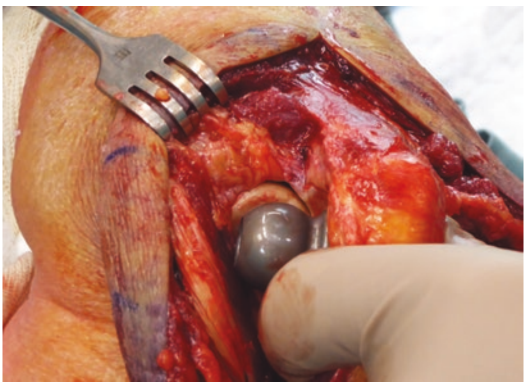

Fig. 3.2 Trial spool sizing shows excellent alignment with the radial head

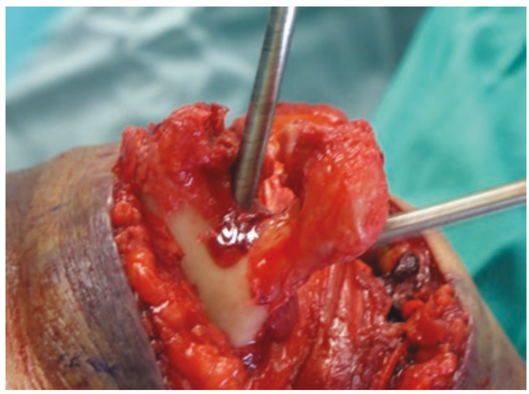

Fig. 3.3 Humerus broaching, maintaining appropriate rotation

is the most accurate way to size the implant in patients with distal humeral fractures (see Fig. 3.2).

3.5.3 Humerus Preparation

Remove the central trochlea with a saw if required to allow access to the medullary canal of the humerus. Enter the humeral canal with a high-speed burr. Broach the humerus to the appropriate depth, whist maintaining accurate rotation along the flexion–extension axis of the elbow (lateral epicondyle to the antero-inferior aspect of the medal epicondyle when present) (see Fig. 3.3). Use flexible reamers to prepare the medullary canal if there is resistance to insertion of the broaches; fractures can occur in the osteoporotic bone if excessive force is used (see Fig. 3.4). If the humeral canal is small and there is a pronounced posterior bow there is a risk of the broach or implant perforating the posterior cortex. Trochlear cuts, when required, are made according to the implant-specific cutting guides. The fin cuts are made in the humerus using a gusset broach or burr.

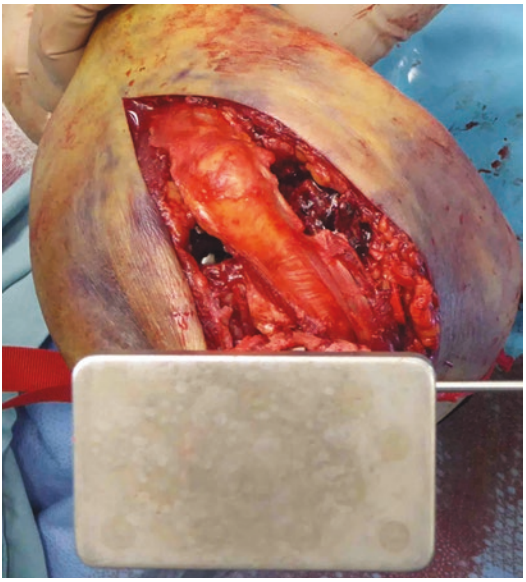

Fig. 3.4 Reaming of the humeral canal over a guidewire

3.5.4 Radial Head Preparation

The radial head is typically retained unless there is a concomitant fracture or pre-existing arthritis. Radial head retention or replacement is required if performing an unlinked arthroplasty to maintain stability. If replaced, the radial head should remain congruent with the capitellum throughout elbow range of motion.

3.5.5 Ulna Preparation

Resect the greater sigmoid notch using the supplied jigs and bell saw taking care to protect the ulnar nerve and soft tissues. Open the medullary canal of the proximal ulna with a curved hemostat. The medullary canal of the proximal ulna is angulated towards the radius; avoid perforation of the ulnar cortex by respecting this curvature. Use flexible reamers and broaches to allow insertion of the ulnar component. Use the flat posterior cortex of the ulna to assist with orienting the ulnar component as it is parallel to its axis of rotation [2].

3.5.6 Trial and Implantation

Insert the trial components and move the elbow through a full ROM, including flexion/extension and pronation/supination. Ensure there is no impingement of the coronoid process on the anterior flange of the humeral component in flexion and the olecranon in extension as this can restrict motion and lead to early loosening. If the radial head is not tracking well or is impinging with the humeral component it can be excised when performing a linked arthroplasty. Assess the elbow for stability and articular tracking when planning an unlinked arthroplasty by temporarily aligning the condylar fractures. Prior to final implantation, cement restrictors are inserted, and the canals are irrigated and dried. Inject bone cement retrograde using a gun with a narrow nozzle and insert the components into the correct position and orientation. Remove any excess cement taking care to not disturb the components as the cement cures. Place autologous cancellous bone graft between the humeral flange and the anterior humeral cortex after the cement has set (see Fig. 3.5).

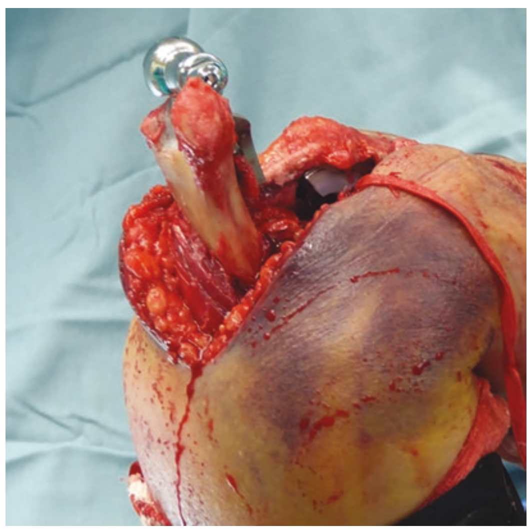

Fig. 3.5 Ulnar and humeral components cemented in situ, with an anterior bone autograft

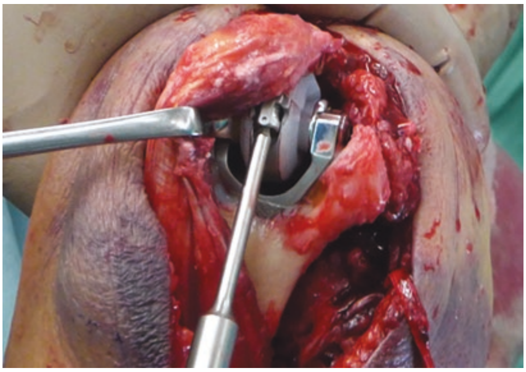

Fig. 3.6 Linkage of the humeral and ulnar components

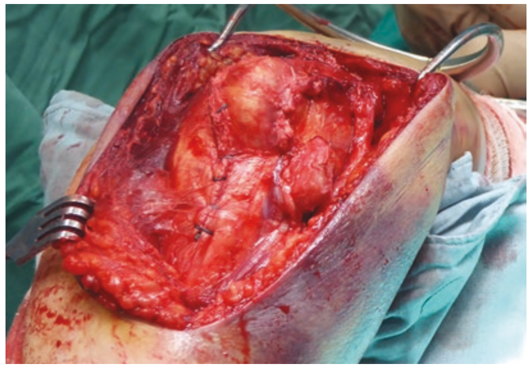

Fig. 3.7 Closure of the para-olecranon approach with buried, interrupted sutures

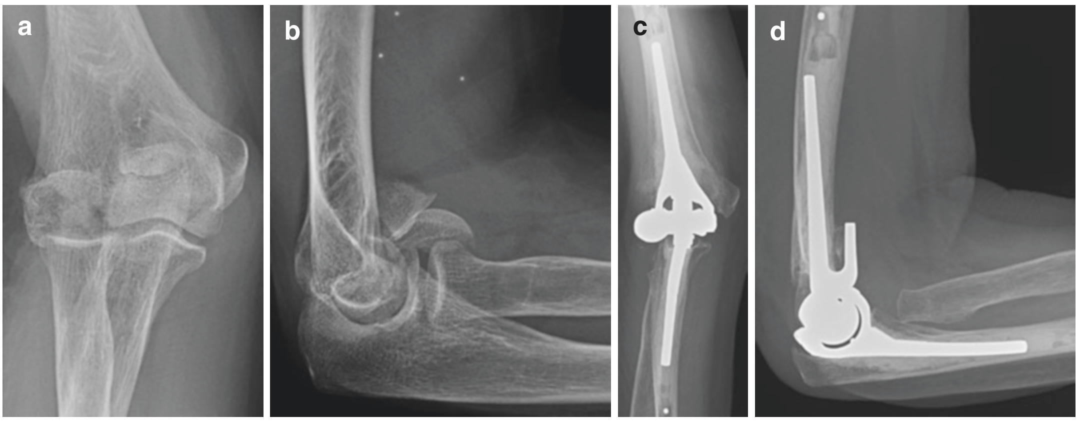

Fig. 3.8 An example case of a 76F with a comminuted capitellum/trochlea fracture. Pre-operative AP (**a**) and lateral (**b**) plain radiographs are shown. Post-operative AP (**c**) and lateral (**d**) plain radiographs at 4 months following surgery

Link the components (see Fig. 3.6). Recheck the elbow for range of motion and impingement. Repair the condyles and collateral ligaments when performing an unlinked arthroplasty.

3.5.7 Closure

Transpose the ulnar nerve anteriorly. Repair the common flexor origin to the medial triceps to cover the implant. Close the triceps split if present with buried non-absorbable sutures (see Fig. 3.7). Use a drain if required. An example of a clinical case is shown in Fig. 3.8.

3.6 Intra-Operative Challenges

3.6.1 Fracture Comminution and Poor Bone Stock

Fracture comminution and inadequate bone stock often preclude using standard anatomical landmarks like the medial epicondyle and capitellum for positioning of the humeral component. In these circumstances the height and rotation may be estimated the following ways:

- The superior aspect of the olecranon fossa corresponds with the position of the anterior flange of the humeral component.

- If utilizing a triceps-sparing approach, tensioning of the soft tissues may suggest the appropriate depth of the humeral component.
- The flexion–extension axis is 14° internally rotated relative the flat posterior cortex of the distal humerus [3].
- Exposure of the ulna can be difficult in more muscular patients with the paratricipital approach. The lateral para-olecranon approach improves visualization of the ulna without compromising triceps strength and early rehabilitation [1].

3.6.2 Intra-Operative Fracture

In the event of an intra-operative shaft fracture, the extent of the fracture should be exposed. Use cerclage wires and reduction clamps to maintain the fracture reduction while cementing a longer stem component. Components should bypass the fracture site by two cortical diameters. Olecranon fractures or osteotomies are repaired with a low profile plate or tension band wires with hardware placed into the ulnar cement mantle for improved fixation.

3.6.3 Instability

Ensure the correct depth and rotation of the components. If using an unlinked prosthesis, ensure a secure repair of the collateral ligaments and condyles. If still unstable, convert it to a linked device.

3.6.4 Impingement

Ensure fracture fragments are excised from the elbow joint. Remove the tip of the coronoid or olecranon if needed.

3.6.5 Ulnar Component Pistoning

Ulnar component pistoning during the trial reduction may be caused by coronoid impingement on the anterior flange or placement of the ulnar component too deep within the canal; revise as appropriate.

3.6.6 Post-Operative Ulnar Neuropathy

Preventative measures include protection of the ulnar nerve throughout the procedure and anterior transposition of the ulnar nerve so it does not lie on the prosthesis. Maintain the vascularity of the nerve during dissection by mobilizing the nerve with its concomitant vessels were possible.

3.7 Post-Operative Protocol

Splint the elbow with an anterior fiber glass slab at 30°–60° of flexion to avoid pressure on the incision for 10–14 days post-op. Active ROM may be started when the wound is healed; a cuff and collar sling may be used for comfort. If a triceps detaching approach was used, active extension and full passive flexion is avoided to protect the repair in the early postoperative period. Nighttime static progressive extension splints may be considered if patients have difficulty regaining extension. Strengthening may begin at 6 weeks, with a lifelong 5–10 pound lifting restriction.

3.8 Linked vs. Unlinked vs. Hemiarthroplasty

The requirements for using an unlinked total elbow arthroplasty are: adequate bone stock, competent collateral ligaments, and an intact radial column. Most patients with distal humeral fractures are not good candidates for an unlinked arthroplasty due to the presence of condylar fractures resulting in elbow instability and the lack of anatomical landmarks of the distal humerus to ensure accurate component positioning; a linked prosthesis is recommended. An unlinked arthroplasty should only be considered in the setting of a younger higher demand patient due to the increased complexity of the procedure with the need to achieve an anatomic reconstruction and healing of the condyles and collateral ligaments.

Distal humeral hemiarthroplasty in now available in many countries. The indications are becoming better defined but these devices are currently being used for younger and higher demand patients with unreconstructable fractures. Careful positioning of the humeral component and restoration of the ligaments, condyles and epicondyles are needed to maintain stability, similar to an unlinked total elbow arthroplasty.

3.9 Outcomes

A randomized trial reported that older low-demand patients that received total elbow arthroplasties had better functional outcome scores (Mayo Elbow Performance Scores) up to 2 years when compared to open reduction internal fixation [4]. The re-operation rate was not significantly different but trended towards a lower re-operation rate in patients with TEAs. A systematic review and meta-analysis showed no statistical difference in functional outcome scores, range of motion, or re-operation rate between ORIF and TEA for fracture [5]. The complication rates remain frustratingly high with both treatments. Male patients are associated with a significantly higher risk of requiring a revision procedure compared to female patients [6]. Implant survivorship of total elbow arthroplasty for distal humerus fracture at 10 years was reported to be 76% in patients with rheumatoid arthritis and 92% in patients without rheumatoid arthritis [6].

3.10 Pitfalls

- Inadequate exposure leading to fracture or component malpositioning.
- Leaving the humeral component too proud resulting in limited extension.
- Implanting the ulnar component too deep leading to impingement, limited flexion, component pistoning, and early loosening.
- Performing an olecranon osteotomy before proceeding with a total elbow arthroplasty.
- Failure to protect the ulnar nerve during all stages of the procedure leading to nerve injury.

3.11 Multiple Choice Questions

1. Which of the following is a contraindication for total elbow arthroplasty for distal humerus fractures?
   (a) Non-reconstructable fracture.
   (b) **Charcot joint.**
   (c) Low-demand elderly patient.
   (d) Pre-existing ulnohumeral arthritis.
2. What approach should be avoided when performing total elbow arthroplasty for distal humerus fractures?
   (a) Triceps split.
   (b) Lateral para-olecranon.
   (c) **Olecranon osteotomy.**
   (d) Bryan-Morrey triceps reflecting approach.
3. What is an acceptable management option for the radial head in total elbow arthroplasty?
   (a) Radial head retention.
   (b) Radial head excision.
   (c) Radial head replacement.
   (d) **All of the above.**

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4 The Internal Elbow Joint Stabilizer

Carl Nunziato, Jorge L. Orbay, and David Ring

4.1 Key Principles

In the management of elbow instability, concentric elbow joint reduction reestablishes the proper length of damaged collateral ligaments In addition, joint motion is important in the maturation and remodeling of the healing ligaments, early motion is important in the prevention of elbow joint contractures and neutralization of forces across fractures supports bony healing (Fig. 4.1).

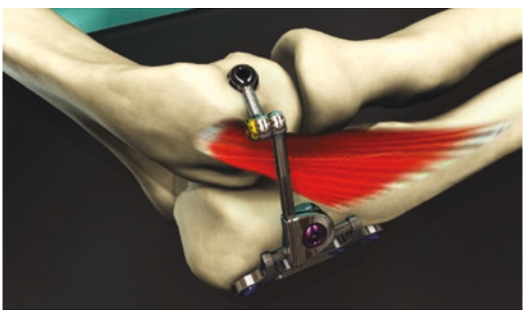

Fig. 4.1 3D model of a right elbow demonstrating placement of the ISJ-E

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4.2 Indications

Surgeons can consider the IJS-E for the treatment of patients with difficult forms of acute elbow instability when there is a temporary need to support healing structures. Acute unstable injuries such as the terrible triad, olecranon fracture-dislocations involving a fragmented coronoid, medial coronoid facet fractures, and recurrent simple elbow dislocations with substantial ligament and muscle avulsion often benefit from the use of temporary support with the IJS (Fig. 4.2).

Most elbows that are out of place for about 2 weeks or longer will not remain aligned after fracture and ligament treatment alone [1, 2]. The IJS-E is an alternative to cross pinning and external fixation in this scenario. Static or hinged external fixation place the radial nerve at risk, are cumbersome, and may not keep the elbow well reduced. This is because the length of the flexible ulnar and humeral pins can allow the elbow to subluxate or dislocate. Cross pinning of the joint with Steinman pins can maintain reduction, but present risks of infection, pin breakage, stiffness, and damage to the articular surface.

There may also be a role for use of the ISJ-E to maintain reduction in the setting of other surgeries which can result in the potential for elbow subluxation or dislocation, such as in the excision of heterotopic bone or release of severe or complex elbow contractures.

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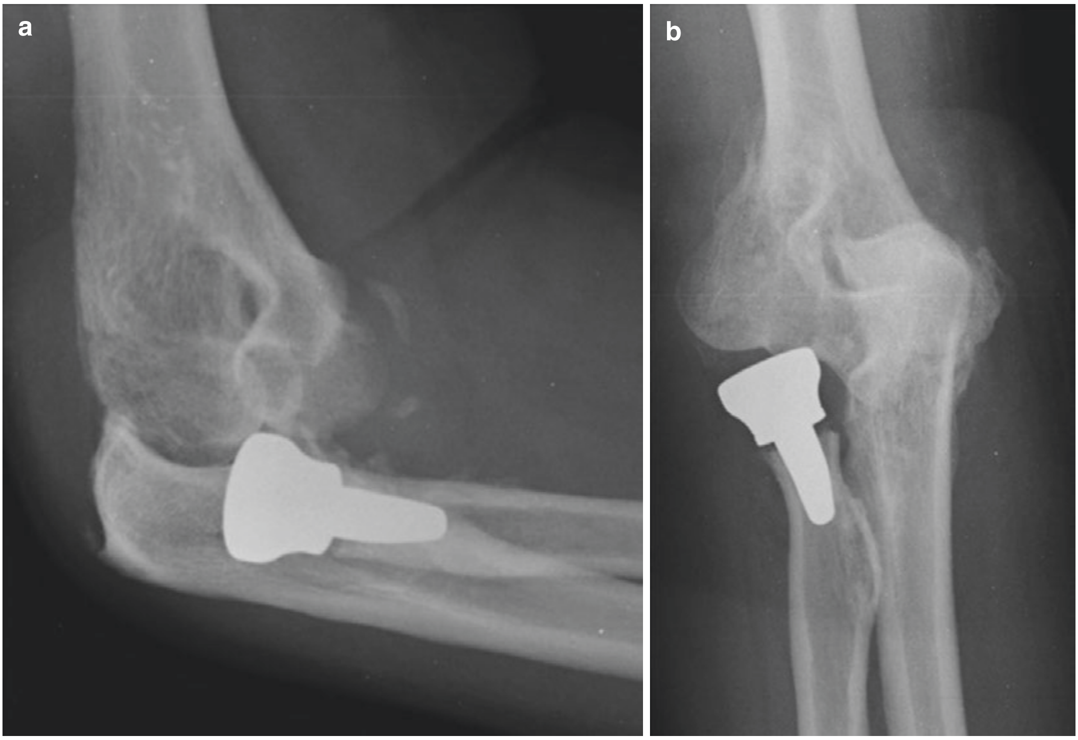

Fig. 4.2 (**a**) Anterior–posterior and lateral (**b**) radiographs of a right elbow demonstrating persistent instability with a comminuted coronoid fracture involving the medial coronoid facet

4.3 Expectations

The ISJ-E is helpful in patients with persistent subluxation and or dislocation despite adequate surgical repair of fractures and ligamentous injuries. One multicenter study reported maintained reduction in 23 of 24 elbows with average arc of motion of 119° (80–150) at 6 months follow up [3]. The device has also been used in the management of chronic instability for unstable elbows following nonoperative treatment and/or in the revision setting [4].

4.4 Contraindications

Notable bone loss in the distal humerus and/or proximal ulna may not allow anchoring of the axis pin or base plate.

Patients with substantial fragmentation of the coronoid may benefit from an IJS-E to maintain reduction of the elbow joint while the coronoid heals.

4.5 Special Instructions, Positioning, and Anesthesia

Patients receiving an ISJ-E may be positioned supine with the arm on a hand table or lateral decubitus with the arm over a bolster or positioning bar.

General or regional anesthesia is appropriate for this procedure.

A sterile tourniquet may improve access to the surgical site.

4.6 Tips, Pearls, and Lessons Learned

Surgeons typically remove the IJS-E 3–4 months after implantation. In patients with purely ligamentous injuries, it may be safe to remove the fixator after 6–8 weeks. Patients that decline implant removal are advised that the effects of long-term implantation are not known [5].

A long-standing elbow dislocation with severe bone deficit may result in such marked elbow instability that the standard application of an IJS-E alone cannot prevent subluxation or dislocation. In these cases the use of two IJS devices, a lateral and a medial one, in which the axis pins meet in the middle of the drilled tract for the axis of elbow motion may adequately restore stability. Other adjunctive techniques such as static external fixation should be kept in mind. A model of the IJS-E that provides bilateral support is in development.

4.7 Key Procedural Steps

Depending on the specifics of each case, a direct lateral, posterolateral, or posterior skin incision is used to implant the IJS-E. Elbow dislocations, commonly result in avulsion of the origin of the lateral collateral ligament from the lateral epicondyle, and occasionally the origin of the common extensors. One can approach between the ECRB and EDC (Kaplan Interval) which splits the common extensors 50:50. The origin of the extensor carpi radialis longus, the brachialis and the anterior capsule can be elevated from the anterior humerus to improve access to the elbow. The avulsed origin of the lateral collateral ligament and the common extensors will be reattached at the end of the procedure. Important associated fractures of the coronoid, radial head, olecranon, and distal humerus are addressed. In the treatment of acute instability, often medial structures such as the medial collateral ligament and the flexor pronator muscles will heal as long as the elbow is maintained in position. When the elbow joint is subluxated or dislocated for more than a few weeks, a medial approach may help to debride, release, and obtain joint reduction and can provide access to the coronoid and/or medial collateral ligament.

A key step in the application of the IJS-E is finding the axis of ulno-humeral rotation. The surgeon identifies two points in the line defining this axis. The lateral point is the geometric center of the dome of the capitellum or the center of a circle that fits the curvature of the articular surface as seen from the lateral view. It is located visually and marked on the bone surface. The medial point on the axis is found using a centering guide that consists of metallic arc of 240° that is inserted over the waist of the trochlea and pushed medially until it self-aligns on the medial trochlear expansion (Fig. 4.3). This centering guide is then used to insert a guide wire that allows drilling for the axis pin tract.

The surgeon applies varus stress to the elbow to visualize the trochlea and place the axis guide (Fig. 4.4). The surgeon confirms that contact with the lateral condyle does not displace the axis guide during guide wire insertion (Fig. 4.5).

The 1.5 mm guide-wire is inserted towards the medial cortex using fluoroscopy. The surgeon must avoid drilling through the medial cortex in order to avoid the risk of ulnar nerve injury. Use of an oscillating drill increases safety. After measuring the length of the axis pin, the surgeon drills over the K-wire using a 2.7 mm cannulated drill to create the axis pin tract.

The surgeon then positions the base plate at the most proximal aspect of the ulna taking care to avoid placing screws into the articular surface. The base plate has a sliding slot that can be used to adjust positioning under fluoroscopic imaging.

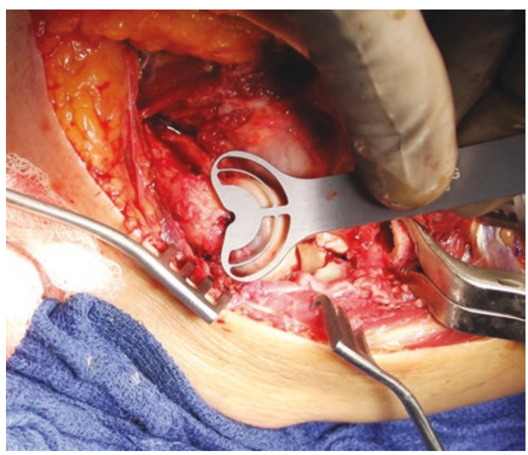

Fig. 4.3 Lateral view of the elbow demonstrating proper placement of the centering guide. The guide is inserted over the waist of the trochlea and slid medially unti it aligns with the medial trochlear expansion

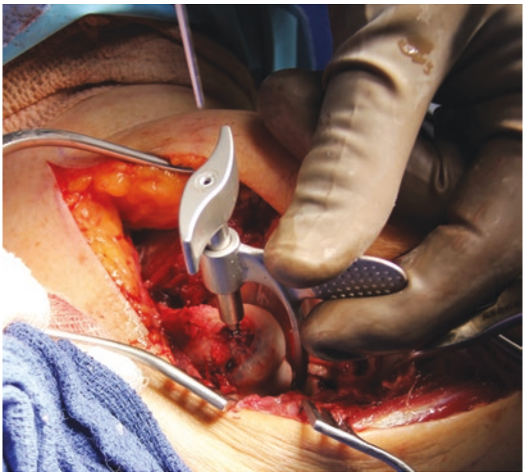

Fig. 4.4 Varus stress is applied in order to place the axis guide

Fig. 4.5 3D model demonstrating proper placement of the axis guide prior to guidewire insertion

After the base plate is secured, the surgeon connects the boom to the axis pin with the head of the locking screw near the axis pin eyelet facing proximally. He or she secures the boom arm with a counter-torque device while tightening the axis pin to prevent its deformation. It is easier to

Fig. 4.6 Ensure concentric reduction of the elbow by placing the patients hand over their face

assemble the axis pin to the boom prior to its insertion into the humerus.

The connecting boom and axis pin are now inserted into the humerus and into the base-plate clamp simultaneously. This greatly facilitates IJS assembly.

Before tightening any of the two locking screws on the boom arm, ensure that the elbow is reduced concentrically by placing the hand over the head of the patient. This removes torsional stresses across the elbow joint by placing the shoulder in the position of neutral resting tension of the humeral rotators (Fig. 4.6). Apply a reducing compressive force on the proximal ulna in line with the humeral shaft and inspect the reduction visually prior to locking the reduction by tightening both the gold boom locking screw and the purple base plate locking screw.

Confirm reduction is maintained through full range of motion using fluoroscopic imaging (Fig. 4.7). Reattach the origin of the lateral collateral ligament and the common wrist and finger extensors to the lateral epicondyle (Fig. 4.8).

4.8 Pitfalls

Common technical pitfalls can be avoided by ensuring the K-wire guide is not in contact with the lateral aspect of the capitellum prior to drilling, as this can displace the axis guide and lead to incorrect placement of the axis pin. Care must also be taken to avoid violating the medial cortex during K-wire placement, which would put the

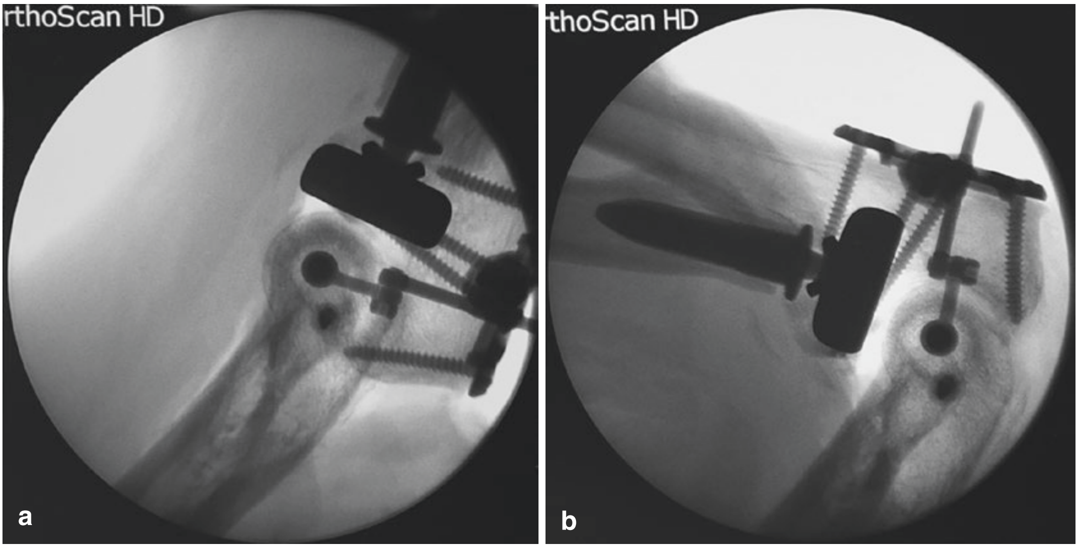

Fig. 4.7 (**a**) Intraoperative fluoroscopic images demonstrating a concentrically reduced elbow with an ISJ-E in extension and flexion (**b**)

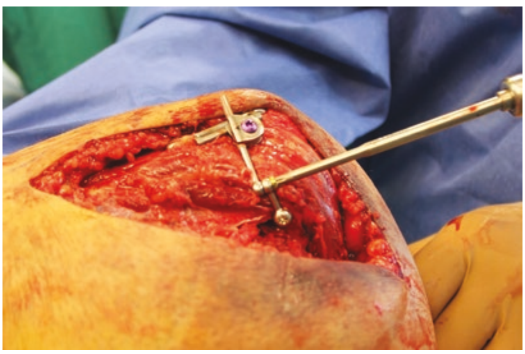

Fig. 4.8 Tightening of the boom, note the proximal locking screw is oriented proximally

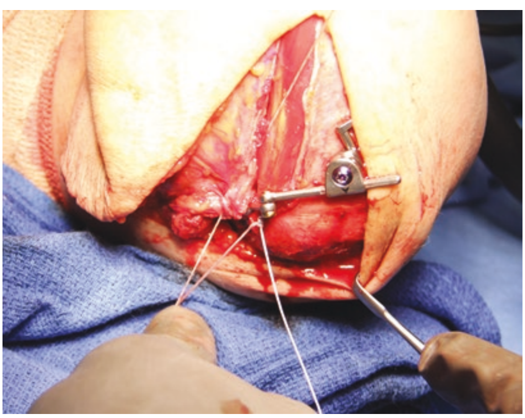

Fig. 4.9 Reapproximation of lateral collateral ligament and common extensor origins

ulnar nerve at risk, or the articular surfaces during placement of the olecranon base plate.

It is also important to ensure the boom is placed in the proper orientation, with the proximal locking screw head facing proximally to allow subsequent tightening (Fig. 4.9).

4.9 Bailout, Rescue, and Salvage Procedures

The surgeon can assess intraoperatively for inadequate bony fixation at either the olecranon base plate or the humeral axis pin, in which case the persistent instability must be treated with another method such as static external fixation. This may also be helpful in cases of persistent instability resulting in subluxation or dislocation visualized under fluoroscopy after placement of the IJS.

The IJS-E can usually be left in place during the treatment of infection and removed when ligaments and fractures are healed (Fig. 4.10). If the IJS-E loosens or breaks and the elbow is concentric more than 2 weeks after surgery, it may not be necessary to replace the IJS-E. Removal of the implant can be done at a time of convenience unless there is an uncomfortable or potentially harmful prominence of the implant.

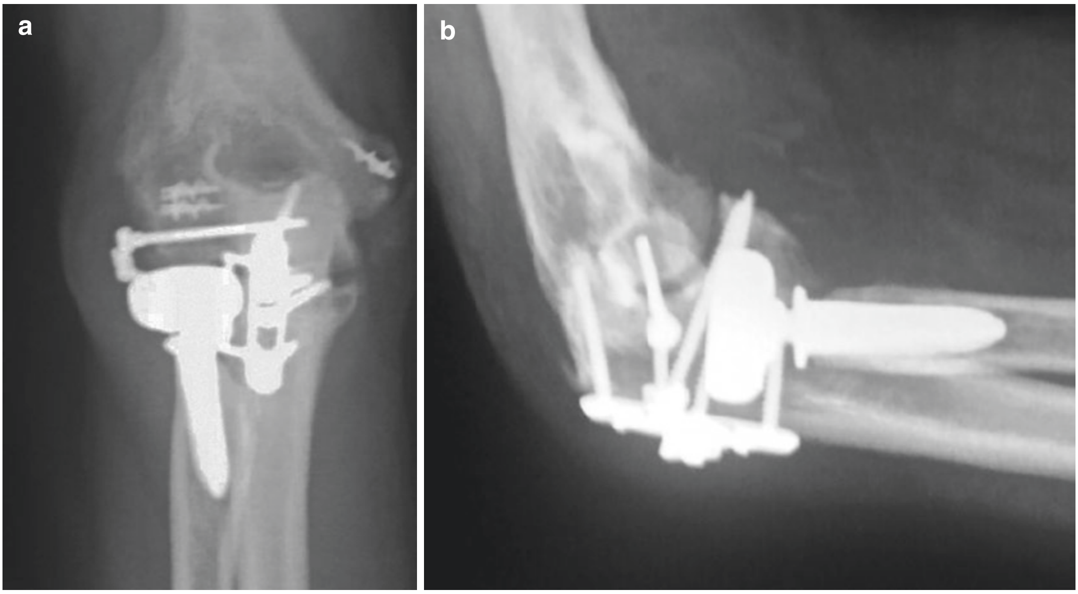

Fig. 4.10 (**a**) Final postoperative anterior–posterior and lateral (**b**) radiographs of an elbow with the ISJ-E in place

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5 Open Reduction Internal Fixation (ORIF) for Olecranon Fractures

Stephan Uschok, Kilian Wegmann, and Lars Peter Müller

5.1 Description

Several fixation methods have been described for olecranon fractures including tension band wiring, recommended by the AO foundation [1], locking plate fixation like the double plating system, intramedullary screw fixation and, more recently, suture osteosynthesis.

5.2 Key Principles

The selection of the implant is depending on the fracture type. According to the Mayo Classification [2] (Fig. 5.1), olecranon fractures are into (I) non-displaced, stable fractures, (II) displaced, stable fractures (III) displaced, unstable fractures. The sub-classification specifies, if the fracture is (a) non-comminuted or (b) comminuted.

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5.3 Expectations

Although, tension band wiring seems to be a simple method, studies have shown, that this type of osteosynthesis is prone to errors [3] mostly due to malpositioning of the k-wires. Furthermore, this technique is only feasible in non-comminuted fractures.

Locking-plate fixation allows for an angular stable osteosynthesis with the benefit of the possibility to address small fragments in comminuted fractures.

5.4 Indications

Non-surgical treatment of olecranon fractures is possible in non-dislocated, stable fractures (Mayo type Ia/b). A frequent radiologic assessment is necessary to detect secondary dislocations, which are common, due to the constant traction of the triceps muscle on the proximal fracture fragment.

Fractures, Mayo type II/III, can be addressed surgically, though conservative treatment has shown to be successful in selected cases. The tension band wiring technique is possible in non-comminuted fractures. Comminuted fractures should be addressed by locking plate osetosynthesis, due to the possibility to address small fragments and thereby achieve an anatomical reconstruction of the articular surface.

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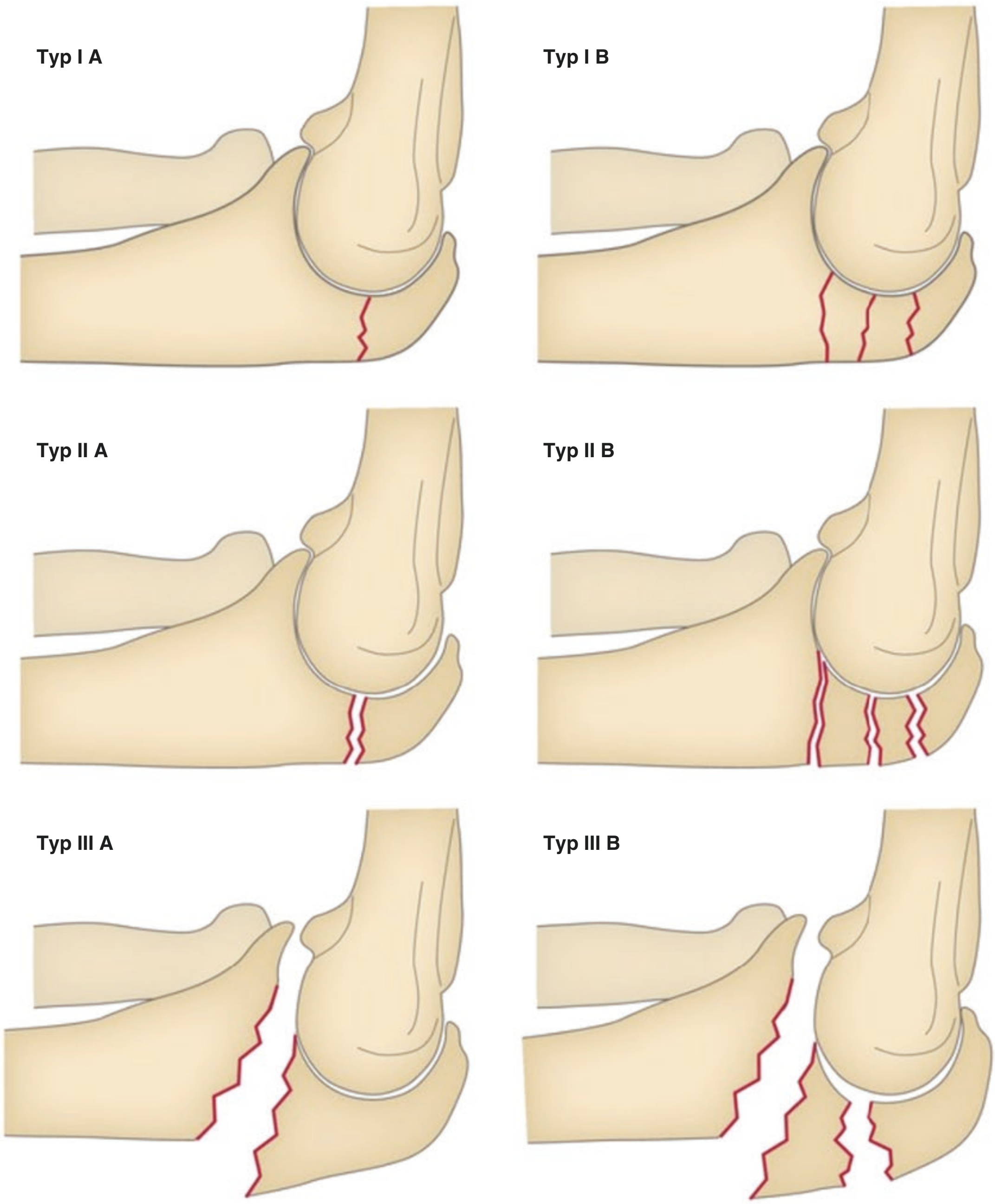

Fig. 5.1 Mayo Classification of olecranon fractures. (Used with permission from Müller LP, Hollinger B, Burkhart KJ, eds. *Expertise Ellenbogen*. Stuttgart: Thieme; 2016:208 [6])

5.5 Contraindications

The dorsal aspect of the olecranon is covered by a thin layer of soft tissue. Therefore, extensive tissue damage is a relative contraindication.

Elderly patients and multimorbid patients may also be treated non-surgical in Mayo type I and II fractures. In those patients satisfying results were reported, although high rates of pseudoarthrosis occurred [4].

5.6 Special Consideration

A preoperative CT (computed tomography) scan facilitates evaluation of the fracture pattern and planning of the operative approach, especially in multifragmentary fractures. Accompanying injuries, such as radial head fractures or dislocations in cases of monteggia fractures and monteggia like lesions have to be evaluated an addressed accordingly.

Nerve injuries, especially injuries to the ulnar nerve, have to be assessed, prior to the surgery.

Strictly anteroposterior and lateral fluoroscopy is essential during the surgery to rule out intraarticular protrusion and to ensure an adequate reduction.

5.7 Special Instructions, Positioning, and Anaesthesia

In our practice the patient is put into a lateral position with the injured arm supported by an Ontario arm rest or in prone position, exposing the dorsal aspect of the elbow and allowing for a free range of motion. General anaesthesia is preferred due to the duration of the surgical procedure and the positioning of the patient.

5.8 Tips, Pearls, and Lessons Learned

5.8.1 Bare Area

The bare area, the area of the trochlear notch not covered by cartilage, has to be taken into consideration during reduction of the fracture.

A shortening of the trochlear notch leads to decreased range of motion and premature osteoarthritis, a widening of the trochlear notch leads to persistent instability.

5.8.2 Varus Angle

The proximal ulna has a varus angulation of about 18°, which has to be maintained and is especially important in distal olecranon fractures. A neglect of the varus angle can lead to incongruency in the proximal radioulnar joint.

5.8.3 Ulnar Nerve

A preparation of the ulnar nerve should be performed in complex fractures and in suspected nerve injuries, preoperatively.

Distal to the ulnar groove on the medial epicondyle, the ulnar nerve can be identified between the humeral and the ulnar head of the flexor carpi ulnaris muscle.

5.8.4 Perfusion

The vascular supply has to be taken into consideration for preparation. The olecranon is supplied proximally by two branches of the proximal arcade via the triceps tendon and distally by a medial branch of the ulnar artery distal to the coracoid process with the watershed line halfway between the tip of the olecranon and the tip of the coronoid process.

5.8.5 Intermediate Fragments

Intermediate fragments should be reduced (Fig. 5.2a). To reduce intermediate fragments, the fragment has to be aligned to the trochlea by pressing the fragment against the trochlea (Fig. 5.2b) and temporarily fixing the reduction (Fig. 5.2c), followed by permanent fixation of the reduction (Fig. 5.2d).

5.8.6 Triceps Off-Loading Suture

In osteoporotic fractures and fractures an fractures with a small proximal fragment, a triceps off-loading suture (Fig. 5.3a, b), reinforcing the triceps tendon to the plate osteosynthesis, helps decreasing the load on the osteosynthesis by load-sharing mechanisms [5].

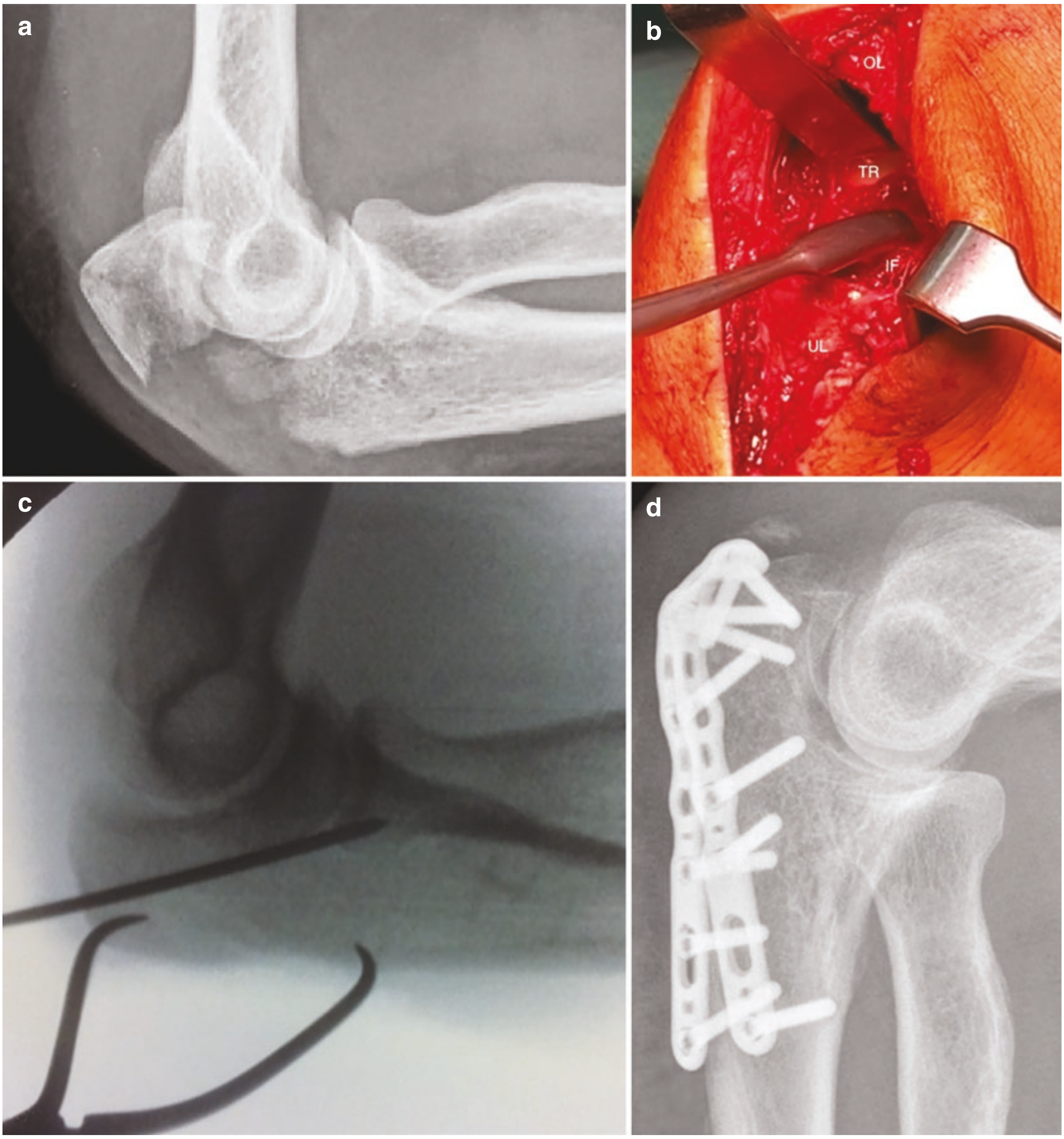

Fig. 5.2 (**a**–**d**) Intermediate fragments. (**a**) X-ray showing an olecranon fracture with an intermediate fragment, (**b**) intraoperative view, *OL* olecranon, *TR* triceps tendon, *IF* intermediate fragment, *UL* ulna, (**c**) temporary fixation, (**d**) double plating osteosynthesis

5.9 Difficulties Encountered

Tension band wiring is possible in simple, transverse, proximal olecranon fractures. Transverse fractures distally to the apex of the trochlear groove and oblique fractures, addressed by tension band wiring, are prone to incorrect reduction and secondary dislocation of the fracture, due to a change of compression forces into shear forces.

In locking plate osteosynthesis, small fragments, that cannot be addressed by the plate, may be addressed by additional “lost” screws.

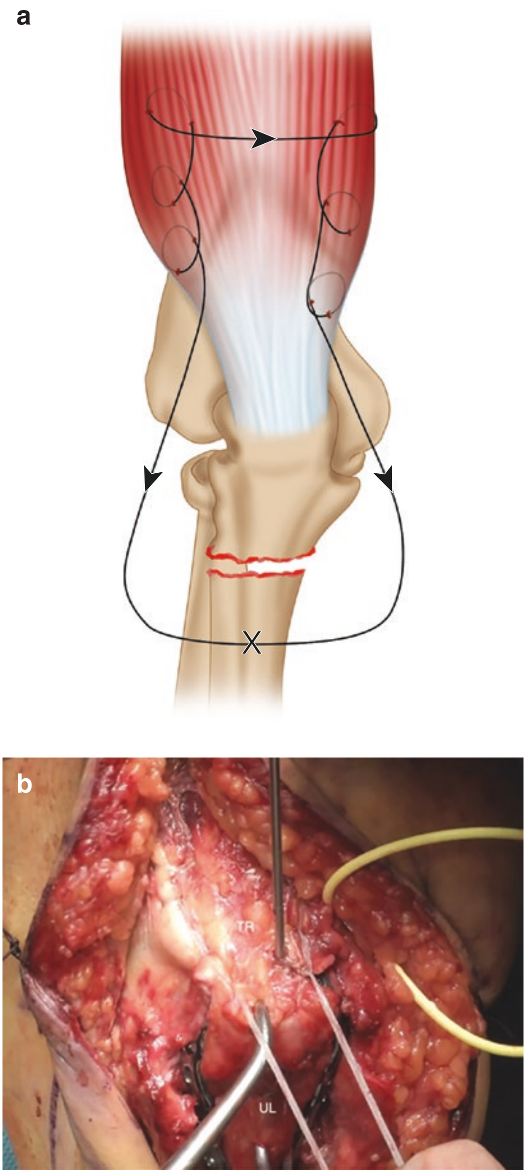

Fig. 5.3 (**a**, **b**) Triceps off-loading suture. (**a**) Schematic of triceps off-loading suture, (**b**) intraoperative view, *TR* triceps tendon, *UL* ulna

5.10 Key Procedural Steps

The fracture may be reduced using a pointed forceps, facilitated by a monocortical drill hole for better hold distally. Alternatively, the fracture may be temporarily fixed using a k-wire.

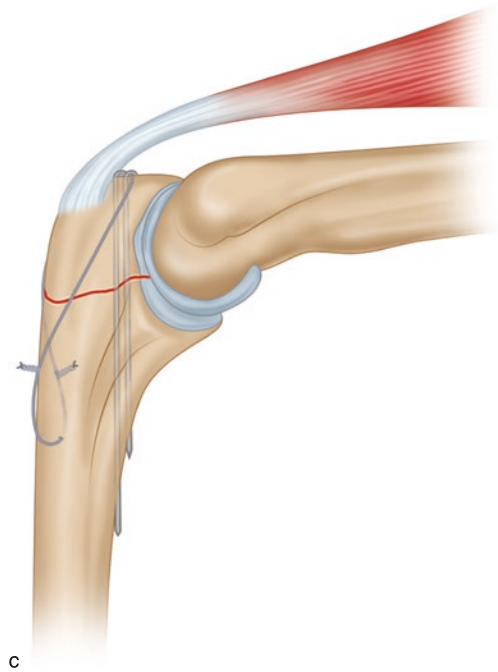

Fig. 5.4 Tension band wiring technique. (Used with permission from Buckley RE, Moran CG, Apivatthakakul T, eds. *AO Principles of Fracture Management. Vol. 2: Specific Fractures*. New York, NY: Thieme; 2018 [7])

For tension band wiring, a 1.6–2.0 mm k-wire is drilled, starting at the dorsoproximal aspect of the olecranon, aiming for the ventral cortex. The k-wire should be drilled close to the articular surface, without protruding it. Strictly lateral fluoroscopy is essential to rule out intraarticular protrusion.

A second k-wire is drilled in the same fashion using the parallel drill guide. Both k-wires are retracted 1 cm, the proximal ends bend and shortened.

A transverse drill hole created 4 cm distally to the fracture and a 1.0–1.5 mm wire is passed through and laid around the k-wires in a figure-of-eight. The wire is tightened, and the k-wires are protruded into the proximal ulna (Fig. 5.4). Small incisions at the distal triceps may facilitated soft tissue coverage.

For the double plating system, the first angulated plate is fixed to the ulna through a gliding

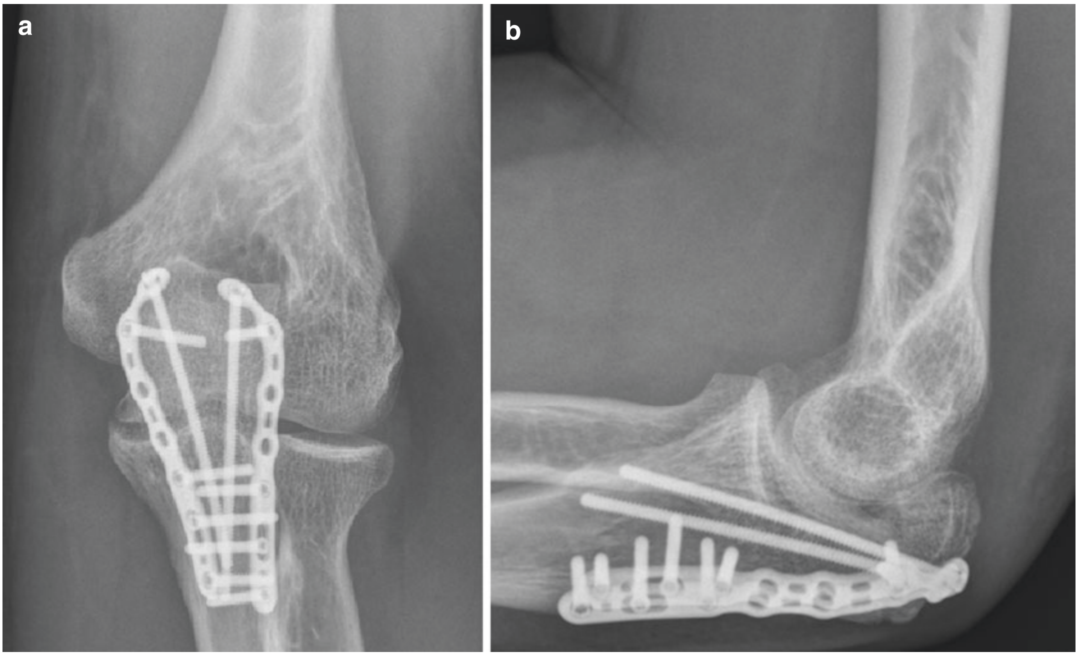

Fig. 5.5 Locking plate technique using a double plating system. Anteroposterior (**a**) and lateral view (**b**) of an olecranon osteosynthesis, using a double plating system

hole. Small incision on the medial and lateral aspect of the triceps facilitate a good bony contact of the proximal plate. The articular surface of the trochlear notch should be visualized to ensure a good reduction. The plate is fixed proximally and distally and the second plate is positioned and fixed in the same way (Fig. 5.5).

The most proximal screw of the double plating system can be placed and angulated in the same way as the k-wire in the tension band wiring technique, in a bicortical fashion.

After reduction and fixation, care must be taken of a good soft tissue coverage.

5.11 Bailout, Rescue, and Salvage Procedures

For more distally located fractures, different plating systems are available, such as a straight double plating system and single plating systems.

Accompanying injuries, such as injuries to the radial head or the coronoid process, should be assessed preoperatively and should be addressed accordingly.

Small fragments, that cannot be addressed by the plating system, can be addressed using additional screws for a more stable reconstruction.

In case of poor soft tissue coverage, a postoperative immobilisation in a slightly extended fashion, may facilitate soft tissue healing, due to reduced tension.

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6 Treatment Options for Nonunion of the Olecranon

Ting Cong, Yiyang Zhang, Trevor Jackson, and Michael Hausman

6.1 Introduction

Olecranon fractures constitute about 10% of upper extremity fractures [1] and have an overall incidence of 12 out of 100,000 person years [2, 3]. In addition to fractures, olecranon osteotomy is a common approach to complex distal humerus fractures. Challenges to successful healing of the olecranon include soft tissue constraints, poor bone stock and bone quality, comminution, instability resulting in high loads on the fixation construct, and metabolic deficiencies. Avoiding and treating complications of olecranon fractures require thoughtful strategies that extend beyond conventional fracture fixation dogma, informed by understanding of the above challenges.

6.2 Angiosome-Informed Incision Design

The entire cutaneous blood supply is organized by angiosomes, as originally described by Manchot and Salmon and elaborated upon by G. Ian Taylor [4, 5]. The elbow maintains a robust blood supply classified into three vascular arcades: medial, lateral, and posterior [6]. The lateral arcade is comprised of radial and middle collateral, radial recurrent, and interosseous recurrent arteries. The medial arcade is formed by the superior and inferior ulnar collateral arteries. The medial and lateral arcades together, along with the middle collateral artery comprise the posterior arcade. This robust vascularity facilitates a variety of surgical approaches to the elbow and allows for formation of large flaps from a posterior approach, both medially and laterally, with minimal risk of tissue devascularization.

Thus, the safest incision is a straight line between the angiosome chains. Curving the incision around the tip of the olecranon, while not proven to prevent tenderness over the incision, cuts through angiosomal irrigation territories of the skin. While this may be well-tolerated in a young, healthy patient, it can result in wound dehiscence in smokers, older and diabetic patients. Therefore, we recommend a straight, posterior incision, unless the surgeon is constrained by a previous incision.

6.3 How Fixation Fails: Pitfalls of Conventional Olecranon Fixation Strategies

Successful treatment of olecranon fractures, osteotomies and non-unions requires consideration of the quality of the bone, the geometry of the fracture and the mechanical properties of the

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fixation construct. It is useful to consider the second area moment of inertia, which is a property of the distribution of material around an axis. For a beam (such as a fixation plate) this can be approximated by the Eq. $I = bh^3/12$. Thus, the resistance to bending is proportional to the third power of the "thickness" measured in the plane of an applied force. As an example, a 3.5 dynamic compression plate-equivalent applied to the medial or lateral cortex would have eight times the bending resistance as the same plate applied to the posterior cortex (Fig. 6.1). "Space frame" constructs, such as the Olecranon Sled™ or tension band, are complex to describe, but their widespread engineering applications outside of surgical implants, such as in performance automobile design, attest to their strength.

6.3.1 Tension Band Wiring

Tension band wiring (TBW) is the traditional method of fixing olecranon fractures. It is indicated in simple transverse fractures without comminution. In theory, the construct produces compression across the anterior cortex of the olecranon as the elbow is flexed.

Potential problems include: penetration of the anterior or lateral ulnar cortex, resulting in neurovascular injury or inadvertent fixation to the proximal radius, limiting pronosupination (Fig. 6.2). Also, TBW may not adequately fix comminuted fractures or osteopenic bone, although incorporation of the triceps tendon insertion and soft tissue can be very helpful in capturing small proximal fragments. The most common complication associated with tension band wiring is the high incidence of hardware irritation and hardware removal. The incidence is reported to be up to 75% in literature [7]. Despite this, patients had excellent outcome scores at 1-year follow-up [8].

Problems can be minimized by careful attention to the indications and the technique of TBW. The use of thin wires can results in unstable fixation, wire breakage or backout and irritation. The use of heavier gauge K-wires (0.062 or greater) and making a small stab incision in the triceps to bury the Kirschnerwire, and then repairing the tendon over the wire, can minimize hardware irritation. Also, a third pin and a second loop (Fig. 6.3) can be used for comminuted fractures.

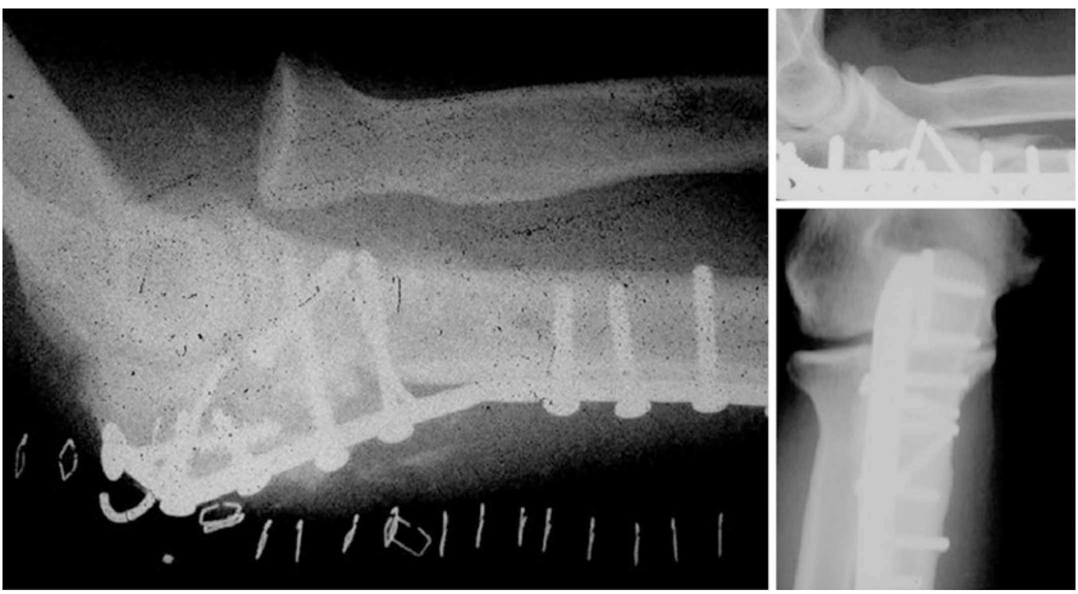

Fig. 6.1 Inadequate fixation using a 1/3 tubular plate (left), salvaged with a plate placed at 90° to the axis of rotation (right), following principles of the second area moment of inertia

Fig. 6.2 Two patients who could not pronate or supinate after olecranon fracture fixation. This is due to hardware directed too lateral and violating the proximal radioulnar joint or interosseous space. Interosseous hardware prominence is especially problematic at the level of the biceps tuberosity where the radioulnar space is minimal. To avoid this complication, screws should be directed midline or slightly medial, and forearm pronosupination should be evaluated for mechanical block or crepitus prior to completion of surgery

6.3.2 Plate and Screw Fixation

Plate and screw fixation has emerged as a popular choice of implant for fixation, especially in the setting of fracture comminution. In good bone, it offers significantly higher compression when compared to the traditional tension band, in both static and dynamic settings [9]. Radiographic and patient outcomes have been excellent [8, 10]. However, it is also plagued with high incidence of hardware irritation, with some reporting upwards of 50% [11–13]. In a compromised healing site, particularly with fixation failure, the increased hardware burden may increase concerns surrounding wound healing or infection.

When compared head-to-head, randomized control trial reveal that elbow range of motion between fracture fixed with tension band and plate and screws to be similar [8, 10]. There is also no statistically significant difference in patient-reported clinical outcomes. The complication rate of symptomatic hardware requiring removal was higher in the TBW group, while infection and revision surgery was more commonly seen in the plate and screw group [8].

However, plate fixation in the proximal fragment may be poor, especially with weak, osteopenic bone. Plates and screws often have inadequate proximal fixation and are primarily dependent on the intramedullary antegrade "home run" screw. If the proximal end of the plate does not reach sufficiently proximal, the triceps fragment may displace and "escape" the plate construct (Fig. 6.4). This complication can be minimized

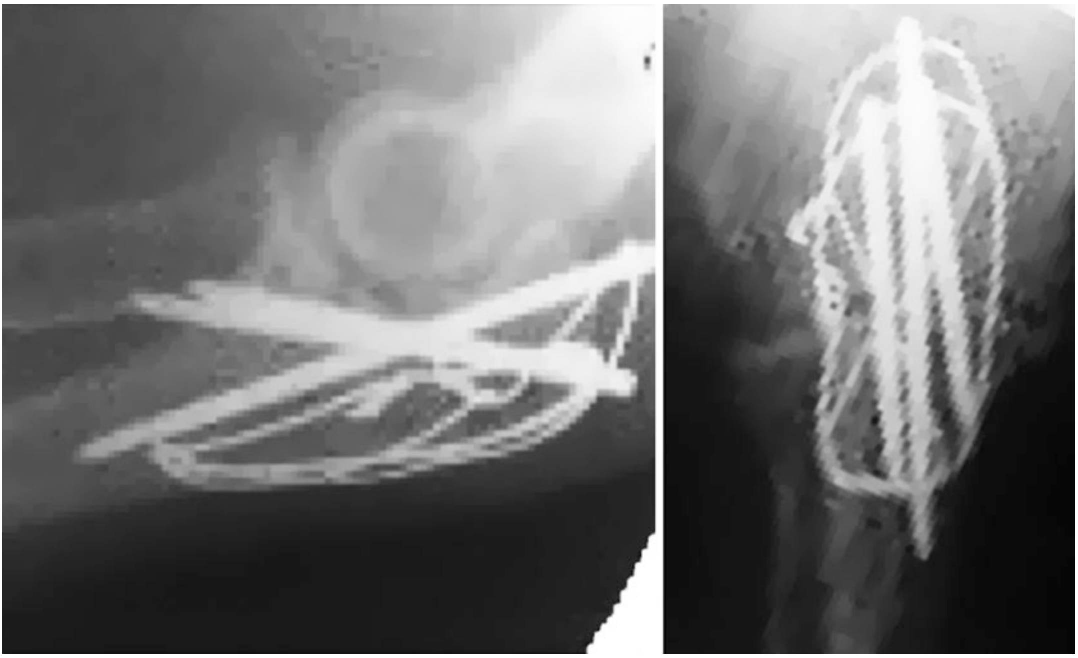

Fig. 6.3 Combining two tension band constructs can provide additional stability especially to the proximal fragment

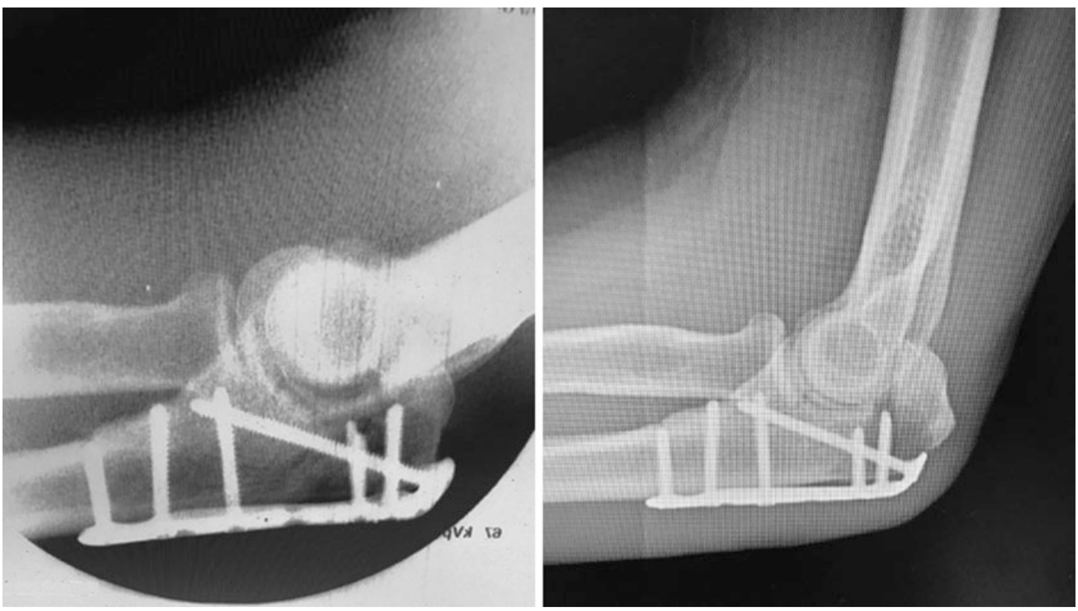

Fig. 6.4 Example of proximal pole fixation failure. A relatively common cause of failure with plates and screw fixation is inadequate fixation of a small, proximal fragment. The unicortical screws in the proximal plate corner contribute little to fixation, and the proximal to distal "home run" screw are be inserted too distally in this plate design to provide any stability to the proximal fragment. Alternative devices that capture both soft tissue and bone would be ideal. If a plate must be used, the design should extend more proximally to ensure capture of the fragment

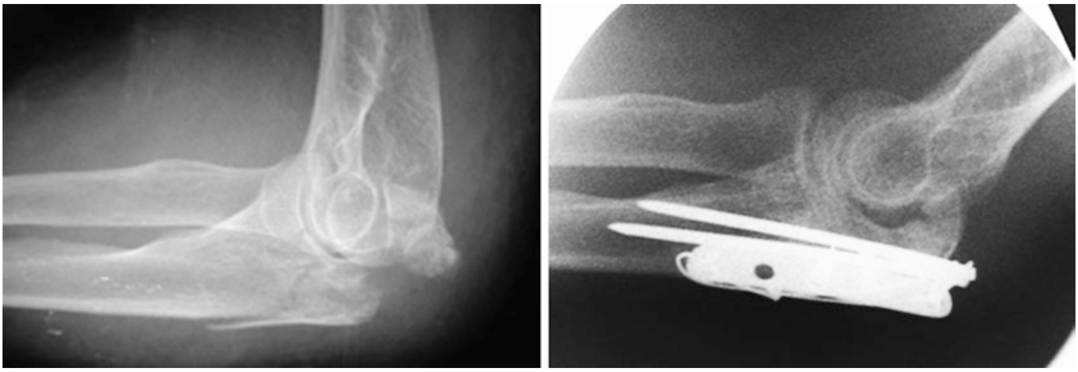

Fig. 6.5 A low threshold to combine fixation strategies can help address comminuted fractures. A comminuted olecranon fracture with a small proximal fragment and metaphyseal wall fracture, stabilized with a combination of tension band and a bridge plate (with bicortical screw purchase) applied to the lateral side of the ulna to maintain fracture reduction and provide additional stability to the proximal fragment

or treated by using a plate designed to obtain additional soft tissue fixation (such as the Trimed Hook Plate™) or one that extends more proximally. Unicortical proximal screws contribute little strength, particularly with osteopenic bone or comminution of the proximal fragment.

Distal fractures can also fail due to fatigue of the plate or loss of fixation. Salvage is often possible using a 90/90 construct. Such fixation is more rigid (greater second area moment of inertia) as well as affording bicortical fixation in the proximal fragment that is not possible with a dorsal plate (Fig. 6.5). Orthogonal plating also addresses sagittal split moieties.

6.3.3 Intramedullary Fixation

Relative stability provided by intramedullary (IM) screw-fixation is best suited for simple transverse olecranon fractures and olecranon osteotomies in younger, denser bone and, thus, probably has limited application to salvage of olecranon fixation failure.

IM screws or a screw and washer are popular for olecranon osteotomy fixation. An IM screw alone may compare poorly in biomechanical strength to IM fixation augmented with a tension band construct [14] and may provide poor rotational control. Intramedullary fixation alone may fail with comminution due to the low number of fixation points. A chevron shape is necessary in osteotomies fixed with an IM screw and can help with rotational stability. Still, IM fixation ranks low in the spectrum of stability, relegating it to be used in stable fracture types in good quality bone. Confident isthmic thread purchase is critical [15]. Failure of IM fixation and olecranon non-union (Fig. 6.6), while the rate is not known, presents as a serious potential complication that can easily be avoided with use of more stable constructions. If IM or large screw fixation fails with olecranon osteotomy for distal humerus fractures, a more challenging problem can result, requiring the surgeon to: address the non-union, and delay rehabilitation for the distal humerus fracture because of the need to immobilize and protect the revised olecranon fracture.

6.4 Novel Implants and Their Relevance to the Failed Olecranon Fracture

More recently, new alternatives to traditional tension band wiring have emerged. A single continuous loop construct (Olecranon Sled™, Trimed) functions as a hybrid tension band and IM device, with the added benefit of being lower profile. The hollow beam geometry is, theoretically, resistant to bending and torsional forces and is similar to the monocoque designs of race cars and airplanes.

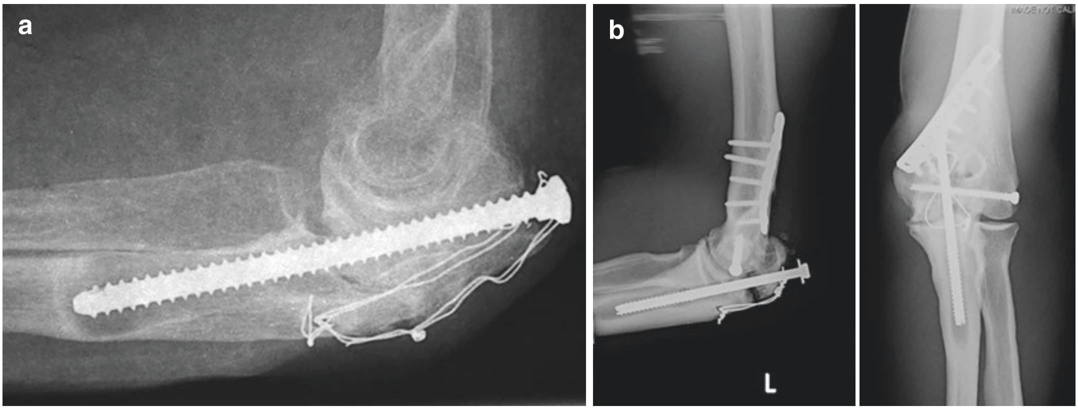

Fig. 6.6 Two examples (**a**, **b**) of inadequate intramedullary fixation and cyclic loading resulting in failure. An intramedullary screw with or without tension banding is a popular means of fixing an olecranon osteotomy. However, it can result in the very complex problem of an elbow contracture and a non-union, which can be avoided more stable constructs

Biomechanical studies comparing the Sled™ to traditional tension band wiring [16] and intramedullary screw tension banding [17] reveal no differences in load to failure [16, 17] with less hardware prominence [17]. Clinical data for the Olecranon Sled™ demonstrates 7.1% hardware removal rate in a series of 14 patients that had undergone olecranon osteotomy for distal humerus fracture exposure with an average follow up time of 33.5 weeks [18]. There were no non-unions in this series. In another series for olecranon fractures, 22 patients were reviewed with a minimum follow-up time of 12 months. All patients in this series presented with a Mayo Type II fracture. The average Mayo Elbow Performance Score was 95.5 with no hardware related complications or non-unions.

Hybrid fixation that combines fixation methods, such as using a tension band with a plate, two tension bands to improve fixation in the proximal fragment or combining a hooked device and a tension band or Sled™ can ameliorate fixation failure risk (Fig. 6.5). In cases requiring additional stability, such as revision surgery for non-union or fixation failure, hybrid fixation is useful, preferably taking advantage of a tension-band construct plus an orthogonal plate device. More recently, suture fixation has also been reported [19], which if used in a hybrid construct as a replacement for the tension band may offer advantages to proximal fragment/soft tissue capture and low prominence.

A tension band-plate developed by Medartis has also been introduced into the market. It combines the advantages of a tension band with angular stability of screw and plate fixation. Biomechanical studies demonstrate no difference in loosening or hardware failure in cyclic loading compared to traditional tension band wiring [20, 21]. To our knowledge, there is currently no clinical data published in literature for this device. However, the biomechanical studies and the low profile of the construct confer optimism to future results.

6.5 Modes of Failure and How to Address Them

6.5.1 Necessity of a Strict Post-Operative Protocol

We do not recommend weight-bearing on a fixed olecranon fracture until at least 6 weeks post-operatively, so long as there is unambiguous evidence of bone healing. Strict patient adherence to a postoperative protocol is critical to success. Immobilization helps assure uneventful soft tissue healing, which requires approximately 2 weeks. Our preference is 2 weeks in a long arm cast that *cannot* be removed by the patient, followed by gradual return to full range of motion with assistance of an occupational therapist. Until 6 weeks, active-assisted elbow extension and active elbow flexion without assistance is allowed. An elbow brace is not necessary unless there was demonstrated instability. In compromised bone healing situations, we recommend immobilization until there is resolution of bony tenderness and signs of bone bridging on radiography or, if necessary, CT.

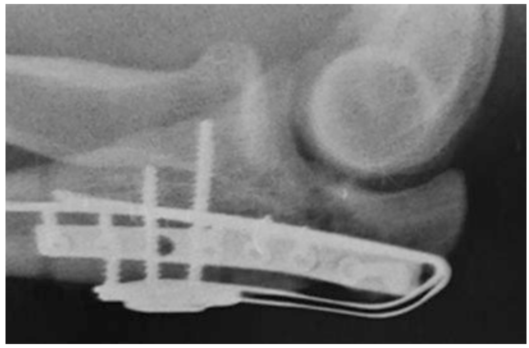

Fig. 6.7 Supplementation of an Olecranon Sled™ (Trimed) construct using a 90° plate for a comminuted proximal pole olecranon fracture

6.5.2 Loss of Hardware Fixation

Failure of fixation is often due to poor fixation in the proximal fragment (Fig. 6.2). In older patients with olecranon fractures characterized by small proximal fragments, comminution, and poor bone quality, plate and screw fixation is not ideal. Incorporation of triceps soft tissue fixation (tension band, the Olecranon Sled™ or a hook plate) is preferable. Newer plate designs that incorporate features of soft tissue fixation may minimize the chances of such failure. Data on use of these devices is understandably lacking, however.

Ironically, older techniques, such as tension band wiring or newer analogues, may be stronger because of their theoretically superior capture of the triceps insertion. Supplementation of a tension band system by combining multiple fixation techniques can be useful in preventing, particularly for comminuted fractures, by taking advantage of the geometric anatomy of the olecranon. For instance, a primary tension band construct can be reinforced, if there is metaphyseal comminution, by using a plate applied to the medial or lateral cortex of the proximal ulna (Fig. 6.7). A common revision strategy employed by the authors is the combination of a hook plate, used medially or laterally, in combination with a tension band, Sled™ or even a posterior plate for more distal fractures. This combination is rigid and affords multiple proximal fixation points in the bone and soft tissue.

Another cause for fixation failure is unrecognized instability, such as a proximal Monteggia fracture reduced by an outside entity and, thus, may present to the surgeon's office appearing as a simpler fracture type. Fixation with conventional olecranon techniques may be insufficiently strong to resist subsequent failure and recurrent subluxation (Fig. 6.8). Intraoperative stress examination should be performed in cases of high clinical suspicion, and considerations be made for ligamentous reconstruction if instability is found.

6.5.3 Delayed Union, Infection, and Bone Loss

For the treatment of delayed union, evaluation should include tests for infection and metabolic abnormalities (such as diabetes or vitamin D deficiency) that could delay or prevent healing. Physical exam findings of erythema, suppurative or chronic inflammatory skin changes, radiographical findings of implant loosening, and elevated levels of C-reactive protein and erythrocyte sedimentation rate are generally considered strong evidence for the diagnosis of implant-associated infection [22].

The management of wound problems depends upon the stage of healing. Post-operative immobilization of the elbow for 10–14 days will usually prevent most problems and should not cause contracture. Acute surgical site dehiscence can be debrided and closed primarily. Subacute dehiscence, which can occur from skin edge necrosis, is usually accompanied by some degree of skin

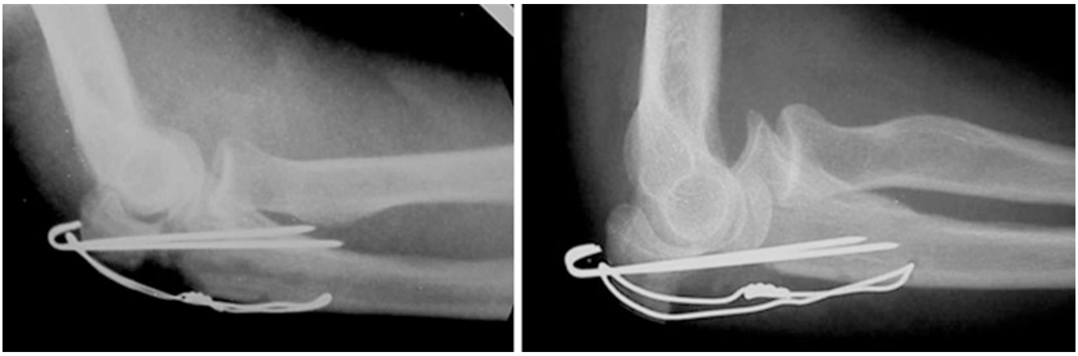

Fig. 6.8 Failure to appreciate a Monteggia fracture type can result in instability and failure of a simple tension band fixation

edge retraction and exposed hardware. The majority of subacute dehiscence can be treated with immobilization, daily wet-to-dry dressing changes, and planned removal of hardware and debridement at 6 weeks once some degree of bone healing has occurred. Subacute dehiscence can also be closed in a progressive delayed fashion if sufficient soft tissue can be mobilized. Oral suppressive antibiotics may anecdotally provide some protection against surgical site infection, though little data supports its use in this setting. Loss of fixation, large severe wound dehiscence, or clinical concern for suppurative or deep infection are reasons to pursue immediate hardware removal and debridement.

Frank infection at the site of olecranon fixation usually requires the removal of hardware, debridement of all infected and necrotic tissue, and subsequent bone and soft tissue reconstruction. This should be performed in a timely fashion in order to limit the extent of infection progression. Overlying soft tissue loss can be managed with serial debridement and surgical coverage once the site is deemed healthy and granulating. Tissue biopsy should be performed for culture at time of the first debridement, and empirical antibiotic treatment started. A considerable degree of art is required of the surgeon in the treatment of complex infected non-unions of the olecranon. While insufficient data describe the appropriate timing of soft tissue coverage at the elbow, if taken in light of literature demonstrating that early tissue coverage improves clinical outcomes in acute open fractures [23], then timely soft tissue coverage should be performed as soon as the surgeon is confident that infection has been cleared. Clinically, robust healthy granulation tissue can be expected to form 5–7 days from time of debridement. Beyond this time frame, granulation tissue begins to consolidate and epithelialize, making flap coverage less reliable. During and after surgical treatment, close coordination with an infectious disease specialist is critical in ensuring a full antibiotic treatment course, based on organism speciation from the initial surgical debridement.

If there is a severely involved segment of the proximal ulna by infection, wide excision may be necessary, followed by reconstruction with a vascularized autograft, such as the fibula. A non-union without a large area of infection might be amenable to treatment with iliac crest autograft and a vascularized periosteal flap, such as that from the medial femoral condyle with a pedicle based on the descending genicular vessels.

Non-union of the olecranon following surgical fixation, defined as delayed union beyond 6 months, is rare. However, delayed union may be seen in cases involving metabolic abnormalities such as smoking, diabetes, low vitamin D, and kidney or liver failure. Modifiable metabolic abnormalities should be corrected as early as possible in the fracture healing process, in order to avoid missing the "biological window" for fracture healing (Fig. 6.9). Metabolic abnormalities are known to interfere with the inflammatory phase of fracture healing causing less callus deposition [24]. Recent evidence suggests that

Fig. 6.9 Delayed union of a distal humerus fracture (with iliac crest bone graft) and olecranon osteotomy site in a patient who was subsequently found to have diabetes and vitamin D deficiency. While the grafted distal humerus fracture has begun to heal, minimal callus is seen at the olecranon osteotomy site at 3 months' follow up, even after correction of metabolic abnormalities. Early correction of metabolic deficiencies may help avoid missing the biological window for bone healing

we may also be underestimating the prevalence of vitamin D deficiency [25].

Bone graft is often necessary to reconstruct a non-union, and use of autogenous iliac crest graft is our preference in almost every case of non-union. There is poor evidence supporting the use of bone graft substitutes or bone marrow aspirate concentrates for this application. If there is no loss of fracture reduction or bony volume, morselized cancellous bone graft may be applied to the surface, spanning the fracture site by a minimum of 1 cm both proximal and distal to the fracture. However, if there is bone loss due to motion at the fracture site, compression of the fracture can reduce the dimensions of the olecranon articular surface so that it is too small to accept the trochlea. In such cases, a structural, tri-cortical graft will be necessary, along with strong supplemental fixation. Again, autogenous graft is the ideal choice for this situation.

For intractable non-union, non-union with severe tissue loss, and infected non-unions, debridement of compromised tissue and bone with staged reconstruction using vascularized tissue may be required. There are a variety of donor sites, depending upon the nature of the defect and the requirements. A pedicled distal radius flap has been described for smaller defects and obviates the need for microvascular anastomosis, while also providing bone and skin for coverage [26]. A periosteal medial femoral condyle free flap can use useful when no volume restoration is necessary. We prefer using vascularized bone graft instead of devascularized autograft for most infection cases.

If larger grafts are needed, fibula, iliac crest and lateral scapula can all be used, along with various combinations of muscle and/or skin, if coverage is problematic.

6.6 Conclusion

Failure of olecranon fracture fixation is a recognizable clinical entity. Addressing the failed olecranon fracture requires flexibility in fracture fixation strategy and familiarity with bone and soft tissue handling. A thorough understanding of elbow angiosomes, hardware options, tissue supplementation options, and considerations for a careful post-operative protocol will help practitioners address the failed olecranon fracture, and inform strategies to prevent future failure.

6.7 Questions

1. A 58-year-old obese male presents to the office with a 3-month-old closed left olecranon fracture that underwent plate and screw fixation. He is a non-smoker and does not drink alcohol excessively. The patient has no pain. There is no sign of infection. Radiography demonstrates delayed healing of the olecranon fracture with minimal callus formation. What is the best next step?
   (a) Continue watchful waiting—patient does not satisfy criteria for a non-union.
   (b) Obtain labs—ESR, CRP, hemoglobin A1C, vitamin D OH-25, TSH, PTH levels.
   (c) Start bone stimulator treatment.
   (d) Increase weight-bearing of the left arm.

   Answer: b. One must be cognizant of metabolic deficiencies that could impact bone healing. Correction of metabolic deficiencies, such as diabetes or vitamin D deficiency, as early as possible in the fracture healing process can rescue a delayed union from becoming a nonunion. There is poor evidence that supports the use of a bone stimulator in this setting.
2. The resistance to bending of a plate is proportional to the ____—power of its “thickness” measured in the plane of movement?
   (a) First.
   (b) Second.
   (c) Third.
   (d) Fourth.

   Answer: c. For a beam (such as a fixation plate) resistance to bending can be approximated by the Eq. $I = bh^3/12$, according to the *second area moment of inertia*.
3. During surgery for a comminuted olecranon fracture in osteoporotic bone, it was found that a dorsal plate and screw construct only captured the proximal-most fragment with a single “home-run” screw. What is the *strongest* option available to avoid failure of the fixation construct?
   (a) Remove the plate and install a tension-band construct.
   (b) Supplement the fixation with an orthogonal tubular plate.
   (c) Supplement the fixation with additional antegrade screws outside of the plate.
   (d) Supplement the fixation with a orthogonal hook plate.

   Answer: d. Hook plates have the added benefit of proximal soft tissue capture which, in effect, prevents further avulsion of the triceps insertion. Additional screws in osteoporotic bone will not sufficiently achieve this.

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7 Radial Head Replacement

Raul Barco and Alfonso Vaquero

Key Points

- Conventional X-ray tends might underestimate fracture comminution and obviate associated injuries, so CT scan is a worthwhile exploration for appropriate injury recognition.
- The typical approach is a lateral one (through the soft tissue injury, Kocher or midline), but depends on the extent and significance of associated injuries.
- The most critical aspect of the technique is to avoid oversizing and overlengthening. Templating the size of the implant to the size to the removed radial head and the height of the implant to match the length of the forearm to the top level of the greater sigmoid notch may avoid the most significant complications. Fluoroscopy may help to avoid this frequent problem. When in doubt, downsizing is a wise option.
- Treatment of the associated injuries is critical to start a safe early motion rehabilitation protocol.
- Long-term results are lacking, but mid-term results show no differences between different arthroplasties with the majority of patients achieving a painless functional elbow.
- Complications include persisting pain, loosening, persisting instability, stiffness, heterotopic ossification, and neurologic injuries.

7.1 Description

Radial head replacement is an operation performed for radial head fractures or arthritis were maintaining the radial head anatomy is beneficial for load sharing and stability of the joint.

7.2 Key Principles

Radial head arthroplasty can be classified according to stem fixation (cemented, ingrowth, loose), the design of the radial head (anatomic, round), type of neck–stem junction (unipolar, bipolar), most of them being nowadays modular to adapt to the wide variation of radial head and neck anatomy. Bipolar prostheses can self-adapt to minor incongruencies of the joint but have been associated with potential failure in the setting of acute instability associated with a radial head fracture. In every case, appropriate sizing is of paramount importance. Radial head height and circumference have to reproduce native anatomy as closely as possible. Over-lengthening the arthroplasty can produce pain, limit flexion–extension, and decrease the rate of healing of the ligament while oversizing the head can produce erosion of the lesser sigmoid notch.

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7.3 Expectations

For radial head fractures in the setting of elbow trauma, the role of a radial head arthroplasty is to achieve effective radiocapitellar contact to improve stability and to provide load transfer through the radiocapitellar joint. It is critical to repair associated ligamentous injuries to improve stability, as radial head replacement alone will not provide enough stability. While some fractures can perform well over the years with a radial head resection, the potential load-sharing of reconstructing the radial head will benefit the joint over time. Long-term results of resection have shown increased rates of degenerative changes, albeit well-tolerated most of the time [1]. Mid-term and long-term results of bipolar and unipolar arthroplasty show degenerative changes of the elbow in more than half of the patients, so further follow-up is still warranted [2–5]. In the setting of an associated mild interosseous membrane (IOM) injury, radial head arthroplasty is indicated to control shortening of the radius. Complete injuries of the IOM probably need some repair or augmentation in association with the radial head reconstruction [6]. Patient expectations are based on associated injuries, but most of the patients achieve a functional range of motion (30°–130°), adequate pain relief but must expect the progression of arthritis over time. We generally encourage patients with an arthroplasty to avoid weight-lifting or other activities that overload the elbow joint on the premises of reducing degenerative changes over time.

7.4 Indications

Unstable elbows with an unreconstructable radial head fracture, as considered by the surgeon, are the primary indication for a radial head arthroplasty. The consideration of instability can be made preoperatively by preoperative imaging but has to be assessed intraoperatively with the patient asleep. Competence of the MCL (valgus load), LUCL (varus load and posterolateral drawer test), and IOM (radius pull test) must be assessed during surgery. Chronic conditions like radial head arthritis or post-traumatic sequelae (e.g., missed Monteggia fractures) are less frequent as they usually affect the other side. In some cases, stiffness treatment may require radial head resection and instability after this procedure may require consideration of a radial head implant.

7.5 Contraindications

The main contraindications are capitellar injuries that preclude effective contact. In chronic cases where the capitellum has not been loaded the patient must be advised that introducing an arthroplasty may produce pain due to loading a previously unloaded bone. In these cases, we prefer to shorten the height of the prostheses 1–2 mm intentionally. Fractures that extend into the neck of the radius can compromise the stability of the arthroplasty, especially in the case of uncemented shorter stems. It is probably advisable that there is enough radial neck to support the arthroplasty (circa 70%). Otherwise, one can use longer stems or cemented stems to increase the stability of the implant.

7.6 Special Considerations

Preoperative planning is essential as with any other operation. These are complex injuries and detection of associated injuries may impact the outcome of the procedure. CT imaging is beneficial to evaluate the location and size of a coronoid fracture, to detect intraarticular fragments, to assess for joint congruity and to detect other bony injuries. Regarding the radial head using a CT will probably “overestimate” the injury to the radial head.

7.7 Special Instructions, Positioning, and Anesthesia

We place patient’s supine with the arm on a small arm table, and we routinely use antibiotics and a tourniquet. While we prefer regional anesthesia for most of the cases, more complex procedures like Monteggia-like fractures that require a radial head implant or patients with an associated nerve injury are good candidates for general anesthesia.

Assessment of associated injuries can be predicted to a degree, but a formal evaluation of ligamentous injuries is performed with the patient asleep prior to skin incision and during the operation. We assess the medial collateral ligament with valgus loading, the lateral ligamentous complex with varus loading and with posterolateral pivot-shift and longitudinal instability with the radius pull test.

7.8 Tips, Pearls, and Lessons Learned

7.8.1 Choice of Approach

Radial head implants can be implanted through a mid-extensor approach (modified Kaplan) or a Kocher approach in posterolateral injuries (terrible triad), and through a Sham and Taylor approach or through the fracture line in complex Monteggia-like injuries. The choice of the approach depends on the injury pattern and the preference of the surgeon. Most typically, the decision is whether to perform a Kaplan or a Kocher approach. I generally favor the Kaplan approach for most of my reconstructions as I prefer to have an intact posterolateral sleeve of tissue; however, some cases have an injury to the posterolateral fascia and, if so, I generally use the injury to the soft tissues to decide my approach.

7.8.2 Radial Neck Resection and Radial Shaft Preparation

The forearm must be kept in pronation to protect the PIN, and the supinator is elevated to expose the proximal part of the radial neck. A curved Hohman placed posteriorly can help present the radius and protect the neck cut. We use a small sagittal saw and perform the neck cut perpendicular to the neck while trying to preserve as much bone as to have a stable circumference of cortical bone. Careful broaching aiming to the radius shaft can be difficult in the more stable elbows. When aiming for the radial shaft with the broach, conflict with the lateral epicondyle can deviate and direct us towards the ulna. This situation can be prevented by using retractors to present the shaft into the wound. Most systems will have a starter awl, and progressive broaches or rasps that are used until cortical contact is encountered. An undersized trial is generally used to assess stability.

7.8.3 Sizing

Most modern radial head implants are modular which provide optimal sizing and reconstruction of the radial height [7]. The radial head has an oval shape with a maximum and a minimum diameter. Most systems recommend sizing the implant according to the minimum diameter. In comminuted fractures, assembling the fracture can be challenging and when assembled they are slightly oversized. When in between sizes most systems recommend going for the smaller size. Regarding height-reconstruction avoid the concept of filling up space as these elbows are unstable and can be overstuffed. I favor two methods to decide the height [8–10]. First, I reconstruct the radial head on an outside table and template it against my extracted radial head. Second, with my trial I aim for the radial head to be parallel to the proximal part of the lesser sigmoid notch. When in doubt about height, I prefer to err on the lower size.

7.8.4 Assessing the Trial Implant

After choosing the correct stem size, neck height and radial head height and size, the trial is assembled in the back table and introduced into the radius. Fluoroscopy is then used to check for over-lengthening the radiocapitellar joint and adequate tracking. A congruent ulnohumeral joint with parallel joint lines should be seen and should articulate with the proximal part of the

PRUJ. The radial head must be centered on the capitellum on both views. Congruity of the DRUJ may be checked at the wrist to assess on changes in the normal variance of the wrist.

7.8.5 Treatment of Associated Injuries

During the approach, I generally tag the humeral origin of the LUCL if injured so that when trialing the arthroplasty tensioning the suture can simulate the "repaired" stability of the elbow. All fragments of the radial head must be carefully removed and reconstructed on the auxiliary table to avoid leaving fragments behind. Some of these fragments may be as further away as the flexor–pronator muscle mass, which highlights an injury to the anteromedial elbow capsule. Copious lavage of the joint is performed to clean the joint from intraarticular bone debris. The necessity of repairing a coronoid fracture is performed according to the impact on stability. It is generally performed after preparing and trialing the radial head implant to reduce stress on the repair. After removing the radial head trial, there is good access to control reduction of the coronoid, and we favor posterior to anterior screws. Generally, I will use 2.7–3.0 mm cannulated screws for this fixation. You may use some sort of aiming device to place the screws (e.g. PCL knee aiming guide). In cases of Monteggia-like fractures or anteromedial coronoid fractures, an associated medial approach to place a buttress plate may be needed.

7.9 Difficulties Encountered

If during the trial, radiocapitellar congruity is not achieved, review the impact of associated injuries, most importantly the coronoid and the lateral collateral ligament complex and address them. Secondly, most systems are based on the forearm axis of rotation, so if the neck cut is not well oriented or during broaching or rasping this axis is lost, our implant can be placed misaligned. While bipolar and loose-stem implants might be able to compensate slightly for this, it is critical for fixed stem implants to be well aligned.

It can be challenging to impact a tight press-fitted implant in elbows without a concomitant LUCL injury. A curved Hohman retractor underneath the radial neck can help in "rolling-out" the radial neck and help with the exposure. Alternatively, some clamps can help in lateralizing the radius and may help in this regard. In radial head fractures, even in young patients, a radial head replacement set should be available in the OR as a bailout.

If by any chance a radial head replacement is not available there are some "salvage" options. Rarely, the native radial head can be used as a spacer with firm repair of the ligaments. If the arm is not longitudinally unstable the elbow can be rendered stable by repair of the ligaments with or without the use of an associated external fixator.

If after repair of the lateral collateral ligaments the elbow remains unstable, it might be due to an unrepaired coronoid fracture or extensive medial soft-tissue injury. In cases with a repaired coronoid, one can protect the healing by applying a lateral external fixator or perform a medial approach and repair de medial collateral ligament and/or the flexor–pronator mass.

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8 Open Reduction Internal Fixation (ORIF) for Capitellum Fractures

Nadine Ott, Michael Hackl, Lars P. Mueller, and Kilian Wegmann

8.1 Epidemiology and Surgical Anatomy

Capitellar fractures are truly rare, accounting for 1% of elbow fractures and 3–6% of distal humerus fractures [1–5]. Basically, two trauma mechanisms are discussed. Some result from a fall on an extended or semi-flexed arm similar to that of radial head fractures. The fracture occurs as a result of vertical stress transmitted onto the capitellum from the radial head. Others may occur following spontaneous reduction after posterolateral elbow subluxation or dislocation. A concomitant injury to the radial head occurs in 25% of all, and an associated collateral ligament injury has been reported [1, 5–7].

The capitellum is directed 30° anteriorly and distally with respect to the long axis of the humerus. The center of rotation is located 12–15 mm anteriorly to the humeral shaft axis. The anterior portion is covered by hyaline cartilage of about 2-mm-thickness. The distal articulation with the radial head forms the radio-capitellar joint. The distal humerus diaphysis has minimal cancellous bone and is supplied by a single nutrient artery. The lateral column is supplied predominately by posterior vessels, whereas the medial column is supplied by anterior and posterior segmental vessels [8]. One of the reasons that the capitulum is prone for subchondral stress fractures is the solitary blood supply [1, 5, 9].

8.2 Classification

The understanding of the anatomic configuration of the fractures of the capitellum has enhanced in the last few years, and the classification of these fractures continues to evolve. Capitellar fractures are often more complex than expected. Therefore, a CT scan is regularly recommended in these fractures.

The classification described by Bryan and Morrey (modified by McKee et al.) is probably most widely used (Fig. 8.1). A type I fracture is defined as a single large fragment, and the type II appears as a thin subchondral shell of the anterior cartilage. A type III fracture involving comminution of the articular surface and the subchondral bone is often found with a radial head fracture. The type IV suggested by McKee et al. involves part or all of the trochlea [1, 3, 6].

The Dubberley classification is a useful framework for decision-making based on the anatomic pattern of the fracture [10]. These fractures were

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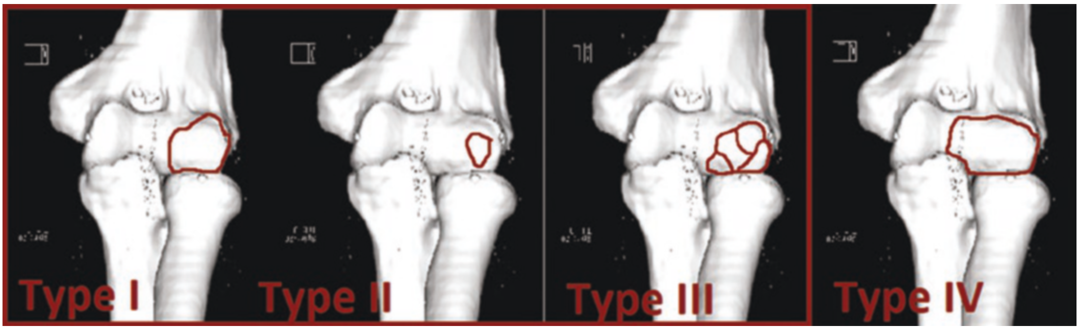

Fig. 8.1 Classification described by Bryan and Morrey, type IV modified by McKee [1, 6]

classified by the presence or absence of posterior comminution (type A or B). Type I fracture involves the capitellum with or without the lateral trochlea ridge, the type II is a fracture of the capitellum and the trochlea as one piece and a type III fracture involve the capitellum and the trochlea separately.

Apart from the present classification, is a rare impacted fracture of the capitellum (the Osbourne-Coterill lesion) with concomitant injuries of the radial head or the coronoid [9].

An important factor which is already not included in a classification is the amount of subchondral bone stock and the depth of the fragments. It could be determining the possible fixation method.

8.3 Tips, Pearls, and Lessons Learned

The current management of capitellar fractures is mostly surgical. Conservative therapy is reserved to non-displaced fractures, or elderly low-demand patients. Surgical treatment options include closed reduction, fragment excision, open reduction and internal fixation (ORIF), arthroscopic fixation and prosthetic replacement [2, 10–20]. ORIF can restore the congruity of articular surfaces by stable reduction and allow early mobilization [21]. The authors prefer the supine position as it allows positioning of the arm for all approaches. Lateral approaches, Kocher or extensile posterolateral exposure, are used for all type 1 and 2 fractures. The variation of lateral approach is directed by fracture pattern. The capitellar fractures are readily treated through an approach which elevates the extensor carpi radialis longus (ECRL) and capsule from the lateral column. It is extended distally by splitting the common extensor origin (CEO), anterior to the lateral collateral ligament (LCL). In simple fractures, a short incision situated over the fragment can be enough to achieve anatomical reduction. Therefore, it is useful to clear the posterior aspect of the lateral column to have a clean fracture line. By that, a clear view on fragment position and correct reposition may be achieved. While performing the reposition, one has to counter the pull of the extensor muscles, whose origin often is still attached to the fragment. Also, the lateral collateral ligament might still be attached to the capitulum. Both structures will exert a distal pull onto the fragment. We achieve temporary fixation by K-wires to have time to check for correct reposition macroscopically and via fluoroscopy. If the reposition is sufficient, in our praxis final stabilization via headless compression screws is performed. The authors prefer to use headless, double-threaded compression screws (Fa. Medartis; APTUS SpeedTip CCS 3.0 mm) (Fig. 8.2). Headless compression screws may not need removal if completely sunk, but still offer a high amount of compression strength. Care is required with small shallow fragments as headless screws may

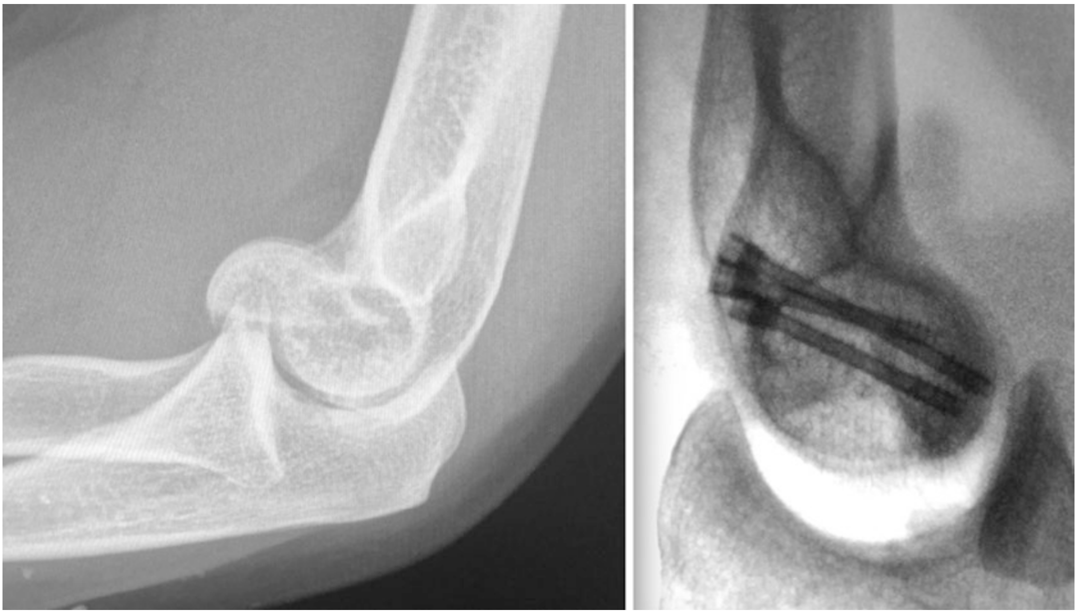

Fig. 8.2 Case of open screw fixation: pre- and postoperative X-rays of a type I fracture; use of 3.0 mm headless, double threaded compression screws for stable fixation

not exert compression, especially in type II fractures. However, in more complex fractures with comminution, plate osteosynthesis is necessary. The comminution usually is found at the proximo-dorsal aspect of the capitellum. Therewith, if only compression-screw fixation is performed, the fracture gap is closed and malpositioning will result. Therefore, in these cases fragment position has to be managed via a plate construct. We prefer posterior plate fixation in the larger part of the complex cases, as the capitulum will allow screw purchase from posterior to anterior (Fig. 8.3). In case of accompanying ligament injuries, these can be addressed via the same approach with transosseous or anchor repair. Arthroscopic assistance is possible, while using an arthroscope to look into the ventral aspect of the joint through the incision. By that, the medial edge of the fragment and the reposition result at the transition of the capitulum into the trochlea can be checked. Depending on the incision size, visual control of that area is not always possible. Reposition of the medial edge of the capitulum fragment can also be achieved by palpation, though.

8.4 Arthroscopic Treatment

All arthroscopic reposition and fixation also is possible. It comes with along with advantages like precise reduction with a better evaluation of associated cartilage lesions. But the skill level necessary to perform the procedure is significantly higher and naturally it takes more time. A critical task for the arthroscopic procedure is countering the pull of the extensor muscles and of the forearm everted onto the fragment via the lateral ligament. In cases of a small fragment where the soft tissues are not attached, this surely is not a problem. For the arthroscopic procedure, the patient is placed in a lateral position. The preparation for surgery corresponds to that of diagnostic elbow arthroscopy. The use of a tourniquet is recommended, but not mandatory. Important anatomical landmarks and the standard portals should be marked (Fig. 8.4).

Figure 8.5 presents a rare case of a combined radial head and capitulum fracture. X-ray and CT scans show the capitulum fragment wedged into the defect in the radial head fracture gap, patient was unable to rotate (Fig. 8.5).

Fig. 8.3 Pre- (**a**) and post-OP (**b**) imaging of a distal humerus fracture, involving the lateral condyle type III; intact anterior periosteal hinge to the capitellum helps orientate the fragment; reduction can be achieved with gently mobilizing the proximally displaced fragments with an elevator or a dental pick; the fragment is held in position with K-wires; for fixation in this case 3.0 mm headless, double threaded compression screws and plate osteosynthesis is used

Anteromedial, anterolateral, proximal anterolateral, and high postero-lateral arthroscopic portals are used to debride hematoma and define fracture configuration (Fig. 8.6a). Reduction is performed with a probe or dental tip through the anterolateral portal, while viewing through the high postero-lateral portal and with further manipulation of the fragment via the soft-spot portal (Fig. 8.6b, c). The effect of varus stress or flexion/extension can be used on fracture reduc-

Fig. 8.4 For arthroscopic treatment, the patient is placed in a lateral decubitus position. The preparation for surgery corresponds to that of diagnostic elbow arthroscopy; important anatomical landmarks and the standard portals should be marked

tion. Joystick-K-wires can be placed transcutaneous to maneuver the fragment. Temporary fixation with percutaneous K-wires is placed to maintain the reduction (2.0–3.0 mm) (Fig. 8.6d). It may be helpful to use directly the K-wires for the headless compression screws (0.8 mm/1.1 mm). The fracture can be fixed with headless compressions screws (Fa. Medartis, APTUS, SpeedTip CCS 2.2/3.0 mm) (Fig. 8.7).

Small, thin osteochondral fragments may be excised without significant consequences [22]. However, excision of lager fragments is not recommended, as it may result in instability. Mostly, lateral ligament injuries affect the joint stability. This may require a mini-open approach to stabilize the fracture and the joint [7].

8.5 Complications

Patients should be advised of the following postoperative complications:

- Irreparable nerve lesion, especially radialis nerve and posterior interosseous nerve.
- Temporary nerve affections or paresthesia.
- Increasing restricted movement of the elbow.
- Stiffness, pain or osteoarthritis.
- Instability.
- Non-union, mal-union or osteonecrosis.
- Articular damage.
- General surgical complications (e.g. wound healing disorder, fistula formation, infection).

8.6 Tips, Tricks and Pitfalls

- Preoperative planning with CT scan and classification allows assessment of approach, fixation, and outcome.
- Work via two anterolateral portal while viewing from anteromedial.
- Use the effect of varus stress and flexion/extension on fracture reduction.
- Supine position allows positioning the arm for all approaches during ORIF.
- Consider use of the K-wires of the headless compression screws for temporary fixation.
- Multiple small-diameter, headless compression screws offer less articular damage and ideal fixation.
- Lateral ligament injuries may affect the joint stability, and a mini-open approach to stabilize the fracture and the joint is required.

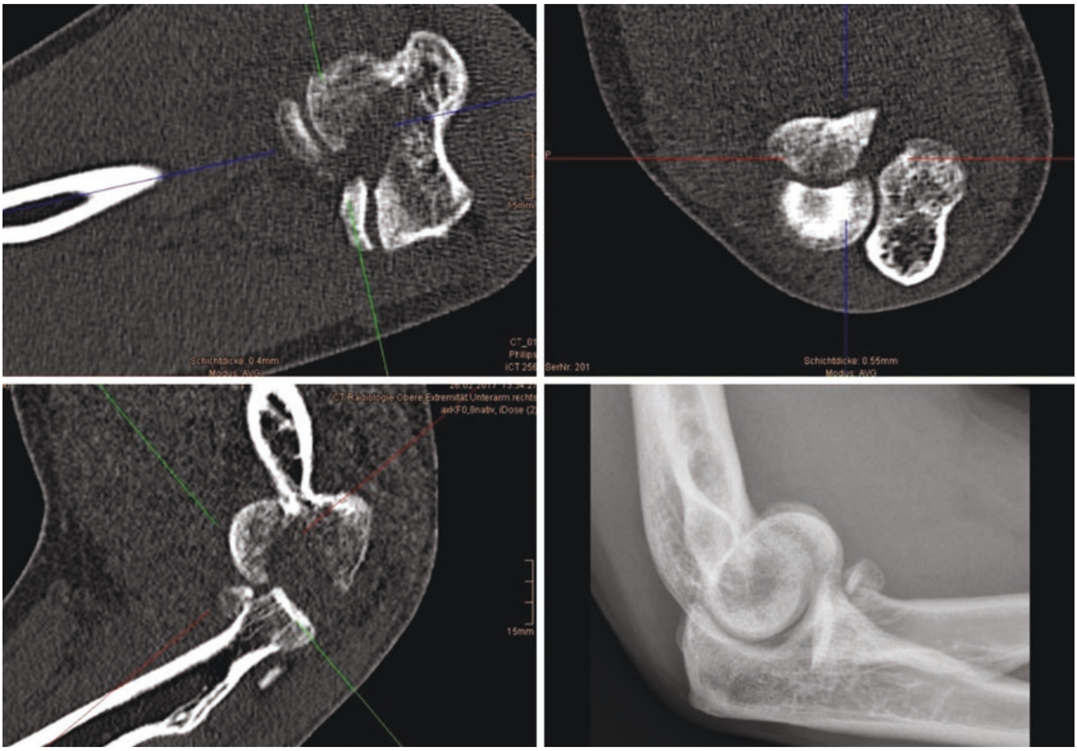

Fig. 8.5 Rare case of a combined radial head and capitulum fracture. X-ray and CT scans show the capitulum fragment wedged into the defect in the radial head fracture gap. Patient was unable to rotate

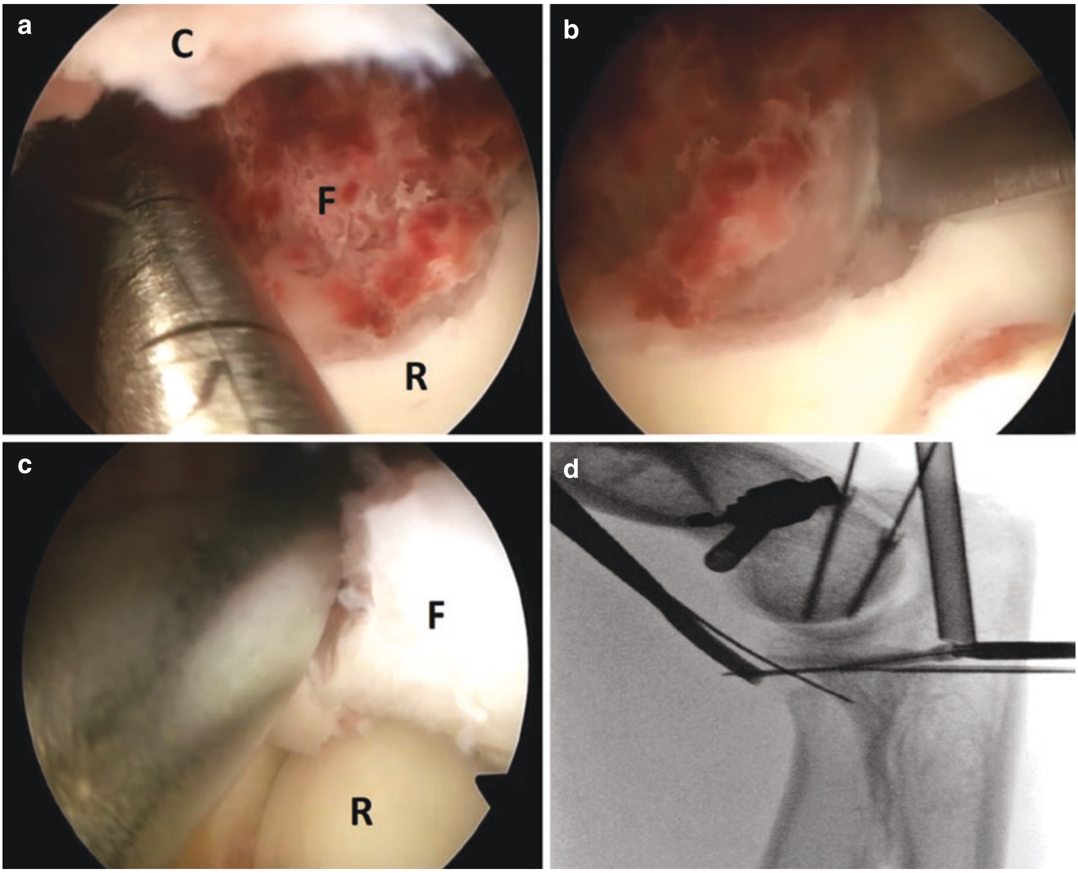

Fig. 8.6 Images of the arthroscopic treatment of the case of Fig. 8.5. (**a**) Initial debridement of the situs. *R* radial head, *F* capitulum fragment wedged into the defect, *C* capitulum/dorsal edge. (**b**) Fragment is mobilized out of the defect using a periosteal elevator. (**c**) Fragment is mobilized back into the fracture bed using the elevator radially and a rasp medially. (**d**) Intra-operative X-ray showing the capitulum-screws in place, inflow-cannula, scope, elevator and guiding K-wires in the radial head

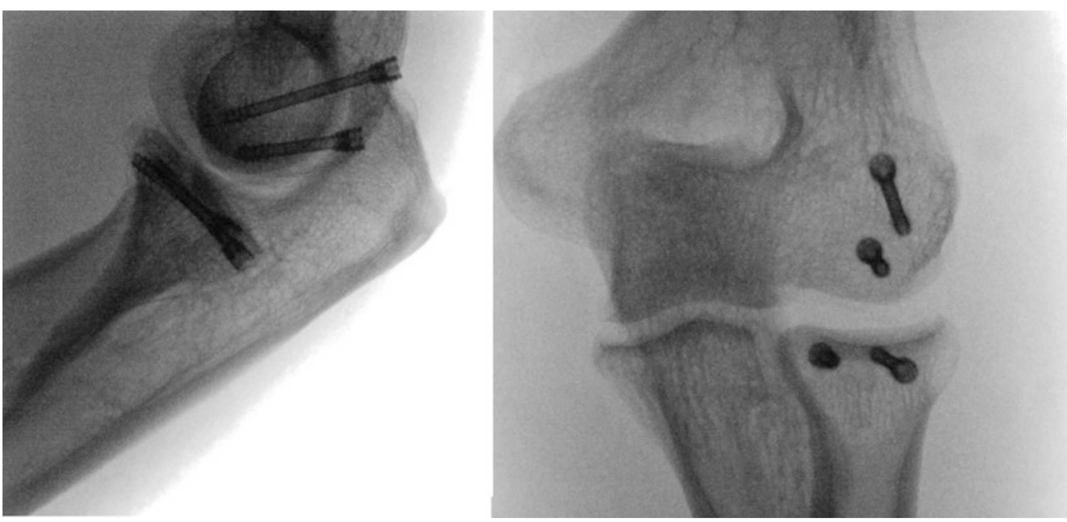

Fig. 8.7 Post-operative X-rays

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9 Open Reduction Internal Fixation (ORIF) for Trochlear Fractures

Pablo Vadillo, Raul Barco, and Samuel Antuña

Key Points

- Conventional X-ray tends to underestimate fracture extension, CT scan is essential for preoperative planning of trochlear fractures.
- Fractures of condyle and trochlea can be addressed through an extensile lateral approach; in cases of isolated trochlear fractures, consider medial approach or olecranon osteotomy.
- Arthroscopic-assisted reduction and internal fixation (AARIF) is a good option in isolated capitellum fractures or associated with simple lateral trochlear fracture.

9.1 Introduction

Isolated fractures of the trochlea are very rare, they usually involve the capitellum and a portion of the trochlea [1]. These fractures may also be present in more complex distal humerus fractures dislocations with concomitant ligamentous injuries. The treatment has evolved from closed reduction or fragment excision to a preference for open reduction and internal fixation. The goals of surgical treatment are to restore articular congruity and obtain stable fixation to allow for early motion, minimizing the risk for posttraumatic sequelae.

9.2 Preoperative Planning

Fractures of the distal humerus are often the result of a relatively low-energy fall on an outstretched arm. Young patients may present after high-energy trauma.

9.2.1 Images

Radiographs should include ipsilateral elbow, forearm, and wrist views. Plain radiographs often cannot identify subtle fractures and may underestimate the extent of comminution. CT examination helps identifying the fracture pattern and comminution. It is recommended in most cases for preoperative planning.

9.2.2 Classifications

Trochlear fractures are classified including the capitellum as coronal shear fractures.

9.2.2.1 Bryan and Morrey

Bryan and Morrey [1] originally described the most commonly used classification for coronal shear fractures, later modified by McKee et al. [2].

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Type I (Hahn–Steinthal fracture) is a complete capitellar fracture with little or no extension into the trochlea.

Type II (Kocher–Lorenz fracture) is an osteochondral fracture of the capitellum with minimal subchondral bone.

Type III is a comminuted fracture of the capitellum.

Type IV is a fracture of the capitellum with medial extension to the trochlea.

9.2.2.2 Dubberley

Dubberley [3] proposed a novel classification treatment which is favored as it gives treatment orientation and is outcome-oriented.

Type I fractures involve the capitellum with or without the lateral trochlear ridge (Bryan and Morrey type I).

Type II fracture involves the capitellum and the trochlea in a single fragment (BM type IV) Fig. 9.1.

Type III injuries consist of fractures of both the capitellum and the trochlea, as separate fragments Fig. 9.2a, b.

Fig. 9.1 CT scan 3D reconstruction of a fracture Dubberley type II

Each fracture type is additionally subclassified as A or B based on the presence of posterior condylar comminution.

9.2.2.3 Ring

Ring et al. [4] identified five articular segment injury patterns according to intraoperative findings:

Type 1: isolated capitellum fracture.

Type 2: extension into the lateral epicondyle.

Type 3: posterolateral column metaphyseal comminution.

Type 4: posterior trochlea comminution.

Type 5: extension to the medial epicondyle.

9.3 Surgical Technique

9.3.1 Patient Position

Patient positioning depends on the fracture type, surgical approach, and surgeon preference. The authors prefer the supine position with the arm placed over the body. Lateral, medial or olecranon osteotomy approaches are possible in this position.

Elbow stability should be tested under general anesthesia at the time of intervention.

9.3.2 Approach

9.3.2.1 Olecranon Osteotomy

Olecranon osteotomy may be indicated in isolated trochlear fractures, especially if trochlear comminution is present.

The incision is placed over the subcutaneous border of the ulna, curves slightly medial to the tip of the olecranon, and continues proximally centered on the posterior aspect of the arm. The ulnar nerve should be identified and protected during surgery. The triceps is elevated from the ulna using a periosteal elevator. The osteotomy is marked with electrocautery in a chevron shape with the tip distally. Two Hohman retractors are

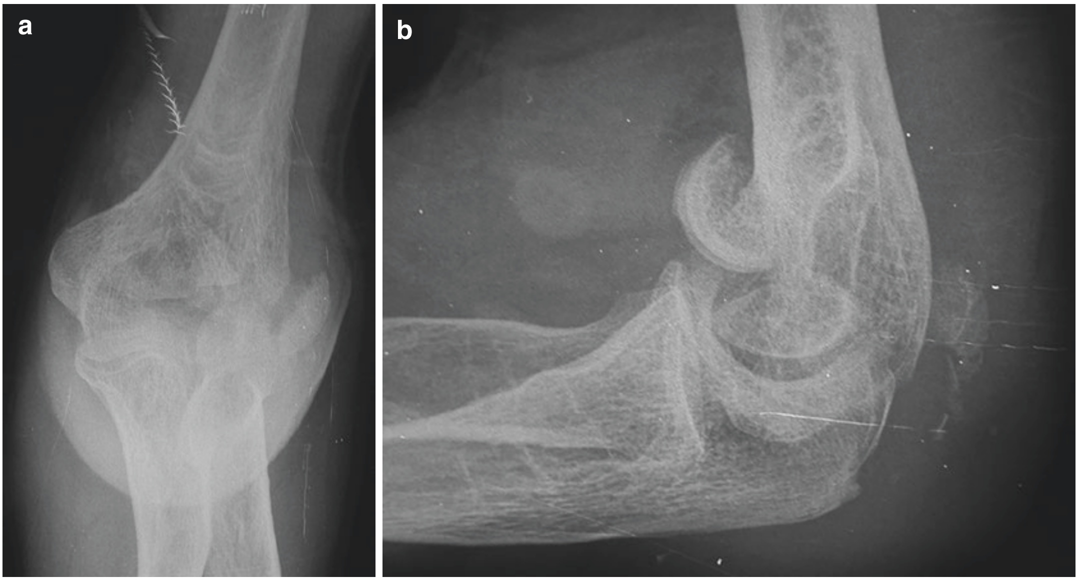

Fig. 9.2 AP (**a**) and lateral (**b**) view of a fracture Dubberley type III

placed medially and laterally to protect distal humerus cartilage. The osteotomy is initiated with a thin micro-sagittal saw and completed with an osteotome.

9.3.2.2 Lateral Extensile

Lateral extensile approach is preferred in fractures of the lateral trochlea associated with capitellum fractures. This exposure usually provides enough visualization of the lateral trochlear even in type 4 fractures. It also allows assessment of concomitant radial head or LUCL pathology. An incision is made over the anterior aspect of the lateral column and is extended distally to the Kocher interval. The forearm is pronated to move the radial nerve away, and the common origin of the wrist extensor and the anterior capsule are elevated. With the elbow flexed, a Hohman retractor is placed over the medial column to elevate the anterior capsule and brachialis. This approach may be extended proximally or distally.

The lateral collateral ligament is often included in a lateral fracture fragment of the capitellum. If intact, the LCL should be spared. Posterior blood supply to the capitellum and trochlea should be protected, avoiding posterior dissection of the epicondyle. In the case of posterior comminution, elevation of the lateral aspect of the triceps could be necessary. In these cases, the authors prefer to release the LCL from its origin on the epicondyle. The LCL is marked with a suture for later reinsertion. The lateral ligament is often attached to a fracture fragment, and this fragment can be released to access the joint and do the fixation of the medial joint. At the end of the procedure, this fragment is solidly fixed to the distal humerus.

9.3.2.3 Medial Based Approaches

In cases when the lateral extensile approach is not enough and compromises the access to the medial elbow, it may be necessary to perform a supplemental medial approach through a flexor–pronator split or elevation to aid in reduction and fixation of the fracture.

9.3.3 Fracture Fixation

Elbow flexion and forearm pronation help in maintaining fracture reduction while temporary fixation with K-wires is performed. There is no consensus on the optimal method of fixation. Large fragments with sufficient subchondral bone can be fixated using lag screws or headless screws. In vitro biomechanical testing has dem-

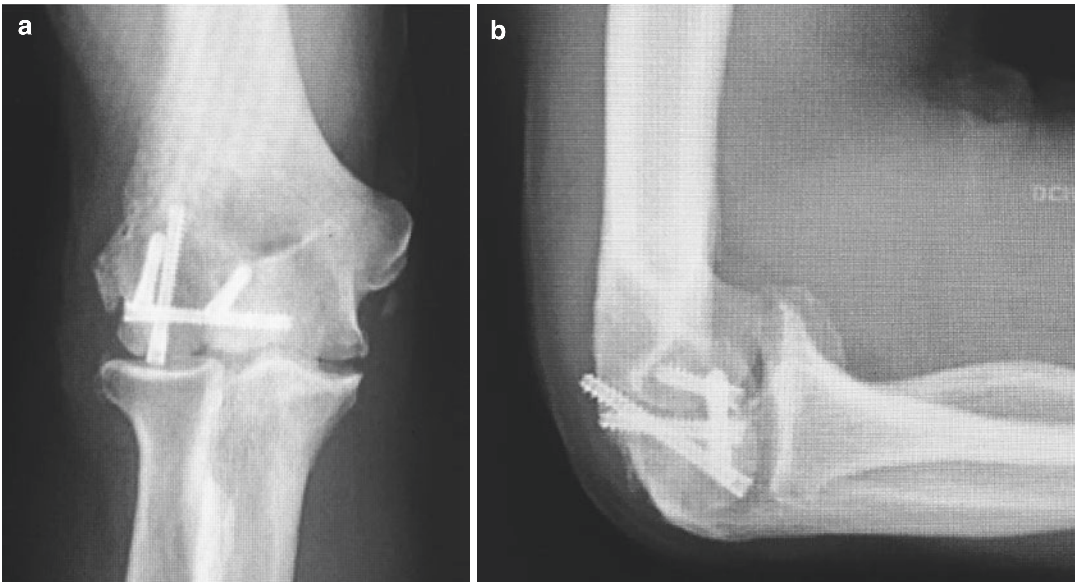

Fig. 9.3 AP (**a**) and lateral (**b**) view after open reduction and internal fixation

onstrated that headless compression screws directed from anterior to posterior are superior to cancellous screws [5]. When there is only a thin shell of subchondral bone, we believe anteroposterior headless screws is a better choice. In our practice, most fractures are fixed with headless cannulated screws introduced from anterior to posterior through the articular surface. Posterior to anterior fixation is favored when reduction and fixation are assisted with arthroscopy Fig. 9.3a, b.

> In cases of extensive posterior comminution, stable fixation often needs locking posterolateral plate fixation.
>
> Bone defects may result from comminution or impacted fracture fragments. These defects should be augmented with bone graft. When possible, the authors prefer to use autograft from the iliac crest, the olecranon, or synthetic bone graft substitute.

9.3.4 Closing

Final fracture reduction and stability should be evaluated clinically and radiographically before closure. Articular surface congruity should be evaluated throughout the full arc of motion from extension and pronation to supination, and finally back to neutral position. In cases of olecranon osteotomy, we favor a figure of eight fixation.

When the LCL was initially injured or had to be detached, it should be repaired before closure. In our practice, the LCL is reattached using a bone anchor placed slightly proximal to the isometric point in the epicondyle. Alternatively, suture through bone tunnels can be used for the repair. If the medial collateral ligament (MCL) is disrupted, the elbow should be examined for residual instability. In most cases, the elbow is stable, and the MCL does not require repair. If elbow instability is present, a MCL repair should be considered.

9.4 Arthroscopic-Assisted Reduction and Internal Fixation (AARIF)

AARIF of distal partial articular fractures of the distal elbow is an expanding indication in minimally invasive surgery. AARIF has the advantage of better visualization of associated lesions, accuracy in fracture reduction, less risk of devascular-

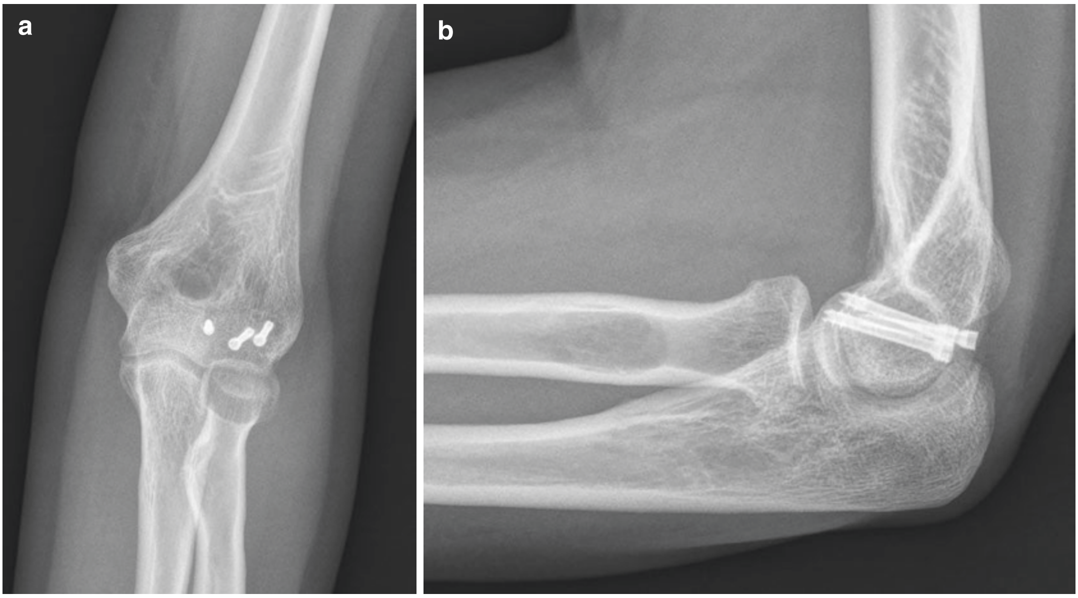

Fig. 9.4 AP (**a**) and lateral (**b**) view after arthroscopic-assisted reduction and internal fixation

ization of fragments, and avoidance of trauma to the elbow stabilizers.

AARIF indications are limited to simple coronal fractures or associated with a small lateral trochlear extension. Posterior comminution or significant bone loss cannot be treated with arthroscopy alone.

Technically, an anteromedial portal is used for visualization, and instruments are introduced through the anterolateral portal. Sometimes an accessory lateral portal can be used to elevate the anterior capsule for improved articular visualization.

Under fluoroscopy and direct visualization, K-wires and cannulated screws are introduced from posterior to anterior. A Freer elevator may help maintain reduction and protect from plunging with the K-wire into anterior structures Fig. 9.4a, b.

9.5 Postoperative Management

Controlled active motion is typically started after 1–2 weeks. In cases of ligament deficiency, ligament-specific rehabilitation is initiated. In an LCL-deficient elbow, rehabilitation is performed in pronation. However, in MCL-deficient elbows, supination stabilizes the elbow. In cases of LCL and MCL are deficient elbow flexion–extension is initiated in neutral forearm rotation. Forearm rotation is encouraged at 90° flexion. Arc of motion is progressed weekly, and unrestricted range of motion exercises are allowed at 6 weeks.

9.6 Results

Good to excellent outcomes have been reported for more than 90% of patients with ORIF when the fractures are isolated to the radiocapitellar compartment. Mild loss of flexion and extension may be expected, while pronosupination is commonly preserved [3, 4, 6, 7]. Fractures with significant medial extension, comminution, or bone loss fare worse.

9.7 Complications

The most common complication after a trochlear fracture is stiffness. Other complications are rare and include post-traumatic arthritis, nonunion, heterotopic bone formation, avascular necrosis, ulnar neuritis, infection, and failure of fixation. Functionally limiting stiffness requiring an operative intervention was reported in 21–29% [3, 4] of patients. Most patients, however, achieved a functional arc of motion through nonoperative treatment. In cases of limiting stiffness, contracture releases have demonstrated good results in these fractures.

Most of these fractures heal if the fixation is appropriate, with reported healing rate from 73 to 100%. Most of nonunions are found in Dubberley 3B fractures. Probably, posterior comminution compromises blood supply which is further jeopardized by extended approaches and complex fixation methods that compromise the local biology of the fracture [8].

Several studies have reported formation of heterotopic bone following ORIF, especially in fractures involving the lateral epicondyle. However, functional limitation caused by heterotopic ossification is commonly minimal and does not require further treatment.

9.8 Questions

1. Which of the following in considered the most common complication following ORIF of trochlear fractures?
   (a) Heterotopic ossification.
   (b) Avascular necrosis.
   (c) Stiffness.
   (d) Nonunion.
   (e) Infection.
2. A fracture of the capitellum and the trochlea in a single fragment can be classified as:
   (a) Dubberley I.
   (b) Dubberley II.
   (c) Dubberley III.
   (d) Bryan and Morrey I.
   (e) Bryan and Morrey II.
3. When is arthroscopic-assisted reduction and internal fixation (AARIF) of trochlear fractures most recommended?
   (a) Posterior comminution.
   (b) Lateral collateral ligament rupture.
   (c) Capitellum fractures associated with simple trochlear fractures.
   (d) Medial epicondyle fractures.
   (e) Trochlear comminution.
4. Which of the following internal fixation is recommended in cases of posterior comminution
   (a) Posterior plate fixation.
   (b) Anterior to posterior headless screws.
   (c) Posterior to anterior lag screws.
   (d) Parallel distal humerus plates.
   (e) Posterior to anterior headless screws.

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10 Open Reduction Internal Fixation (ORIF) for Coronoid Fractures

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Key Points

- Coronoid fractures occur in complex elbow injuries involving other fractures of the proximal radius and ulna and ligamentous disruptions that include terrible triad, traumatic varus posteromedial rotatory injury, transolecranon fracture-dislocation, and Monteggia fracture-dislocation.
- Coronoid fractures may be classified using the O'Driscoll classification system, which accounts for a spectrum of coronoid fractures seen with complex injury patterns including tip fractures, anteromedial fractures, and basal fractures of the coronoid.
- Exposures (including medial and lateral approaches to the elbow), reduction methods and fixation modalities (including fixation by suture lasso, screws, and plate and screw constructs) are determined by fracture pattern and concomitant injuries in the elbow that require surgical intervention.

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10.1 Injury Patterns and Fracture Classification

Coronoid fractures commonly occur in the context of complex elbow injuries involving other fractures of the proximal radius and ulna and/or ligamentous disruptions on the lateral and medial aspect of the elbow. The position of the elbow and the direction of force contributes to the injury pattern. There is evidence that a valgus posterolateral rotatory force on the elbow results in sequential injury to the lateral ulnar collateral ligament (LUCL) of the lateral collateral ligament (LCL) complex, radial head, coronoid, and anterior bundle of the medial collateral ligament (MCL) [1, 2]. Patients with this injury pattern often present with a terrible triad that includes an elbow dislocation, radial head fracture, and coronoid tip fracture. A varus posteromedial rotatory force can result in LCL injury and anteromedial coronoid fracture, while sparing the radial head [2]. An axial load to the dorsal aspect of forearm, particularly with the elbow in flexion, can produce a transolecranon fracture-dislocation and concomitant basal coronoid fracture [3]. Collateral ligament integrity is generally preserved in anterior olecranon fracture-dislocations, while the LCL is often avulsed in posterior injuries [2, 3]. Rotation around a fixed hand and axial loading of the forearm can result in a posterior Monteggia fracture-dislocation, which involves a proximal ulna fracture and proximal radioulnar

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joint disruption [3]. This injury pattern is commonly associated with coronoid fractures of varying size, radial head fractures, and ligamentous injuries [3, 4].

Coronoid fractures were historically classified based on fragment size on the lateral radiograph of the elbow using the system of Regan and Morrey [5, 6]. The O'Driscoll classification system accounts for a broader spectrum of coronoid fractures seen with complex injury patterns including tip fractures, anteromedial fractures, and basal fractures of the coronoid [2]. Monteggia fracture-dislocations are classified using the Bado classification system, while posterior injury patterns (Bado Type II), some of which contain a coronoid fracture, are found within the Jupiter classification system [3, 7, 8].

10.2 Surgical Indications

Coronoid tip fractures that occur without associated fractures of the proximal radius and ulna may be treated nonoperatively in elbows that have a concentric joint space on imaging and are stable with motion. The indications for surgical management of coronoid fractures hinge on the location and size of the fragment and on the relative contribution of this fracture to elbow stability. In the context of complex elbow fracture-dislocations, ORIF of coronoid fractures is one step in the algorithm of restoring elbow stability. Terrible triad injuries are commonly unstable and warrant surgical intervention [9]. However, nonoperative management can be considered for terrible triad injuries with relatively small coronoid fractures present in the context of a concentric elbow joints on imaging, radial head fractures that do not cause a mechanical block to rotation, and elbows with a stable arc of motion demonstrated with extension to 30° before becoming unstable [1, 10]. Anteromedial coronoid fractures are treated surgically unless the coronoid fracture is noted to be small and minimally displaced, and there is no evidence of elbow joint subluxation [11]. Transolecranon fracture-dislocations and Monteggia fracture-dislocations generally require surgical management [3, 4, 12–14]. Although treatment algorithms guide management, decisions require consideration of medical comorbidities and other injuries in the context of polytrauma.

10.3 Preoperative Considerations

A thorough examination of the injured extremity is required with careful attention taken to identify skin compromise and neurovascular injury. Ulnohumeral and radiocapitellar dislocations warrant closed reduction. The elbow should be splinted to maintain joint reduction and optimize fracture position. Anteroposterior (AP) and lateral radiographs of the elbow are obtained. Advanced imaging of the elbow with computed tomography (CT) is recommended to understand coronoid fracture morphology, assess joint congruence, and characterize other fractures of the proximal radius and ulna. Capability for post CT multiplanar reconstruction is helpful as standard axial cuts provide oblique slices through a flexed elbow.

10.4 Positioning and Anesthesia

General anesthesia with endotracheal intubation and ventilation or regional anesthesia delivered proximal to the elbow at the level of the brachial plexus with concomitant sedation are options for anesthesia. The patient is placed supine on an operating table and a radiolucent hand table is placed on the side of the table to support the injured extremity during treatment of tip and anteromedial fractures of the coronoid. For injury patterns in which there is an associated olecranon fracture, such as a transolecranon fracture-dislocation or Monteggia fracture-dislocation, the patient is placed in the lateral decubitus position with the injured elbow resting over a padded post or bolster. A non-sterile tourniquet is placed on the proximal arm. The involved upper extremity is prepared and draped in a sterile fashion with the upper extremity free to allow for manipulation during the case. A sterile bump created from folded towels is placed under the arm to optimize position of the extremity above the level of the table during the exposure in the supine position. A C-arm is used to provide fluoroscopic imaging throughout the procedure.

10.5 Exposures

Lateral approaches to the coronoid include the following: (1) extensor digitorum communis (EDC) splitting approach, (2) Kocher approach between anconeus and extensor carpi ulnaris, (3) Kaplan approach between EDC and extensor carpi radialis longus/brevis (ECRL/ECRB), and (4) available interval approach in which a traumatic interval created at the time of elbow injury is utilized for exposure during surgery [15–17]. Medial approaches to the coronoid include the following: (1) FCU-splitting approach, (2) Hotchkiss over-the-top approach between flexor carpi ulnaris (FCU) and palmaris longus/flexor carpi radialis (FCR) with brachialis reflected laterally with palmaris longus, FCR and pronator teres, and (3) Taylor–Scham approach between the ulna and FCU [15–17]. A coronoid fracture is exposed through lateral or medial approaches to the elbow depending on the location and pattern of coronoid fracture and other bony and ligamentous injuries that require surgical intervention. Finally, a coronoid fracture can be approached posteriorly through a concomitant olecranon fracture [3, 4].

10.5.1 Coronoid Tip Fracture

A coronoid tip fracture is commonly exposed through a lateral approach to the elbow. If a traumatic interval has been created at the time of injury, it can be utilized. Kocher, EDC-splitting and Kaplan intervals are options, although the injury pattern should be considered when selecting an approach given that each provides varying access to lateral sided structures of the elbow. The Kocher approach provides superior access to supinator crest, lateral epicondyle, and LUCL, and may be more appropriate if an LCL repair is required. The Kaplan approach provides more direct exposure of the coronoid, and the EDC-splitting approach provides a compromise between these other exposures. In the context of a terrible triad injury, the coronoid is exposed just anterior to the radial head fracture or through the fracture site via an EDC-splitting or Kocher approach. Exposure is improved if the radial head is excised with the plan for radial head replacement. If adequate exposure is not attained through a lateral approach, a Hotchkiss approach is used to expose a coronoid tip fracture from the medial side of the elbow [1].

10.5.2 Anteromedial Coronoid Fracture

An FCU-splitting approach is utilized to access an anteromedial coronoid fracture.

10.5.3 Basal Coronoid Fracture

A basal coronoid fracture is exposed through a Taylor–Scham approach. In the context of a transolecranon fracture-dislocation or Monteggia fracture-dislocation, the coronoid can be exposed through the olecranon fracture.

10.6 Fixation Methods

Fracture fixation method is dependent on fracture morphology, fragment size, and location.

10.6.1 Coronoid Tip Fracture

The suture lasso technique is utilized particularly in the context of a small coronoid tip fragment that is not large enough for screw fixation or for comminuted fragments, although this technique may also be employed for, or as adjunct to other internal fixation for, fixation of larger coronoid tip fragments. Suture is used to capture the anterior capsule adjacent to the coronoid fracture fragments and passed through bone tunnels and tied over a bridge on the dorsal aspect of the ulna

(Fig. 10.1, lower panels). Larger coronoid tip fragments can be fixed to the ulna through volar-to-dorsal (antegrade) or dorsal-to-volar (retrograde) mini-fragment screw fixation.

10.6.2 Anteromedial Coronoid Fracture

An anteromedial coronoid fracture is treated with anatomic reduction and rigid fixation using a mini-fragment buttress plate (Fig. 10.2, lower panels).

10.6.3 Basal Coronoid Fracture

A basal coronoid fracture is treated with anatomic reduction and rigid fixation using a mini-fragment plate. In the context of transolecranon fracture-dislocations, dorsal-to-volar interfragmentary screws can be used to capture the coro-

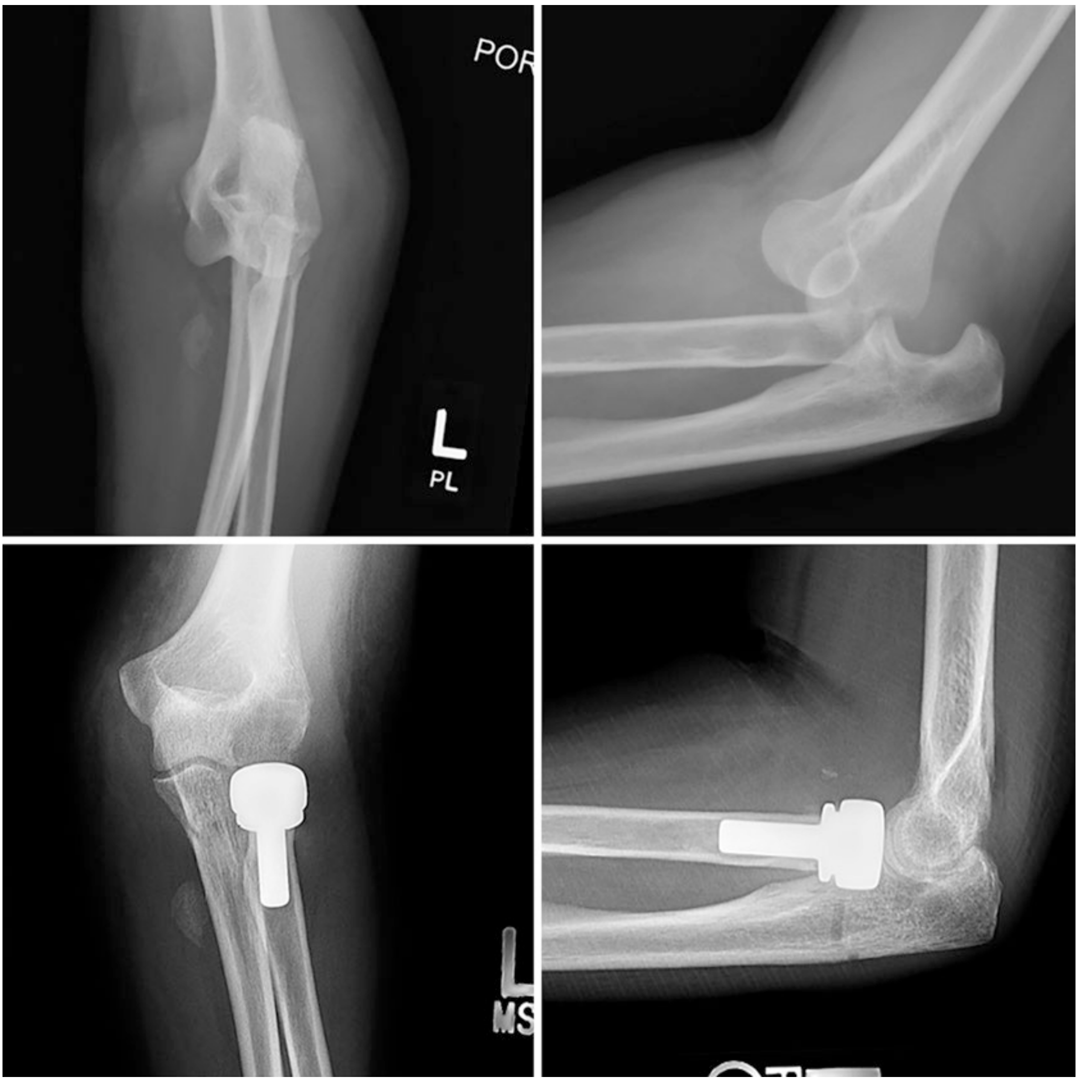

Fig. 10.1 Terrible triad injury. Preoperative radiographs demonstrate a posterior elbow dislocation, radial head fracture, and coronoid tip fracture (top). Surgical treatment involved radial head replacement, suture fixation of the coronoid tip fracture and anterior capsule through bone tunnels in the proximal ulna, and lateral collateral ligamentous complex repair using suture anchors (bottom)

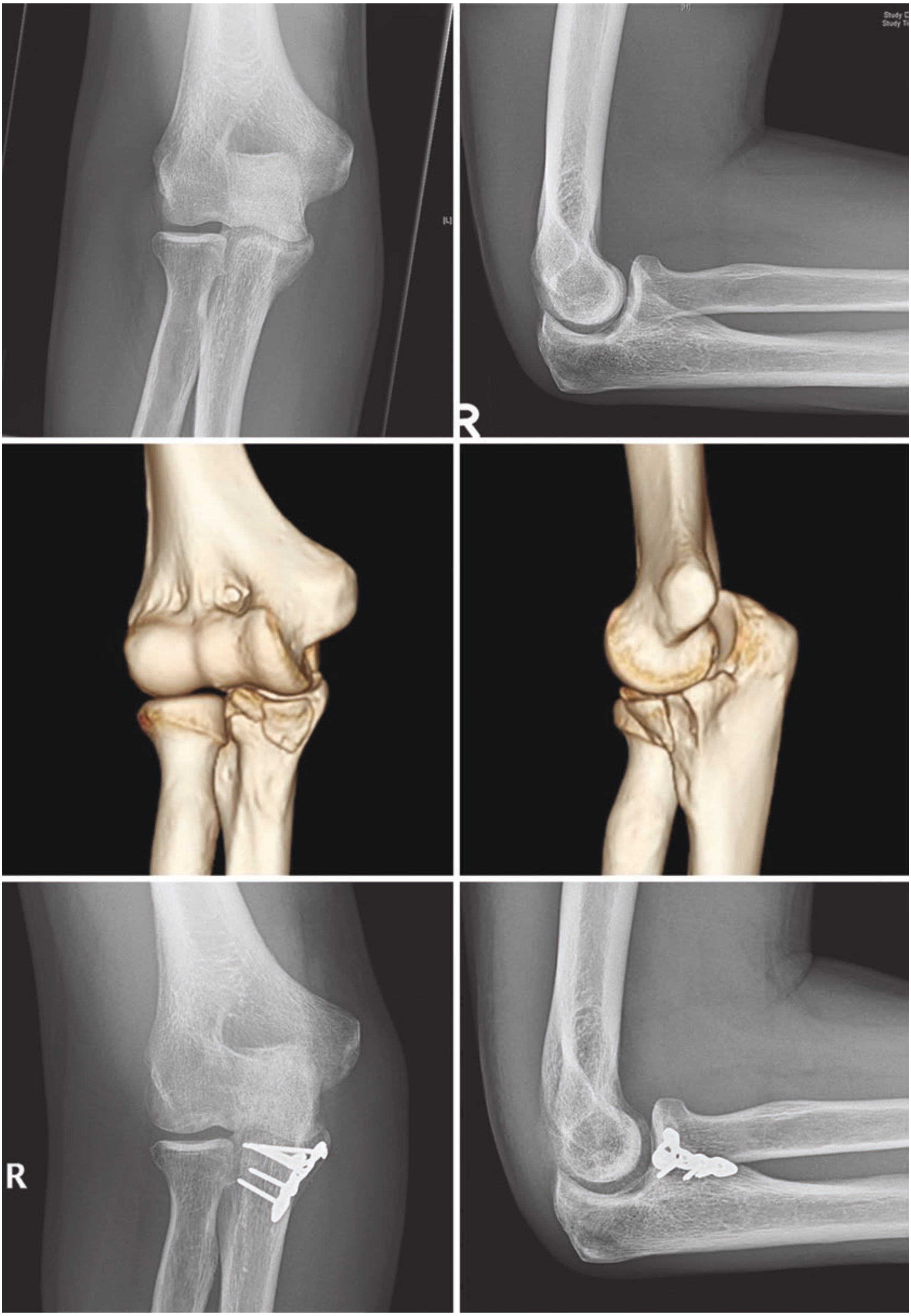

Fig. 10.2 Anteromedial coronoid fracture. Preoperative radiographs demonstrate an anteromedial coronoid fracture (top). Surgical treatment involved ORIF of the anteromedial coronoid fracture using a 2.7-mm buttress plate (bottom)

Fig. 10.3 Transolecranon fracture-dislocation. Preoperative radiographs demonstrate transolecranon injury with coronoid fracture (top). Surgical treatment involved ORIF of several proximal ulna fragments using 2.4-mm reconstruction plate and 2.7/3.5-mm olecranon plate (bottom). Dorsal-to-volar interfragmentary screws were used to capture the coronoid fragment

noid fragment either independently or through a small- or mini-fragment plate on the dorsal aspect of the olecranon (Fig. 10.3, lower panels).

10.7 Structures at Risk

The ulnar nerve is at risk during medial exposures to the coronoid. This nerve should be isolated and protected prior to developing intervals used in FCU-splitting and Hotchkiss approaches. The posterior interosseous nerve is at risk during lateral exposures to the coronoid fractures. The forearm is pronated to protect this nerve during deep exposure, fracture reduction, and fixation of coronoid and radial head fractures. The median nerve and brachial artery are at risk during the Hotchkiss approach. Subperiosteal dissection is performed deep to brachialis to protect these structures.

10.8 Key Procedure Steps

10.8.1 Coronoid Tip Fracture ORIF in Terrible Triad Injuries

A curvilinear incision centered over the radio-capitellar joint is made on the lateral aspect of the elbow. A rent in the fascia and underlying extensors related to the initial trauma is identified and extended to gain access to the radial head and coronoid. If this soft tissue defect is not present, the EDC is split longitudinally. Fractures of the radial head and coronoid are identified and characterized. The sequence of coronoid fixation, relative to other steps used to manage the radial head, are important technical subtleties.

Before definitive management (ORIF or arthroplasty) of the radial head, preparations, but not definitive stabilization, are made for coronoid fixation. For small or comminuted coronoid tip fractures, suture repair is performed. Suture (size #2, non-absorbable, e.g., Ethibond or Fiberwire) is passed through the coalescence of the brachialis tendon and anterior capsule as it attaches to the coronoid fracture fragment. Care is taken not to anchor the suture too distal or too anterior as this can over tension the anterior capsule and make restoration of extension difficult. A small incision is made over the dorsal aspect of the proximal ulna for drill holes. Using a 2.5 mm in diameter drill, two holes are made from dorsal into the coronoid fracture bed to serve as tunnels for the previously placed sutures (Fig. 10.1, lower panels). A targeted drill guide, such as that used to drill the tibial tunnel during anterior cruciate ligament reconstruction surgery, may be used for this step [1]. Each limb of the suture is passed using a suture passer. The sutures are tied over a bridge on the dorsal aspect of the ulna after definitive fixation of the radial head. Deferring final tying of the coronoid sutures allows manipulation of the radiocapitellar joint without risk of disrupting the coronoid fixation. If the coronoid tip fracture is large enough to be amenable to screw fixation, the fragment is reduced to the ulna and provisionally fixed with a Kirschner wire (K-wire) or pointed reduction clamp. A mini-fragment (2.0–2.7 mm) screw is inserted from the dorsal aspect of the ulna into the fragment under fluoroscopic guidance. Treatment of the radial head fracture and any associated LCL injury is then performed (Fig. 10.1, lower panels). The coronoid sutures are then definitively tied. Elbow stability is then assessed. If the elbow is unstable, repair of the MCL complex is considered and the previous fixation revised if necessary.

10.8.2 Anteromedial Coronoid Fracture ORIF

An incision is made over the posteromedial aspect of the elbow. Subcutaneous dissection is performed, and the ulnar nerve is identified proximally, dissected from proximal to distal, and protected throughout the case. The two heads of the FCU are identified, split, and retracted. The coronoid process is exposed. The anterior band of the MCL, which may be attached to the anteromedial fracture fragment, is protected. Hematoma is evacuated and fracture edges are debrided. Reduction is performed using joysticks and pointed reduction clamps. K-wires are inserted for provisional fixation. A mini-fragment straight or T plate is contoured and inserted to serve as a buttress plate with lag screws across the fracture (Fig. 10.2, lower panels). Elbow stability is assessed. If the elbow is noted to be unstable, an LCL repair is performed through a Kocher approach on the lateral side of the elbow.

10.8.3 Basal Coronoid Fracture ORIF in Transolecranon Fracture-Dislocations

A posterior skin incision and approach to the olecranon are used to expose the olecranon fracture. The basal coronoid fracture fragment is visualized and manipulated through the olecranon fracture site, and provisional fixation is performed with 1.6-mm K-wires. For improved exposure, a Taylor–Scham approach is used [18]. The ulnar nerve is dissected and protected, and the interval between the flexor–pronator mass and medial aspect of the ulna is developed. The FCU is retracted anteriorly and the MCL is preserved. The basal coronoid fracture is identified. Hematoma is evacuated and fracture edges are debrided. The fracture is anatomically reduced and held with a pointed reduction clamp. A mini-fragment (typically 2.7 mm) reconstruction plate is contoured and applied to provide fragment-specific fixation of the basal coronoid fracture [18]. The olecranon fracture is then reduced with a pointed reduction clamp and fixation is provided with a mini-fragment (2.7 mm) plate contoured to the olecranon or a small-fragment (3.5 mm) olecranon-specific plate. Dorsal-to-volar interfragmentary screws may be used to capture the coronoid fragment either independently or through the posterior plate (Fig. 10.3, lower panels).

10.8.4 Coronoid Fracture ORIF in Monteggia Fracture-Dislocations

A posterior skin incision and approach to the proximal ulna are used. The fractured olecranon is reflected to expose the radial head and coronoid, and the Taylor–Scham interval is used to improve exposure of the medial coronoid. If a proximal radius fracture is present, ORIF or radial head replacement is performed. If radial head replacement is required, the coronoid and ulnar shaft fractures are temporarily reduced and held with provision fixation to allow for arthroplasty component sizing, and redisplaced for implantation [4]. The ulnar shaft fracture and commonly present anterior oblique proximal ulnar fragment, which can contain the base of the coronoid, are anatomically reduced and fixed using lag screws and mini-fragment (typically 2.7 mm) reconstruction plates [4]. The coronoid fracture is then reduced and fixation is provided through suture fixation, multiple mini-fragment (2.0–2.7 mm) screws inserted from the dorsal aspect of the ulna into the fragment, or a mini-fragment (2.4–2.7 mm) plate depending on the fragment size and comminution (Fig. 10.4, lower panels). If suture fixation is required, sutures may be passed prior to insertion of the prosthetic radial head. The olecranon fracture is then reduced with a pointed reduction clamp, and a small-fragment (3.5 mm) compression plate or olecranon-specific plate is placed to provide fixation of the olecranon fracture and ulnar shaft fracture. Dorsal-to-volar interfragmentary screws may be used to capture the coronoid fragment (Fig. 10.4, lower panels).

10.9 Knowledge Testing Questions

1. A terrible triad injury of the elbow commonly involves which of the following components?
   (a) Radial head fracture, coronoid anteromedial facet fracture, and LCL injury.
   (b) Ulnohumeral dislocation, radial head fracture, and coronoid fracture.
   (c) Ulnohumeral dislocation, olecranon fracture, and basal coronoid fracture.
   (d) Ulnar shaft fracture, radial head fracture, and anterior oblique fragment containing the base of the coronoid.
   (e) Ulnohumeral dislocation, radial head fracture, and MCL injury.
2. A fracture of the anteromedial facet of the coronoid is commonly exposed through which approach?
   (a) Kocher approach.
   (b) Hotchkiss approach.
   (c) FCU-splitting approach.
   (d) Taylor–Scham approach.
   (e) Boyd approach.
3. Which of the following fixation constructs are used to treat a basal coronoid fracture?
   (a) Suture lasso.
   (b) Mini-fragment plate fixation.
   (c) Dorsal-to-volar interfragmentary screws through a dorsal plate on the olecranon.
   (d) All of the above.
   (e) b and c only.

Answers to Knowledge Testing Questions

1. b.
2. c.
3. e.

Fig. 10.4 Monteggia fracture-dislocation. Preoperative radiographs demonstrate Monteggia injury with proximal radius fracture and proximal ulna fracture with coronoid involvement (top). Surgical treatment involved radial head replacement, ORIF of the medial proximal ulna using a 2.4-mm reconstruction plate and 2.0-mm lag screw, ORIF of the lateral proximal ulna using a 2.0-mm reconstruction plate, and placement of a 2.7/3.5-mm olecranon plate on the dorsal aspect of the proximal ulna (bottom)

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11 External Fixation of the Elbow

Michael DiBenedetto, Joshua A. Baumfeld, and Eric T. Tolo

11.1 Introduction

External fixation of the elbow is commonly thought of as a "last resort" for elbow stability. In truth, elbow external fixation has a wide variety of indications from distraction arthroplasty to protection of ligamentous repair and contracture release. The use of hinged external fixators allows elbow motion while maintaining stability. While the application of static external fixation is relatively simple, hinged external fixation requires technical precision to avoid changing elbow biomechanics. While hinged external fixation is still the most commonly used spanning fixation of the elbow, recent data on static external fixation and the advent of internal fixation devices have decreased its use.

External fixation was first described in the nineteenth century, and has been in use for fixation of upper arm and forearm fractures since the early twentieth century [1]. Spanning fixation of the elbow at that time was primarily accomplished through the use of trans-articular pinning and static external fixation. Hinged fixation was first described in the Russian literature, with the first English language article published in 1975 [1]. Between the 1980s and 2000 multiple external fixation designs were developed [2–13]. All of these designs simplify the biomechanics of the elbow to a simple hinge and require accurate placement of the hinge along the plane of the biomechanical axis of the elbow. The initial devices were large and bulky, however, more recent designs have been lower profile and have incorporated features such as the ability to adjust compression/distraction (Fig. 11.1).

11.2 Biomechanics

The elbow is commonly referred to as a hinge joint [14–20]. While, the elbow is not a perfect hinge, a relatively tight locus of points with a dimension of less than 5 mm comprise the center of rotation of the joint [16, 17, 20]. The ulnohumeral joint primarily moves in the flexion–extension plane, due to a high degree of articular congruency and ligamento-capsular constraint. However, in instances where the articular or soft-tissue constraints are lost, the ulnohumeral articulation can experience three major rotatory degrees of freedom: flexion–extension, abduction–adduction, and axial rotation. In these cases, reconstruction of the injured structures is preferred, often in conjunction with some sort of protection of the repair, such as bracing or cast immobilization [11, 21, 22].

Due to the inherent slight laxity of the ulnohumeral joint, any off axis placement of a rigid, hinged device can decrease range of motion and

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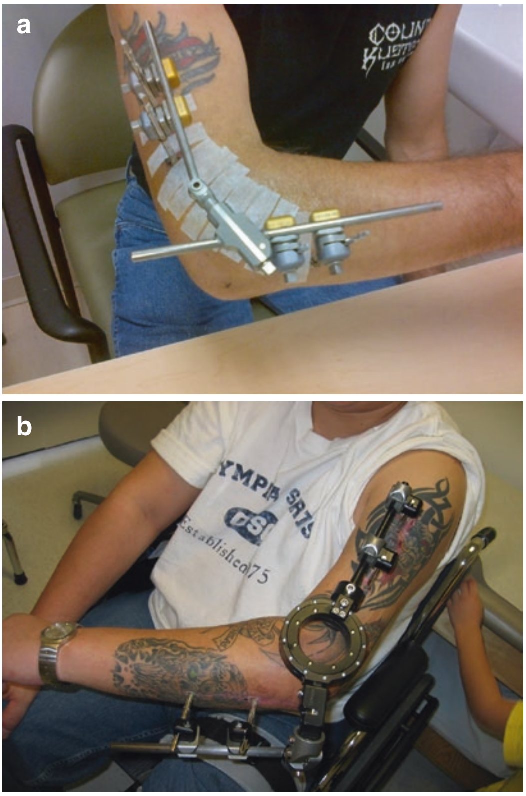

Fig. 11.1 Examples of external fixation devices. (**a**) Stryker DJD 2 (Kalamazoo, MI). (**b**) EBI OptiROM (Parsippany, NJ)

increase the energy required to move the forearm through the abbreviated range of motion when compared to an optimally placed device [23]. Thus, to best replicate the kinematics of the normal elbow joint, the hinges of dynamic devices should be placed at the anatomic center of rotation [23]. This locus has been defined as passing through the center of the capitellum laterally, at the tubercle of the lateral collateral ligament origin, and through the center of the trochlea, emerging at a point at the antero-inferior aspect of the medial epicondyle [7, 17, 20].

11.3 Indications

Generally speaking, external fixation of the elbow is indicated when repair or fixation of bony and ligamentous structures fails to maintain elbow stability or when internal elbow stabilization is not feasible. External fixators can also be used in reconstructive cases where joint distraction is required such as simple distraction arthroplasty or distraction-interposition arthroplasty.

The most common indication for spanning humeral external fixation is acute trauma. In traumatic cases an external fixator can function as a temporary device before definitive fixation or as an adjunct for persistent instability after fracture fixation is performed [24–30]. Some fracture and fracture-dislocation patterns such as proximal radioulnar fractures, coronoid fractures, and the so called "terrible triad" fracture-dislocation can create significant instability which, sometimes, cannot be cured with internal fixation and soft tissue repair.

Additionally, when managing elbow instability in acute trauma there are situations where immediate internal fixation is not ideal. These situations usually involve significant soft tissue trauma or vascular compromise. Gunshot wounds and high energy motor vehicle collisions can cause significant open fractures which cannot be closed primarily. Often these cases will require serial debridement prior to definitive fixation and coverage. In delayed presentations, closed soft tissue injury and swelling may prevent definitive fixation. In these instances, static external fixation provides a rigid form of elbow stabilization and allows for easy access to the wound.

Surgeon, patient, and environmental factors are also important when making the decision between temporary spanning external fixation and internal fixation. A surgeon in the community may not have experienced staff, adequate equipment, or the technical expertise required to perform immediate definitive management. In addition, patient factors such as neurologic trauma, cardiopulmonary trauma, or hemodynamic instability can limit the operative time available for initial treatment. In polytrauma there are frequently injuries to other extremities that may take precedence over the elbow. In military or disaster medicine, time spent treating an unstable elbow may be limited. In these situations, a temporary external fixator may be appropriate. With an understanding of external fixation principles, static external fixation is technically simple to apply and can be performed within minutes whereas internal fixation of these fractures is often difficult, requiring hours.

Splinting is a viable alternative to external fixation in the above emergency situations. However, splints provide less rigid fixation and can be difficult to manage in an intensive care setting. Splints do not allow access to traumatic wounds and can be a challenge for wound care. In addition, the skin must be monitored as fluid shifts are common in critical care patients and can lead to skin breakdown or compartment syndrome. Because wounds can be easily missed underneath compressive bandages, splints should be changed frequently. This can be difficult for healthcare providers and cause significant pain. During splint changes, unstable fractures also risk interval displacement. Treating surgeons should be aware of the nature and frequency of complications from both splinting and external fixation.

External fixation can also be used as an adjunctive treatment in unstable fractures and dislocations [2, 5, 8–12, 24–38]. In fractures of the distal humerus anatomic restoration of ligamentous structures may not be possible, leading to residual instability. External fixation can be used to increase construct stability or protect intraoperative ligamentous repair. Cobb and Morrey showed excellent results using an external fixator as an adjunctive treatment for unstable coronoid fractures [11]. Multiple studies have demonstrated successful use of a hinged Ilizarov fixator or hybrid fixator for open contaminated fractures of the distal humerus [4, 39, 40]. In a multicenter prospective case series, elbow external fixation, when used as an adjunctive treatment in for traumatic instability, led to improvement in patient-reported outcomes. Flexion/extension improved 63° and pronation/supination arc improved 75° [38]. When treating complex elbow dislocations, the surgeon must make a careful intraoperative assessment of elbow stability and determine if an external fixator is needed or whether modified postoperative rehabilitation protocols and bracing are sufficient. When treating complex fractures and dislocations, an external fixator should be available.

Patients with missed or neglected dislocations often require extensive soft tissue dissection for anatomic reduction leading to persistent instability. For these patients, external fixation is a useful adjunct. Recurrent instability can also be missed after treatment for simple or complex acute dislocations (Fig. 11.2). The chronically dislocated elbow can develop severe contractures with significant deformity and bony remodeling. Open reduction of these injuries can be challenging, often requiring division of the collateral ligaments and extensive contracture release. This will frequently lead to secondary instability which can be treated with external fixation. Distraction can be utilized to maintain the reduction and offload the joint. Rao et al. retrospectively evaluated 20 patients treated with static external fixation for chronic instability [41]. They reported excellent results with regard to range of motion, however, 40% underwent unplanned reoperation. Jupiter and Ring reported results of hinged external fixation in 5 patients [42]. All had good or excellent results. In a retrospective study of patients with persistent instability after elbow fracture-dislocation, AlQahtani et al. found no difference in range of motion, complications, and revision surgery between patients treated with static vs. dynamic external fixation [43]. Alternatives to external fixation include transarticular pinning [44].

Contracture release of the elbow requires a careful elevation of the soft tissues and debridement of bone to obtain motion. Collateral ligaments must sometimes be partially or completely released, causing iatrogenic instability. Hinged external fixation devices have been used in this context with success in achieving post-operative motion without sacrificing stability [33, 45–47]. Ring et al. retrospectively analyzed 23 patients who underwent contracture release with application of hinged external fixator with distraction and compared these patients with those who did not receive external fixation [46]. Small improvements in motion were not significant and did not justify increased complications seen with use of external fixation. In another retrospective review, patients with severe contractures treated with contracture release and hinged external fixation

Fig. 11.2 Patient treated with external fixation for persistent traumatic instability. Anteroposterior (**a**) and lateral (**b**) view of a complex fracture dislocation. The patient underwent open reduction and internal fixation. Postoperative anteroposterior (**c**), lateral (**d**), and sagittal plane CT (**e**) show persistent instability due to failure of the anteromedial facet of the coronoid. The patient was treated with open reduction and hinged external fixator (**f**) placement. The patient healed uneventfully and regained functional range of motion and strength

improved significantly in arc of motion and Mayo elbow score [47]. Because of the high rate of complications of external fixation and the lack of data showing improvement with distraction, the authors recommend against routine use in contracture cases. The use of external fixation for this indication should only be limited to those patients with instability after contracture release.

Distraction arthroplasty with or without interposition has been used to treat patients with moderate to severe osteoarthritis and motion loss who are not candidates for total elbow replacement. Interposition arthroplasty utilizes a biologic interposition to resurface the joint. Distraction was added to interposition arthroplasty to reduce forces on the interposed tissue and add stability as the approach for this procedure usually involves release of the lateral ulnar collateral ligament. In addition it reduces theoretically reduces shear forces and permits motion [11, 48, 49].

11.4 Surgical Technique/Tips

The patient is usually placed in the supine position. There may be lateral, medial, or posterior incisions which depends on the pathology being addressed (fracture-dislocation, ligamentous instability, excision of heterotopic ossification, or contracture release). While historically multiplanar external fixators have been used successfully, unilateral/lateral-based external fixators are most commonly used today. The lateral humerus half pins can be placed percutaneously, however, the authors do not recommend this approach due to the proximity of the radial nerve. In a cadaver study, Kamineni described the location of the radial nerve crosses the lateral humeral metadiaphysis as a ratio of the transepicondylar distance [50]. The radio is measured by first determining the transepicondylar distance then multiplying by 1.4. This equals the minimal distance the radial nerve sits proximal to the lateral epicondyle along the lateral humeral cortex (Fig. 11.3). For example, if the transepicondylar distance is 7.0 cm, 1.4 × 7.0 cm = 9.8 cm. The radial nerve will be located approximately 9.8 cm proximal to the lateral epicondyle on the lateral humerus. Even if the surgeon stays distal to this region but places the humeral half-pins percutaneously, it is still possible to entrap the adjacent soft-tissue and possibly injure the radial nerve. All half-pins should be placed with bicortical purchase to provide adequate stability.

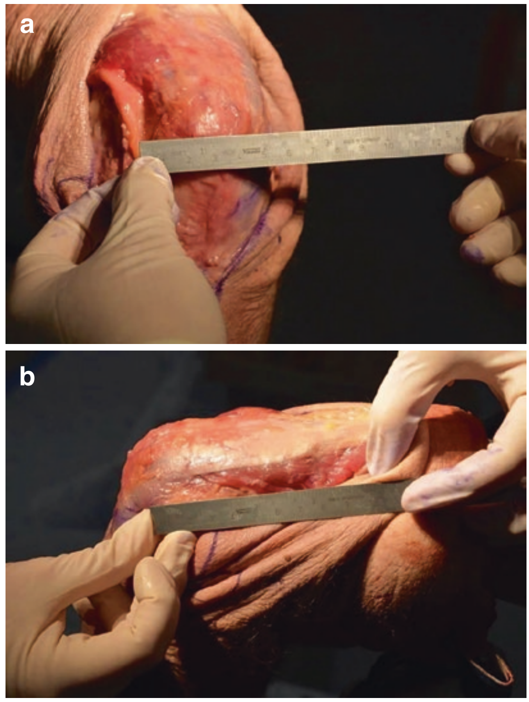

Fig. 11.3 Technique for measurement of the lateral safe zone for pine placement. (**a**) Measurement of the transepicondylar distance. (**b**) The transepicondylar distance is multiplied by 1.4 and this distance from the lateral epicondyle is marked. Pin placement proximal to the mark puts the radial nerve at risk

For dynamic or hinged external fixation the surgeon must identify the anatomic axis of the elbow. There are a number of methods than can be used. If using a “free-hand” technique it is imperative to obtain a true lateral radiograph of the elbow to where a concentric circle represents the lateral epicondyle. The elbow axis of rotation can be represented by a line drawn perpendicular to the center of that circle in the medial/lateral plane (Fig. 11.4a). The center of the circle also approximates the origin of the lateral ulnar collateral ligament. A 2–3 mm guide wire is advanced through the distal humerus, parallel to

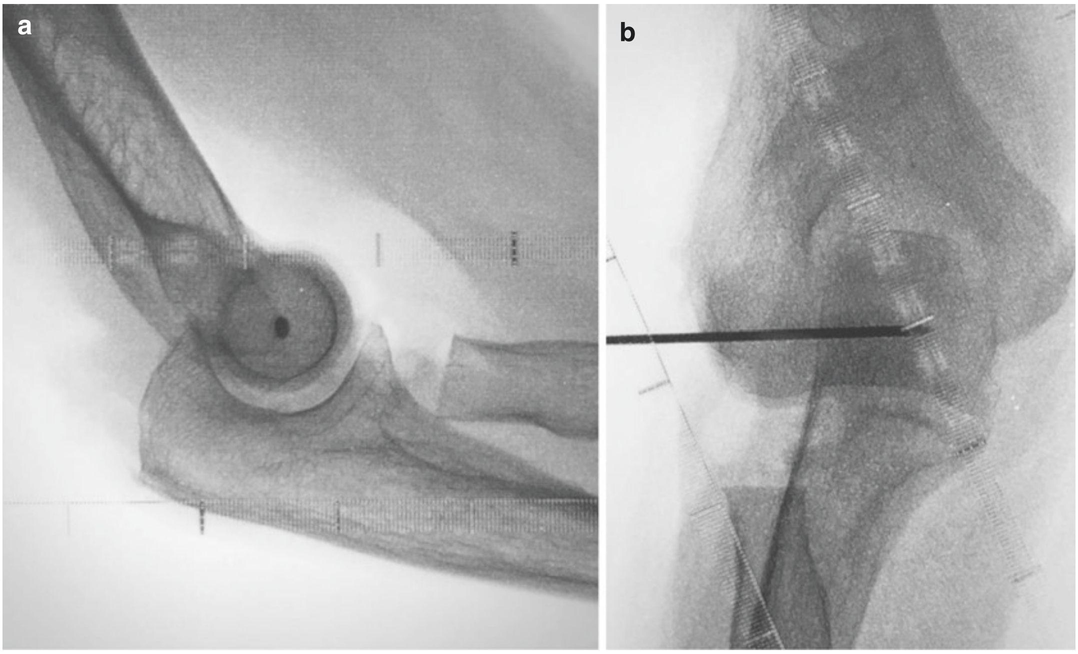

Fig. 11.4 Anteroposterior (**a**) and lateral (**b**) radiograph demonstrating appropriate position of the axis pin for a winged external fixator

the articular surface, aiming towards the base of the medial epicondyle where the ulnar collateral ligament originates (Fig. 11.4b). Alternatively, once the starting point of the axis pin is identified, a targeting guide can be used to assist in accurate placement of the axis pin. This includes an ACL-targeting guide with the target point just anterior to and distal to the medial epicondyle, or at its base. An internal targeting system, which is available for the internal joint stabilization internal fixator (IJS, Skeletal Dynamics), can also be used in accurately placing the axis pin for external fixation. Begin et al. have studied an extracorporeal technique in cadavers that positions the external fixator without the need of placing a fixator axis pin [51]. Song et al. designed a navigation system that places the axis pin without using intra-operative X-ray or fluoroscopy [52].

Once the fixator axis pin is accurately aligned with the anatomic axis of the elbow, the 4–5 mm half pins are inserted into the lateral cortex of the humerus. Each pin should achieve bicortical purchase. The proximal portion of the fixator is then connected to the humeral pins with a pin-to-bar clamp or connector. The 3–4 mm ulna half-pins are placed along the lateral or posterior cortex and bicortical purchase is achieved. The ulnar nerve must be protected during the ulnar pin placement. Before attaching the ulna half-pins to the external fixator the surgeon must confirm that the ulnotrochlear and radiocapitellar joints are reduced and congruent. Flexing the elbow and placing the arm in an overhead position can allow gravity to help maintain reduction. Alternatively, the ulnotrochlear joint can be temporarily cross-pinned to maintain reduction during final positioning of the external fixator.

While one of the features of the dynamic hinged external fixator is that elbow stability can be achieved while allowing for elbow motion. However, unless the axis pin is positioned accurately along the anatomic axis the dynamic external fixator may not be able to maintain stability through an arc of motion. Using a static external fixator, as with other complex, unstable injuries in the body, can maintain joint or bone stability while the injured structures heal. Rao and Cohen reported that 95% of 20 patients treated with static external fixation for bone or soft-tissue elbow stability achieved a congruous joint with adequate functional and clinical outcomes at nearly 6 years follow-up [41]. AlQahtani et al. compared 16 patients treated with static and eight patients with dynamic external fixation in complex elbow fracture-dislocations. They found no difference in range of motion, complications, and revision surgeries after static versus dynamic external fixation of persistently unstable elbow-fracture dislocations [43]. They concluded that due to ease of application, static external fixation is their preferred treatment for these injuries. Placing a static external fixator to the elbow can be done using a two-bar, three-bar, or four-bar configuration. Placing the external fixator in a triangular configuration may enhance stability. Before tightening the pin-to-bar and bar-to-bar connections it is important to confirm joint reduction using the methods described above.

11.5 Complications

Historically, external fixation of the elbow was associated with frequent complications. In some studies, complication rates exceed 50%. O'Driscoll and Morrey published the largest series of outcomes for hinged external fixators [53]. In their series of 100 consecutive hinged external fixators, 15% of patients had minor complications which did not affect treatment and 10% had major complications, affecting their treatment or requiring reoperation. The majority of complications were due to infection, with 9% of patients having cellulitis or non-purulent drainage, purulent drainage in 1%, and deep infection in four patients. Local skin tension requiring release under local anesthesia was present in 6%. Other major complications included loosening in 4% and fixator malalignment in 1% of patients. Mechanical failure of the pins and reflex sympathetic dystrophy have also been described [21]. There are numerous case reports in the literature of radial nerve palsies secondary to proximal lateral half-pin placement [50, 54–57]. The authors recommend an open approach for lateral pin placement to avoid direct or indirect injury to the nerve. For medially placed frames, ulnar nerve injury can occur from medial half-pin and axis pin placement [22]. These injuries can be minimized by careful dissection to bone when placing medial pins or open release with or without transposition. Fracture of the ulna and posterior interosseous nerve injury have been described with placement of the distal pins [11, 58]. A recent study compared external fixation to trans-articular pinning and found fewer total complications in the pinning group with similar functional outcomes and motion in patients with subacute instability [44, 59].

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12 Surgical Treatment of Pediatric Supracondylar Humerus Fractures

Matthew S. Fury and Benton E. Heyworth

12.1 Description

Supracondylar humerus fractures are the most common elbow fractures seen in the pediatric population. Modern surgical approaches, most commonly involving percutaneous pin fixation, have improved functional outcomes.

12.2 Key Principles

12.2.1 Evaluation

A careful examination of the entire upper extremity must be performed to detect additional injuries and the potential need for additional radiographs. If an open injury is diagnosed, tetanus history should be obtained and updated, and antibiotics should be administered expediently.

A detailed neurovascular exam is required preoperatively, as this information will dictate surgical urgency. Motor and sensory function should be tested for the median, radial, and ulnar nerves, as well as the anterior (AIN) and posterior interosseous nerves (PIN). Because the development of compartment syndrome is more common in supracondylar fractures with associated nerve palsies, such cases should be triaged more rapidly, with careful monitoring for the signs of compartment syndrome both before and after surgery. Up to 20% of displaced supracondylar fractures are associated with vascular compromise [1]. Therefore, specific detail regarding the presence and quality of a radial pulse, the color and warmth of the hand and fingers, and the duration of the digital capillary refill should be compared to the uninjured extremity and documented. In the setting of a compromised pulse, use of a Doppler ultrasound should be considered to document whether an absent, biphasic, or triphasic signal is present.

Radiographic assessment of supracondylar humerus fractures using the Gartland classification allows for basic guidance of treatment, so communication of the "type" of fracture with the entire care team optimizes understanding and treatment planning [2, 3].

12.2.2 Reduction

The vast majority of reduction maneuvers for supracondylar fractures occur in the operating room, in conjunction with a pinning procedure. Occasionally, in scenarios of multiple surgical emergencies being diagnosed simultaneously at a trauma center, delayed access to the operating room in the setting of a Gartland III supracondy-

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lar fracture with vascular compromise may prompt consideration of a provisional reduction maneuver in the emergency room under sedation. The reduction maneuver for type II and type III fractures is slightly different.

The standard reduction maneuver for Gartland II fractures is a simple hyperflexion maneuver on the elbow, sometimes requiring an anteriorly-directed force on the distal fragment through the surgeon's thumb on the posterior aspect of the olecranon and the fingers directing a posterior force on the anterior aspect of the proximal fracture fragment/distal humeral shaft. For Gartland III fractures, axial traction and restoration of the coronal plane deformity, if present, must precede the hyperflexion maneuver. For all fracture types, it is critical to understand the location of compromised periosteum and how to utilize the intact periosteal sleeve to facilitate the reduction.

Successful treatment of supracondylar humerus fractures requires the restoration and maintenance of key anatomic and radiographic relationships. The anterior humeral line (AHL) is a radiographic line utilized to assess the normal anterior condylar offset in the sagittal plane, relative to the humeral shaft. This line is drawn down the anterior cortex of the humerus and should intersect the capitellum on a true lateral view radiograph of the elbow. This intersection normally occurs in the middle-third of the capitellum in children 5 years and older, although variation exists, especially in younger children [4]. Restoration of this relationship indicates reduction in the sagittal plane and is critical for preserving the flexion–extension arc of motion that should eventually be achieved postoperatively after bony healing is complete (Fig. 12.1a, b).

Baumann's angle is the radiographic relationship between the long axis of the humeral shaft and the lateral condylar physis. This angle is measured on an anteroposterior radiograph and normally ranges between 9° and 26°. A decreased angle may indicate medial column comminution, collapse, and inherent fracture instability. Although controversy exists regarding the variability and interpretation of Baumann's angle, restoration of an angle greater than 10° is considered an acceptable reduction in the coronal plane in order to prevent cubitus varus angulation, a deformity that can be cosmetically and functionally unsatisfactory.

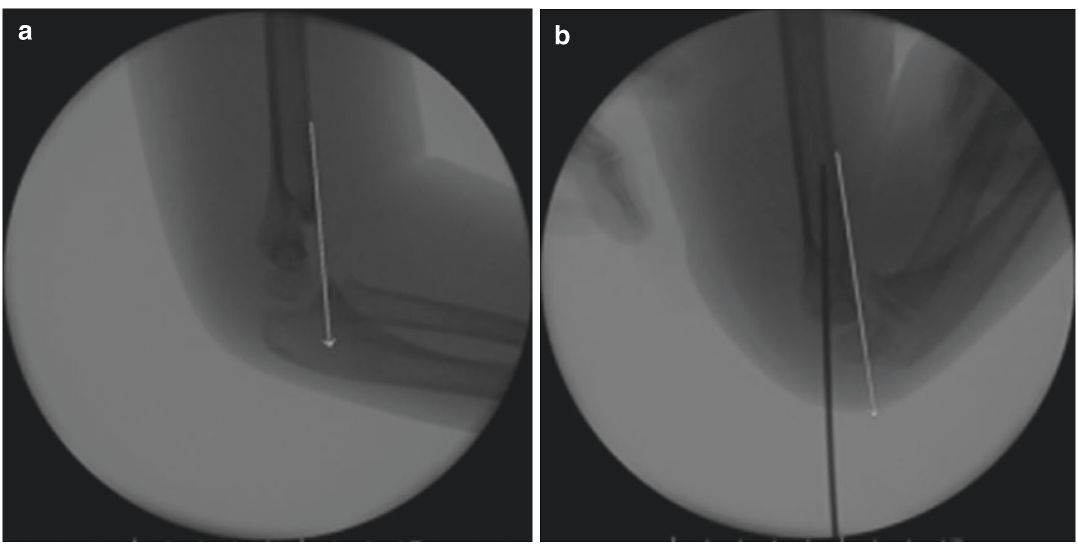

Fig. 12.1 (**a**) Lateral fluoroscopy showing displaced fracture before reduction. (**b**) Fluoroscopy after successful reduction and fixation

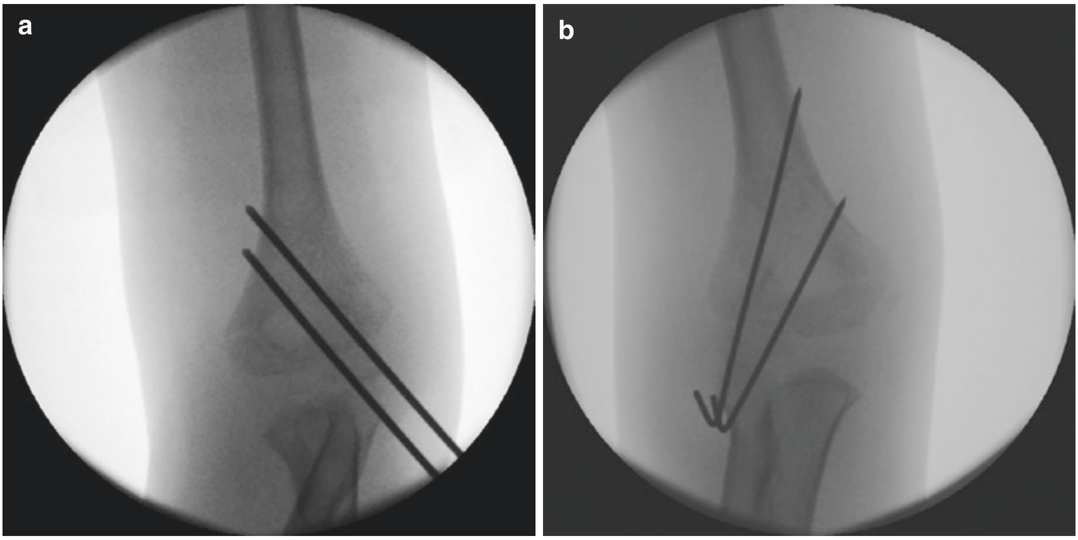

Fig. 12.2 Anterior to posterior fluoroscopy showing pin fixation of a supracondylar humerus fracture using (**a**) parallel and (**b**) divergent pin configurations

12.2.3 Fixation

Percutaneous fixation with lateral-entry Kirschner wires (K-wires) is the current standard of care for displaced fractures (Fig. 12.2a, b). Multiple studies have identified the following key principles: [5, 6]

- Two pins are usually sufficient for Gartland II fractures, but three pins should be utilized for Gartland III and IV injuries. However, additional pins should be placed if the fracture remains unstable after the above fixation is executed.
- Pins should be placed in a parallel or slightly divergent pin construct to engage sufficient bone in the distal fracture fragment as well as both the medial and lateral columns of the proximal humeral fragment.
- Maximal pin spread at the fracture site should be obtained to enhance stability. The closer pins are to each other at the point at which they cross the fracture line, the less stable the construct.
- All pins should achieve bicortical fixation.

The utilization of a medially-based pin, as in a cross-pin construct, provides additional torsional stability, but introduces an increased risk of iatrogenic ulnar nerve injury. Although current evidence fails to demonstrate an improvement in outcomes with the utilization of a medial pin, it can be a valuable technique in fractures with persistent instability after lateral pin placement or in injuries with medial comminution or oblique fracture planes that exit proximally on the medial cortex, as this limits the space for bicortical fixation of laterally-based pins.

12.3 Expectations

The goal of surgery for supracondylar humerus fractures is to produce a well-perfused extremity with anatomical alignment and stable fixation, while causing minimal morbidity to the patient.

12.4 Indications

Displaced fractures, Gartland Types II–IV, are treated with reduction and percutaneous fixation.

12.5 Contraindications

Gartland Type I fractures are stable, non-displaced or minimally displaced patterns that generally do not need surgical intervention. This injury is treated with cast immobilization.

In patients with severe medical comorbidities or underlying compromise to normal upper extremity function, the potential benefits of surgical fixation should be weighed relative to medical and anesthesia risks, taking into consideration the potential outcome of a malunion and how detrimental some component of deformity might be to one's baseline function.

12.6 Special Considerations

12.6.1 Neurovascular Compromise

Nerve injuries from the initial injury are common, but nerve transection is relatively rare. Meticulous examination and documentation of neurological status is a critical step preoperatively. If patient age or discomfort limits cooperation and completion of an accurate neurologic assessment, these limitations should be clearly stated in the medical record as well. In the setting of injury, nerve recovery generally occurs in the first 2–3 postoperative months. Therefore, observation of isolated nerve injuries is recommended unless another indication for exploration exists.

The management of vascular injury depends on the preoperative and intraoperative exam. Preoperative dysvascular hands (white, pulseless) are surgical emergencies. Color, capillary refill, and pulse is reassessed after reduction and stabilization, but vasospasm commonly persists. The management of the pink, pulseless hand remains an area of controversy. The pink hand with a Dopplerable pulse may be splinted and observed closely. If a dysvascular hand persists despite a reasonable reduction, exploration with dissection of all accessible portions of the brachial artery is indicated. The artery is often interposed in the fracture or kinked by an entrapped segment of soft tissue or fascia. Laceration or thrombosis of the artery may warrant vein grafting, so the appropriate personnel, in the form of a hand surgeon, plastic surgeon, or vascular surgeon, should be contacted far enough in advance of the moment of intra-operative discovery of such a phenomenon that excessive delays under anesthesia do not occur.

12.6.2 Medial Comminution

The presence of medial comminution may indicate instability and a predisposition to collapse into varus alignment. Special attention should be made to restoring a sufficient Baumann's angle intraoperatively, and patients should be followed for the possible development of cubitus varus.

12.6.3 Flexion-Type

Flexion-type injuries require a different reduction maneuver than extension injuries. Reduction is frequently obtained via traction and elbow extension, rather than flexion. These injuries are often more unstable than extension injuries, and the technique described in Sect. 12.9.1 may be beneficial.

12.6.4 Occult T-Type

In older children and adolescents, imaging should be scrutinized to ensure the injury is not a T-condylar fracture of the distal humerus. This injury is often treated with ORIF using bicolumnar plating, as in the adult population. Though in younger children with a non-displaced intercondylar extension, a transverse percutaneous pin can be added to a standard lateral three-pin construct. A CT scan may be utilized for fracture characterization.

12.7 Special Instructions, Positioning, Anesthesia

Surgery is performed under general anesthesia with administration of prophylactic antibiotics. Most children can be positioned supine on a standard operating room table. The table is turned 90° from the anesthesia team, and the fluoroscopy unit enters from the foot of the bed with monitors positioned directly in front of the operating surgeon. The patient is translated to the edge of the bed in order to expose the fracture to the fluoroscopy beam. Traditionally, in most Gartland II and III fractures, the base of the fluoroscopy unit was used as the extremity table, and the arm rotated to obtain the lateral and oblique imaging. However, this practice may be evolving to better limit radiation absorption and scatter. In patients with severely unstable Gartland III fractures, flexion-type fractures, Gartland IV fractures, or in procedures where an open reduction or exploration is indicated, a radiolucent arm board is generally favored. This allows for a larger and more stable operative field, as well as the ability to rotate the fluoroscopy unit around the arm without losing reduction, which may be needed in unstable fracture patterns.

12.8 Tips, Pearls, and Lessons Learned

12.8.1 Pin Sizing

The authors use 5/64″ pins for children ≥20 kg and 0.0625″ for children <20 kg. This recommendation originates from the protocol of the randomized controlled trial by Kocher et al. [7].

12.8.2 Traction and Milking

For severely displaced type III fractures, the arm may need to be placed into 20° of flexion and steady traction applied for up to 5 min. This maneuver is helpful to overcome soft tissue tension and interposition. Dimpling in the antecubital fossa often indicates that the proximal fragment has pierced through the brachialis muscle. Forcibly milking the brachialis muscle from proximal to distal may also release the proximal spike from the soft tissues.

12.8.3 Pronation/Supination

The position of the forearm may assist in obtaining and maintaining reduction. In medially displaced fractures, the lateral periosteum is disrupted. Therefore, the forearm may be pronated to tension the extensor muscles as a stabilizing force across the fracture. In laterally displaced injuries with medial periosteal disruption, supination may tension the flexor-pronator mass.

12.9 Difficulties Encountered

12.9.1 Global Instability

Reduction of Gartland IV fractures is often tenuous as there is no periosteum to tension and hold alignment. Initially, an attempt is made to hold the reduction in space while passing pins as described below. If unsuccessful, drive K-wires with appropriate starting point and trajectory into the unreduced distal fragment without exiting at the fracture site. Reduction is then performed, and the pre-positioned K-wires are passed into the proximal fragment. This technique minimizes extraneous movement in a tenuous fracture.

12.9.2 Open Reduction in Flexion vs. Extension Types

If an open reduction or exploration is to be performed, the location of damaged periosteum should be considered in the surgical approach. An anterior approach in a flexion-type injury may find intact periosteum and inability to access the fracture site without further disrupting periosteal tissues. Surgeons may consider a medial or posterior approach in these injuries.

12.9.3 Entrapment of Neurovascular Structures

If there is persistent widening of the fracture on fluoroscopy and the reduction feels "rubbery," or if the pulse or clinical perfusion worsens from the preoperative status, it may be assumed that the artery and/or periarterial soft tissues have been entrapped in the fracture site. Fixation can be removed and the fracture unreduced to release structures prior to repeat reduction and fixation.

12.9.4 Compartment Syndrome

Forearm compartment syndrome is a rare but catastrophic complication, and prompt recognition is paramount to preservation of extremity function. Patients with delayed presentation, excessive swelling, ipsilateral forearm fractures, high-energy or crush injury mechanisms, immobilization in hyperflexion, or injuries with associated neurovascular compromise are at a higher risk for development of compartment syndrome. Patients with median nerve injuries may have impaired sensation to the forearm, and the presentation in these patients may be diminished or atypical.

In contrast to the "5 P's" utilized to diagnose compartment syndrome in the adult population, the "3 A's" are more useful in children—increasing anxiety, agitation, or analgesic requirements. In a developing compartment syndrome, the patient should be emergently mobilized to the operating room for consideration of compartment pressure monitoring and/or fasciotomy. In the interim, circumferential dressings should be removed and the arm extended.

12.10 Key Procedural Steps

The surface landmarks of the lateral elbow—the radial head, lateral condyle, and olecranon—are palpated. A free-hand K-wire is placed against the skin, and the starting point and trajectory are verified on the AP imaging. A lateral image may be obtained, but the authors find that it is beneficial to use external cues—such as the trajectory of the pin relative to the humeral shaft, which is held parallel to the floor—for pin initiation. The pin is then pushed through the skin and into the lateral condylar cartilage. Since the capitellum is an anterior structure relative to the humeral shaft, laterally-based pins are angled in a slight anterior-to-posterior direction. When desired position and trajectory is obtained, the wire driver is engaged and the pin is advanced. The authors begin by placing the transversely-oriented, medial column pin first as this allows for incremental adjustments to be made for maximal subsequent pin dispersion. An intermediate pin is placed if indicated. The medial column and intermediate pins may traverse the olecranon fossa on their way to the far cortex. This is considered acceptable, as the pins are temporary, and the additional cortices of fixation may help improve construct stability. The final, laterally-based K-wire is inserted obliquely in order to obtain bicortical purchase as far proximal in the medial column as possible. Use light tactile pressure at the far ulnar cortex of the distal humerus with this pin to prevent skiving up into the medullary canal. The fracture stability is then assessed in the sagittal and coronal plane.

In persistently unstable fractures or in the previously described oblique or comminuted fracture patterns, a medially-based pin may be placed. The medial epicondyle is palpated as well as the position of the ulnar nerve. The elbow is extended in order to relieve tension on the nerve and allow it to fall posteriorly. An incision is made through the skin over the medial epicondyle, and a blunt instrument is used to spread down to bone. A drill guide must be used to prevent the binding of the ulnar nerve or more commonly, the perineural soft tissues. The medial epicondyle is a posteriorly-based structure relative to the humeral shaft; therefore, the direction of this pin will be slightly posterior-to-anterior. After placement, the K-wire is examined while gently ranging the elbow in order to ensure there is no impingement of the ulnar nerve.

After fixation is satisfactory, the vascular status is assessed. Further operative decisions may be guided by the discussion in Sect. 12.6.1. The wires are bent and cut with ample distance from the skin to allow for postoperative swelling. Xeroform should be thoughtfully folded around the wires rather than wrapped excessively, which makes for difficult removal in the office. A sterile gauze or felt is subsequently applied around the pins. A well-padded long arm cast is applied in 70–80° of flexion after confirming adequate perfusion in this position.

12.11 Open Reduction or Exploration

The vast majority of supracondylar fractures are extension injuries, and if an open reduction is needed, an anterior approach should be utilized. A transverse incision is made over the medial antecubital fossa. The bicipital aponeurosis, if not already disrupted, may need to be incised. The biceps tendon is a stable landmark, as the neurovascular anatomy may be distorted. Normally, the brachial artery is just ulnar to the tendon while the median nerve lies just ulnar to the artery. If the neurovascular bundle is not located in this position, further exploration should be performed to assess for either entrapment in the fracture or laceration of the artery with retraction of the injured ends. There is often large soft-tissue disruption from the injury, and gentle finger dissection is all that is required to access the fracture site. Consultation with a vascular surgeon, or a surgeon with extensive vascular experience, is recommended if an arterial injury is identified.

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Part II

Degenerative Conditions of the Elbow

13 Revision Total Elbow Arthroplasty (TEA) with Osseous Augmentation

Mark E. Morrey, Adnan N. Cheema, and Jacob J. Triplet

13.1 Key Principles

Revision techniques require restoration of skeletal integrity to ensure a stable implant and functional elbow.

13.2 Indications

Septic (after staging) or aseptic loosening of TEA with or without periprosthetic fracture and bone defects or significant bone loss.

13.3 Contraindications

- Active infection.
- Infirm patient unable to tolerate surgery.

13.4 Special Considerations

- Preoperative assessment for infection.
- Bone defects can be on the distal humerus, proximal ulna or both (Fig. 13.1). Revision requires detailed preoperative assessment and planning for accurate placement of implants and bone grafts when the humeral implant flange is unsupported and or the olecranon and or extensor mechanism is absent.

Fig. 13.1 Failed TEA with massive bone loss. Osteolysis from wear creates loosening which leads to canal expansion and thinning cortical bone, reactive cortical perforations and periprosthetic fractures

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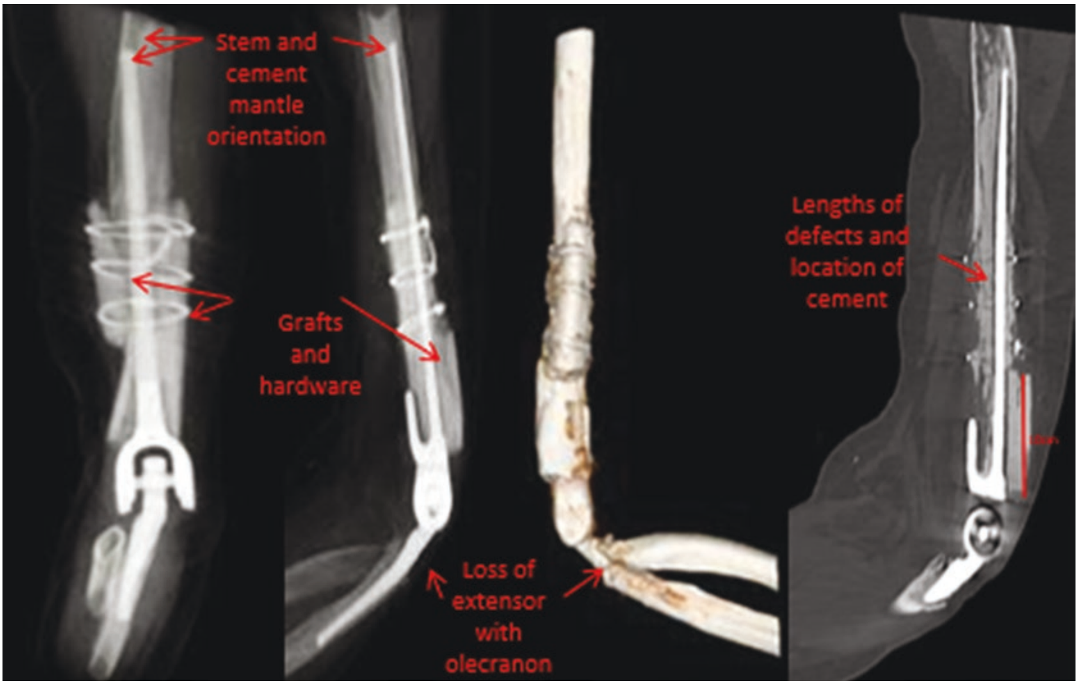

Fig. 13.2 A CT scan is completed for planning purposes. Prior grafts and hardware can be marked and measured accurately as can the lengths of cortical defects and location of the cement for removal. The orientation of the stems within the cement mantle can be accurately determined so that removal will not cause additional bone destruction

- CT allows for the following:
  – Three-dimensional understanding of the bone loss (Fig. 13.2).
  – The relationship of the implant to the bone loss.
  – Identification of areas of thin or expanded bone.
  – The location of cement.
  – The proximity of the neurovascular structures at risk.
  – Component orientation.
  – The ability to measure for preoperative planning of struts and APC's to avoid stress risers during reconstruction.
  – Models and cutting guides for planning and intraoperative preparation.

13.5 Special Instructions, Positioning, and Anesthesia

- The patient is placed in the supine position to the edge of the bed to facilitate intraoperative imaging if required.
- Tilt the OR Table 10° opposite the operative extremity to allow comfortable positioning of the arm and facilitate access to, and manipulation of, the elbow.
- If proximal dissection is required for humeral defects, a sterile tourniquet or Esmarch can be utilized and removed if proximal dissection is needed.
- Distal dissection requires that the hand be prepped if exposure to the wrist is necessary.

- General anesthetic is preferred with a postoperative axillary block for analgesia after neurologic assessment in the postoperative recovery area.
- Intraoperative fluoroscopy for preparation of bone to avoid creating a perforation or intraoperative fracture during bone preparation.

13.6 Tips, Pearls, and Lessons Learned

13.6.1 Exposure

- A detailed understanding of the proximity of neurovascular structures is requisite.
- The soft tissue envelope around the elbow is thin and prone to breakdown. Multiple prior surgeries are frequently encountered with prior soft tissue coverage procedures (Fig. 13.3). An assessment by our plastic surgery colleagues is helpful to plan adequate coverage.
- The subcutaneous border of the ulna is palpated and an incision planned for exposure to the wrist if there is significant bone loss of the ulna.
- The investing fascia of the triceps is entered and traced to both the medial side for identification of the ulnar nerve and lateral side for the radial nerve (Fig. 13.4) [1].
- The nerves are protected with a vessiloop and they are tied instead of clamped to avoid traction injury. If the ulnar nerve can be palpated anteriorly and is out of the surgical field it may not need to be exposed.
- The radial nerve crosses the humerus obliquely through the spiral groove on the posterior aspect of the humerus distal to the deltoid insertion and proximal to the brachioradialis and should be dissected and protected when proximal exposure is required. Other useful landmarks for the radial nerve include the triceps raphe between muscle and tendon. Finally, the posterior cutaneous nerve of the arm can also be used to trace back to the radial nerve as it pierces the intermuscular septum proximally (Fig. 13.4) [2].
- The anterior aspect of the humerus is safe to expose as long as dissection remains directly on the bone. The apex of the humerus is useful landmark for humeral rotation and placement of bone graft for the flange.
- With the trials in place, the hand should reach the mouth with flexion as a secondary check of proper rotation and function of the TEA.
- Elbow flexion during dissection facilitates safe exposure to the anterior humerus by

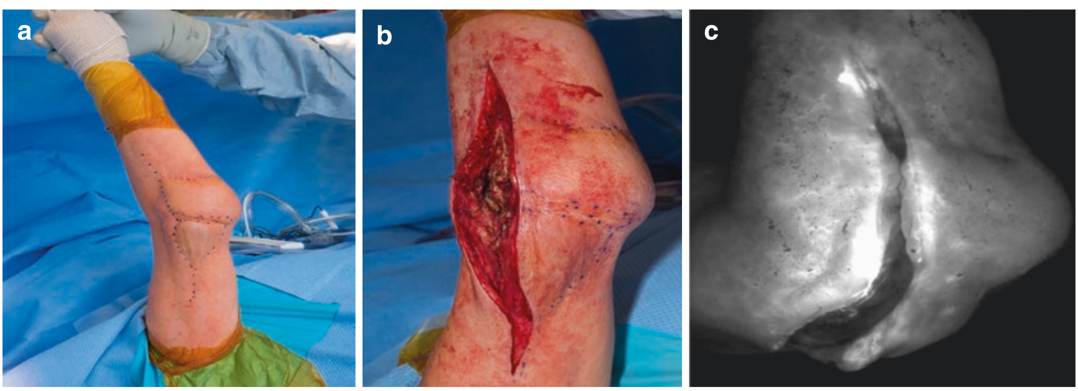

Fig. 13.3 It is not uncommon to encounter multiple incisions or prior flap coverage in a multiply revised TEA (**a**). In these situations, the most lateral of the incisions is utilized and dissection carried to the bone so that minimal dermocutaneous flaps are raised to avoid devitalization of the skin edges and the potential for dehiscence (**b**). Laser angiography can be used intraoperatively to ensure that viable skin edges remain at the end of the case as evidenced by visual perfusion of the skin edges with the viewer (**c**)

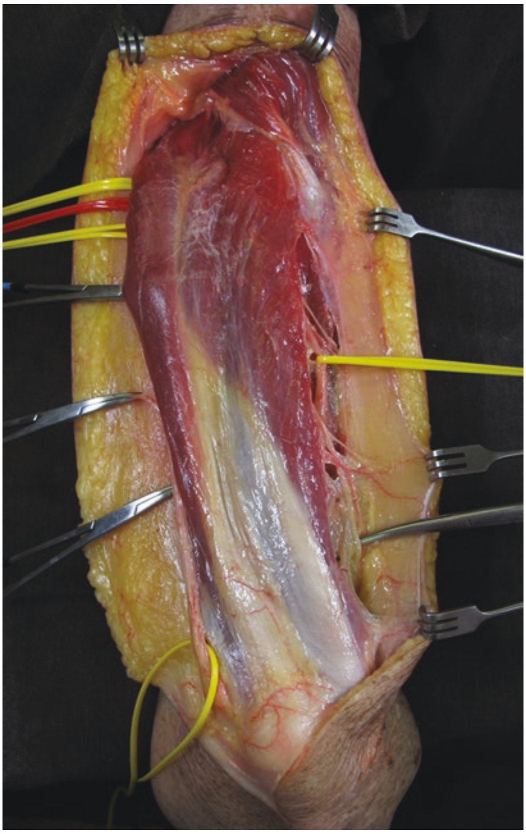

Fig. 13.4 Posterior exposure surgical anatomy of the humerus is critical to understand for safe exposure of the neurovascular structures. The investing fascia of the triceps (in the rake retractors) can be used to trace the fascia back to the intermuscular septum on the medial and lateral sides which leads the surgeon to the ulnar and radial nerves respectively. Often the ulnar nerve has been transposed and a more proximal dissection in required to identify it on the medial margin of the triceps. On the lateral side, the posterior cutaneous nerve can be found in the subcutaneous tissue just lateral to the triceps and traced proximally to the radial nerve. The nerve courses obliquely across the posterior humerus just proximal to the triceps raphe which can also be used as a landmark for its identification

increasing the working space as anterior neurovascular structures are relaxed from the anterior humerus.

- If the extensor mechanism is intact, every effort is made to maintain its continuity to the proximal ulna to avoid insufficiency and poor extension strength.
- The anconeus branch of the radial nerve and its blood supply enter the muscle proximally and remain intact when performing a lateral para-olecranon approach [3, 4].

13.7 Humeral Bone Loss

- Most cases of TEA with humeral bone loss can be treated with impaction grafting and allograft strut grafting if cortical defects are encountered. The reconstructive choice depends on whether or not there is enough bone for the humeral flange to capture the graft and host bone (Fig. 13.5).
- Shortening of the arm by up to 2 cm can performed if it enables the humeral flange to engage the humerus [5]. If more than 2 cm of shortening is required, an allograft prosthetic composite (APC) is recommended (Fig. 13.6).

13.8 Ulnar Bone Loss

- Every effort should be made to preserve the extensor mechanism.
- With a large degree of olecranon bone loss, the extensor attachment is compromised and in this situation an APC with soft tissue attachments for reconstruction of the triceps should be entertained.
- An assessment of the soft tissue envelope and an ability to close the wound over the graft is essential prior to placement.
- If adequate soft tissue is available for function and closure, reconstruction of the olecranon can also provide an additional barrier preventing implant erosion through the tendon and skin.

13.9 Difficulties Encountered

13.9.1 Considerations

- Loose implants lead to native bone expansion and thinning and predispose the patient to periprosthetic or implant fracture, metallosis, metal debris and thick non-compliant tissue. Without reconstruction the function of the elbow is severely limited.

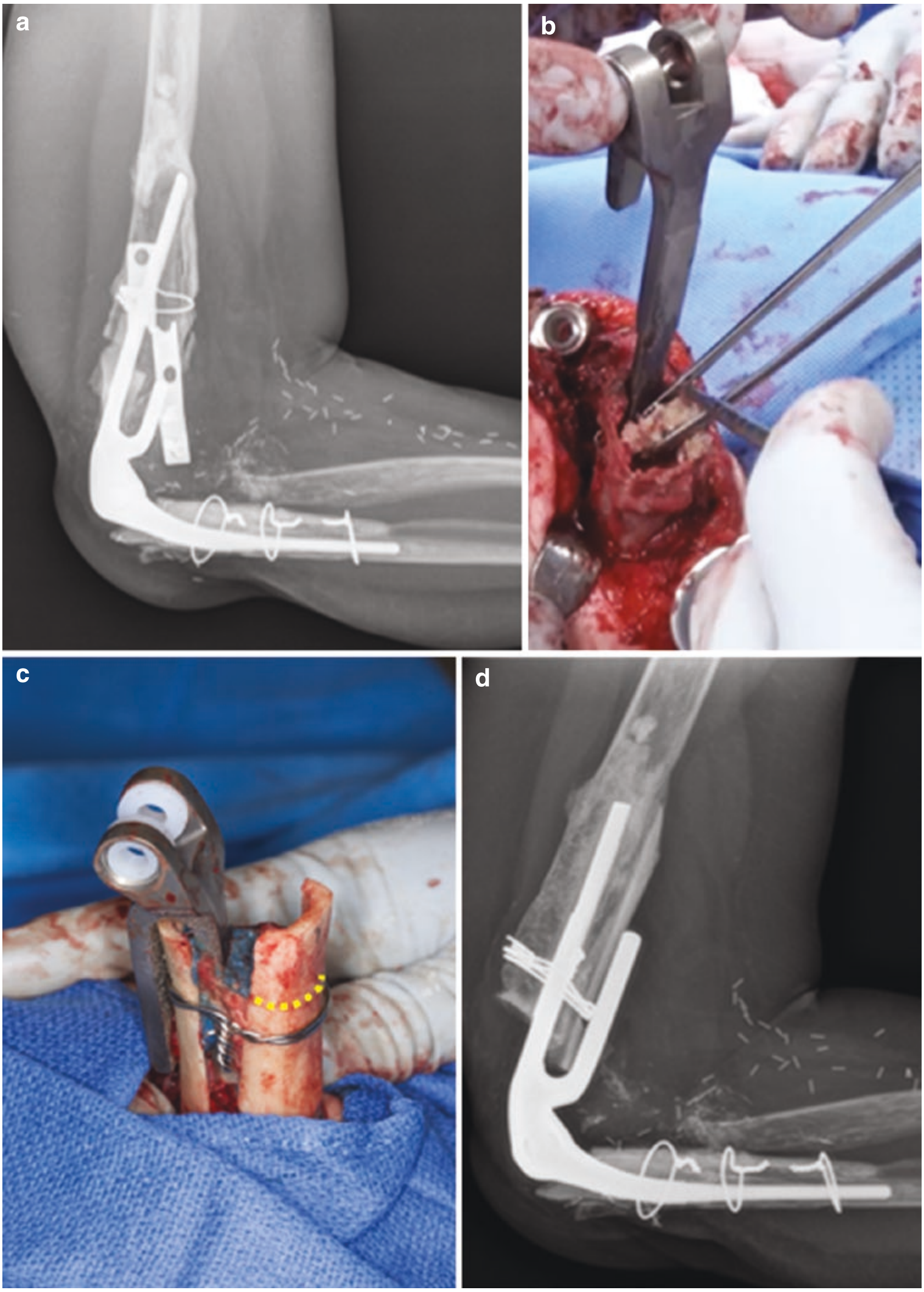

Fig. 13.5 Bone loss and failure of prior revision TEA with broken hardware, loose implant, and bone loss with expanded cortical bone (**a**). Reconstructive techniques are employed to add skeletal support in this case with impaction bone grafting (**b**) and cortical struts both anterior and posterior to the implant (**c**) to restore skeletal integrity. A portion of the posterior graft in (**c**) was later removed to the level of the native bone to avoid prominence and potential triceps irritation or incarceration. The X-ray in (**d**) shows the 3-year result with maturation of the grafts and incorporation of the bone graft from the impaction grafting

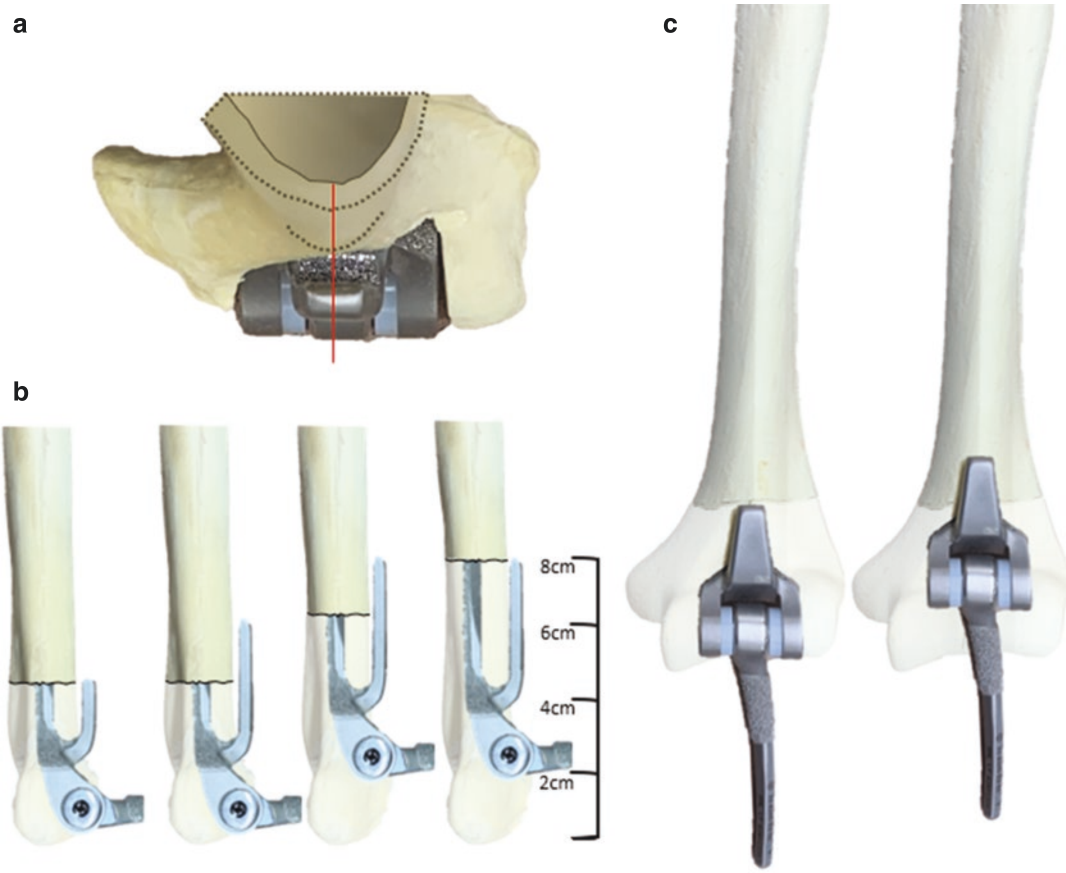

Fig. 13.6 With absent condyles the apex of anterior humerus can be used to help identify the correct rotation of the implant (**a**). Humeral bone loss can be managed with up to 2 cm of shortening with a long-flanged implant as seen on the lateral in (**b**) and anteriorly in (**c**) which illustrates the normal axis of rotation of the humerus and acceptable flange lengths and shortening. If greater than 8 cm of bone loss is encountered, even a long flange component will not engage the anterior cortex and greater shortening will significantly reduce strength. In these cases an APC is performed

- Have knowledge of the elbow implants for replacement of parts and mechanisms of failure.
- Retain implants if well-fixed if possible.

13.10 Key Procedural Steps

- Prior skin flaps are marked and the lateral most incision utilized to preserve blood supply.
- Prior posterior in skin incisions are utilized and excised if infection is a concern.
- Range of motion in flexion and extension and pronation and supination is documented to determine surgical release which may be required. Flexion contractures can be improved with shortening on the humeral side and pronation and supination may be improved with radial head resection which can be determined prior to surgery.
- Prior skin incisions (as is the case when patients have had flap coverage) are outlined. The lateral most incision is typically used in these situations as described above.
- Cutaneous flaps are avoided if possible in order to prevent wound breakdown secondary to perfusion problems. Dissection is typically carried to the bone by raising minimal flaps. In complex wounds, laser angiography can be

used to assess tissue perfusion in real time and aid decision making.

- A triceps-on para-olecranon approach is most often utilized in the revision setting with an intact olecranon. A facial split is created along the lateral and/or medial side of the ulna depending of the specific defect encountered allowing the remainder of the soft tissue to remain intact. Soft tissue attachments with the extensor mechanism are left in place as: (1) later repair is facilitated, (2) the blood supply remains to the bone, and (3) the extensor mechanism is not violated. If no olecranon is present and/or a triceps reconstruction is needed, a split in the fascial remnant is used. The split should allow for closure around the reconstruction at the completion of the case (Fig. 13.7) [1, 3].
- Minimal dermocutaneous skin flaps are raised off the fascia of the forearm distally and triceps proximally allowing for just enough exposure to address bone defects and protect the neurovascular structures. Digital palpation is used alone if prior transposition has been performed and the nerve is out of the operative field.
- With proximal exposure, the investing fascia of the triceps is used to locate the ulnar nerve medially and the radial nerve laterally.
- A 3–4 mm soft tissue sleeve of the fascia is incised off the subcutaneous border of the ulna for later closure. Subperiosteal dissection of the ulna is then performed for exposure. The medial and lateral sides of the implant, if present, are identified to gain access to the articulating mechanism for uncoupling. A

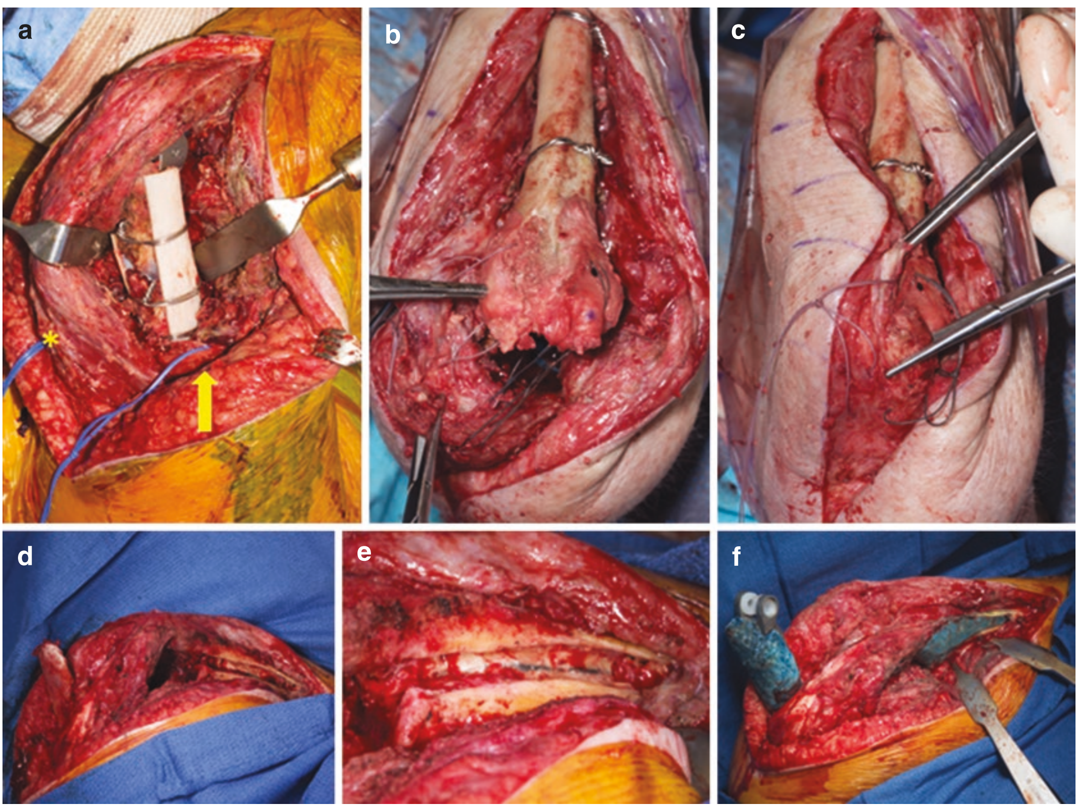

Fig. 13.7 The approach to the elbow should allow for extension of the exposure to dissect free radial (arrow) and ulnar nerves (*) along the humerus while maintaining soft tissue attachments to the forearm as in this lateral paraolecranon approach in (**a**). Extensive defects may require a split as in (**b**) and allow for closure of the soft tissue sleeve after reconstruction of the triceps (**c**). The approach should allow for exposure and management of the defect as the medial defect in (**d**) caused by a deflected reamer in the case of an extensive infection was managed with a medial paraolecranon approach removal of the cement in (**e**) and articulating antibiotic spacer in (**f**)

periosteal elevator is then used to mobilize the triceps from the posterior aspect of the humerus.

- After triceps mobilization, the distal humerus is release of soft tissue attachments allowing disarticulation of the implant and dislocation. The arm is flexed to allow protection of the neurovascular structures anteriorly.
- At this point, the implants are removed and bony defects assessed (see techniques below).
- Depending on the length of humeral defects, the radial nerve may need to be dissected to avoid injury.
- Specific techniques to address the bone loss are addressed below.

13.11 Techniques

13.11.1 Implant Removal

- Preservation of available bone and soft tissue attachments is mandatory for the durability and function of the reconstruction. If one component is well fixed, it can be retained (in the absence of infection). If staging is required, removal of well-fixed implants is at times requisite.
- To remove well-fixed implants, a thin router can remove the cement around the implant (Fig. 13.8a, b). Taking time to circumferentially remove cement from the coated portions of the stem will allow for removal with minimal bone destruction. After circumferential use of the router, a slap hammer with a hook or vice grip plier's attachment can be used to attempt disimpaction of the implants (Fig. 13.8c, d).
- If the slap hammer is unsuccessful, an episiotomy can be made along the medial or lateral border of the ulna (Fig. 13.9a, b) or posterior aspect of the humerus along the implant stem and an osteotome used to break the remaining cement from the implant.
- After the episiotomy, use the slap hammer to again attempt removal. In some cases, even after episiotomy, the router must be used again.
- If these techniques are unsuccessful a formal osteotomy can be created connecting the prior episiotomy on the ulna for a long olecranon osteotomy (Fig. 13.9c, d) or cortical window in the posterior aspect of the humerus (Fig. 13.10a, b). The router can then be inserted under direct visualization of the stem cement interface for removal.

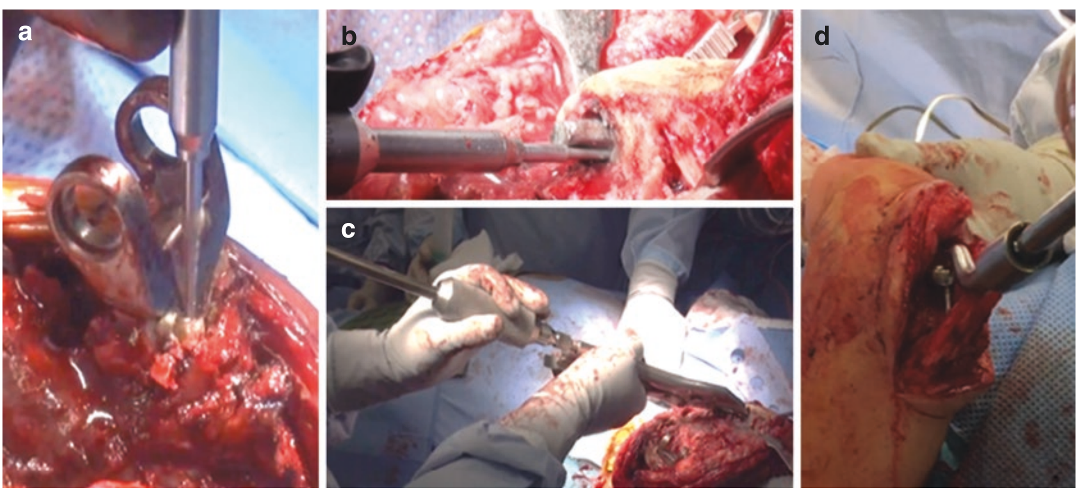

Fig. 13.8 Removal of implants should try and minimize bone destruction. A thin router is used to remove cement circumferentially around the humeral (**a**) and broken ulnar (**b**) components. A slap hammer with vice grip (**c**) or hook attachment (**d**) can be utilized to try and dislodge and remove the implants

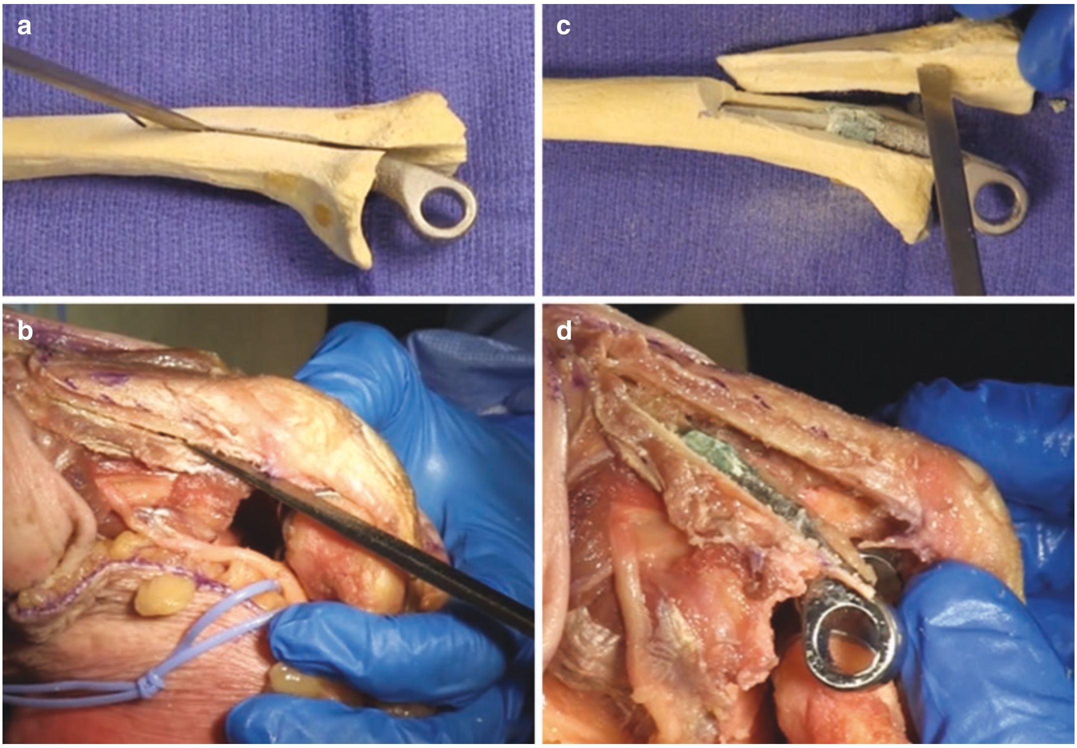

Fig. 13.9 An osteotome can be inserted in an olecranon episiotomy in (**a**) and (**b**) which can debond the implants just enough to allow for removal. If this is unsuccessful, a formal osteotomy (**c**, **d**) is utilized which maintains the extensor attachment and allows access for cement removal

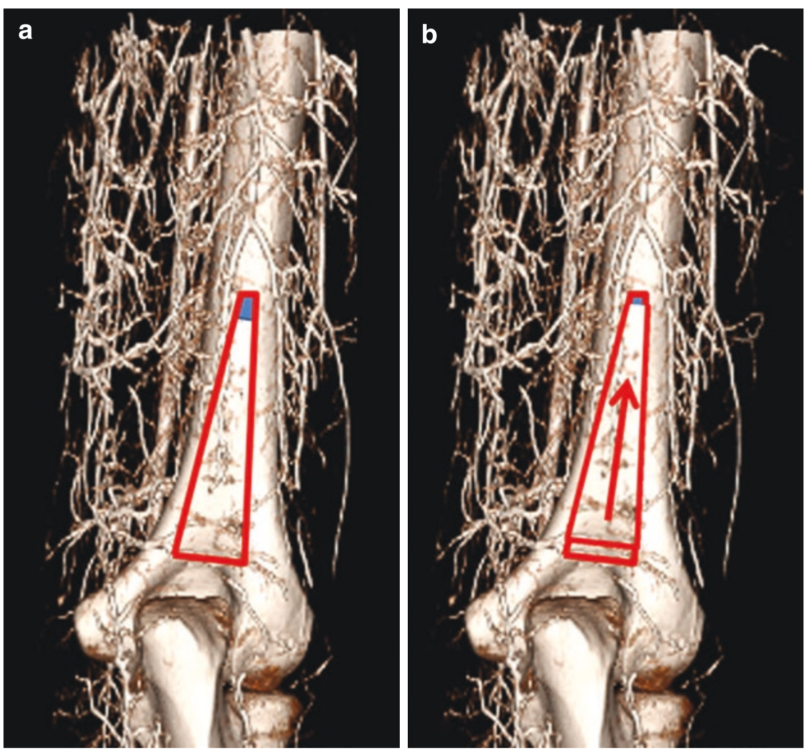

Fig. 13.10 A posterior trapezoid osteotomy is illustrated in (**a**) with overlying vasculature to illustrate preservation of the blood supply to the humerus. The oblique fragment can be impacted proximally (**b**) to allow for a tight fit and compression of the edges prior to adding a wire to increase interdigitation and healing rates

- After implant removal, some cement remains distal to the implant and should be removed if possible. Using a long bur or drill bit can help create a central starting point in the mantle. This can enable introduction of a drill, Steinmann pin or guide rod into the cement mantle without violating cortical bone.
- The use of fluoroscopy can help locate the center of the mantle in two planes (Fig. 13.11e, f). If a short segment or plug is encountered, the use of a threaded Steinmann pin can provide enough purchase in the cement and allow for an attachment of the slap-hammer and removal of the plug (Fig. 13.11a–d). In infections it is critical to remove all cement and an arthroscope can identify retained cement (Fig. 13.12a, b).
- In some cases, all the cement cannot be removed without destroying extremely thin bone. In this situation, enough cement should be removed to place the new prosthesis. After creation of a track through the cement with a drill, serial reaming over the guidewire can facilitate removal of cement but care should be taken to ensure that cortical bone is not removed as the cement mantle is harder than the cortical bone and can deflect the reamers and create cortical defects. This is the reason that a centralized starting point is so critical.

13.11.2 Impaction Grafting Technique

- With extensive expansion of the humeral canal, impaction grafting is used restore bone stock [6, 7] (Fig. 13.13). If no fracture has occurred, the impaction technique is the same on the humerus and ulna although it is far more common on the humeral side.
- After the cement is removed and the canals are clean, a cement restrictor or compact bone is

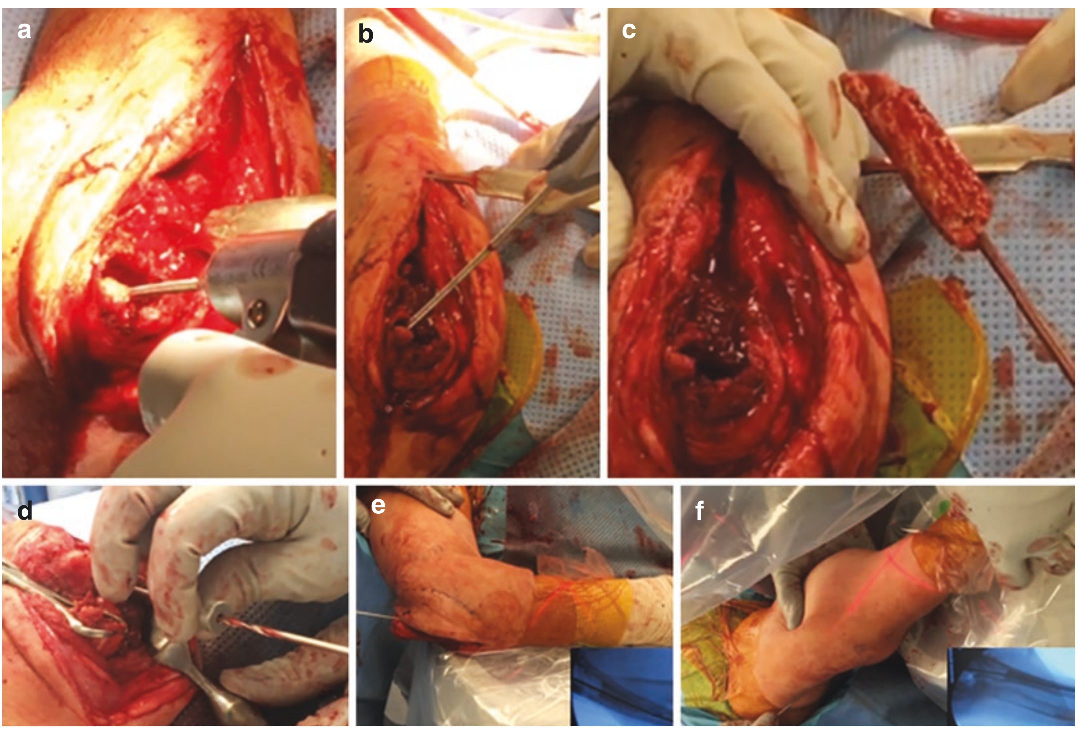

Fig. 13.11 Cement removal can also be facilitated by placing a threaded Steinmann pin into the mantle (**a**) and removing with a vice grip slap hammer (**b, c**). Alternatively when the mantle is well fixed a drill with drill sleeve can be used to center a hole in the mantle (**d**) and under fluoro control (insets) in both lateral (**e**) and anterior posterior planes (**f**) can be used to centrally direct a guidewire for reaming

Fig. 13.12 If retained cement must be removed as in the case of infection, an arthroscope in (**a**) can be employed to identify and remove the cement (**b**) (→) without destroying the cortical bone (**b**) (*)

wedged into the canal just distal to the tip of the stem to act as a platform for impaction grafting.

- A trial component, spacer (a cut stem is useful for this purpose) or cement nozzle is placed in the humeral canal to determine the correct diameter of the implant that will allow access for an impaction tool and morselized graft to still fit around the component.
- More cancellous graft is packed posteriorly on the humerus to allow the flange to engage native cortex anteriorly.
- In severely expanded bone, the implant may be driven anteriorly by the graft and place undue tension on the triceps. In these cases a wedge of bone is removed and the humerus collapsed with a wire.
- A small amount of morselized cancellous graft is placed at a time and compacted.
- Until the graft bed is firm. The shape of the trial should remain to allow enough space for a cement nozzle to fit down without dislodging the graft into the canal. The spacer is left in place until ready to cement.

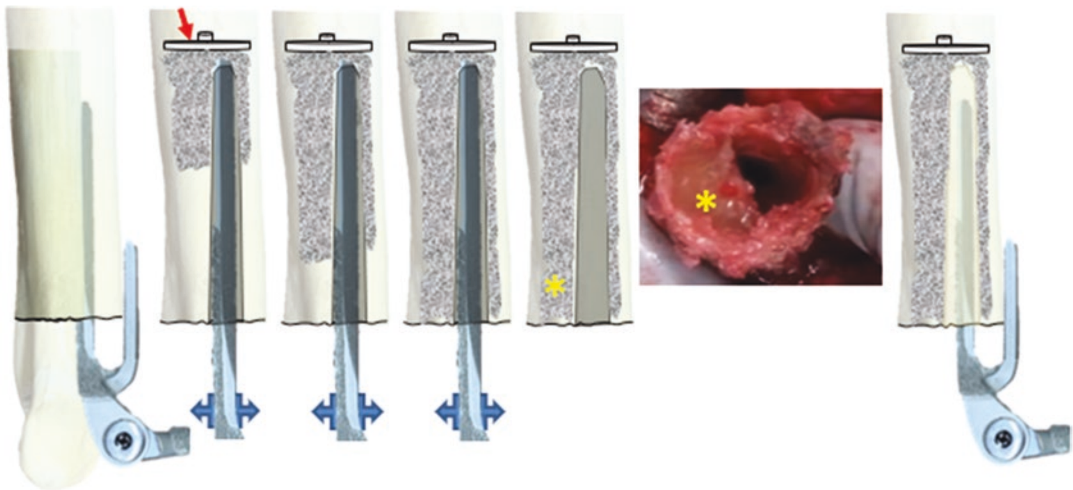

Fig. 13.13 Impaction grafting technique is illustrated. The technique is ideal in expanded canals which is illustrated with the normal bone and ghosted expanded bone in the first panel. Bone is introduced into the canal around a spacer (in this case a cut stem) after a cement restrictor (→) is placed. The bone is compacted with a tamp and by wiggling the tamp back and forth to create a space (inset clinical photo) to ultimately allow for cementation of a new implant. The bone should be selectively packed posteriorly (*) in order to allow the flange to engage the expanded cortical bone anteriorly

- In cases of severe bone loss where both medial and lateral epicondyles are missing, the anterior humeral apex can be used to judge rotation (Fig. 13.6). Additionally, the hand should easily bend to reach the mouth with the arm at the side as a double check for rotation with trial components in place.

13.11.3 Allograft Prosthetic Composite (APC)

- If significant bone loss is encountered, an APC is utilized to gain length and support of the implant (Fig. 13.14a–c) and also to reconstruct an absent triceps by using the triceps allograft and tying into the triceps proximally (Figs. 13.15, 13.16 and 13.17) [8].
- The allograft is sized to be larger than the native bone and to maximize native bone to allograft contact and, in most cases, allow for a strut to lie over the patients remaining cortex to bridge the interface. Humerus or femoral grafts can be used to allow for both a strut and contact with the native humerus while allowing alignment of the intramedullary canals for the stem of the implant (Fig. 13.18). The strut allows additional reinforcement of the native bone and in our experience heals reliably.
- A plate can be added to allow for compression and rotational stability of the allograft to native humeral bone. This is typically secured with a trial in place to avoid hitting the implant. The plate length should not overlap at the same level as the strut or stem to avoid a stress riser. Ideally two cortical diameters is sufficient overlap beyond the bone defect. If necessary, the implant can be cut to ensure the plate, graft and implant stem end at different levels (Fig. 13.19).
- A cement restrictor can be placed after the trials are removed and the graft secured in order to irrigate the canals for cementation. At this point, voids can be identified and plugged so that cement extrusion and injury to neurovascular structures is avoided. Small defects can be plugged with a moist sterile glove to prevent cement extrusion.

13.11.4 Ulnar Bone Loss

- The type of bone loss encountered on the ulna directs the solution. Voids or perforations need

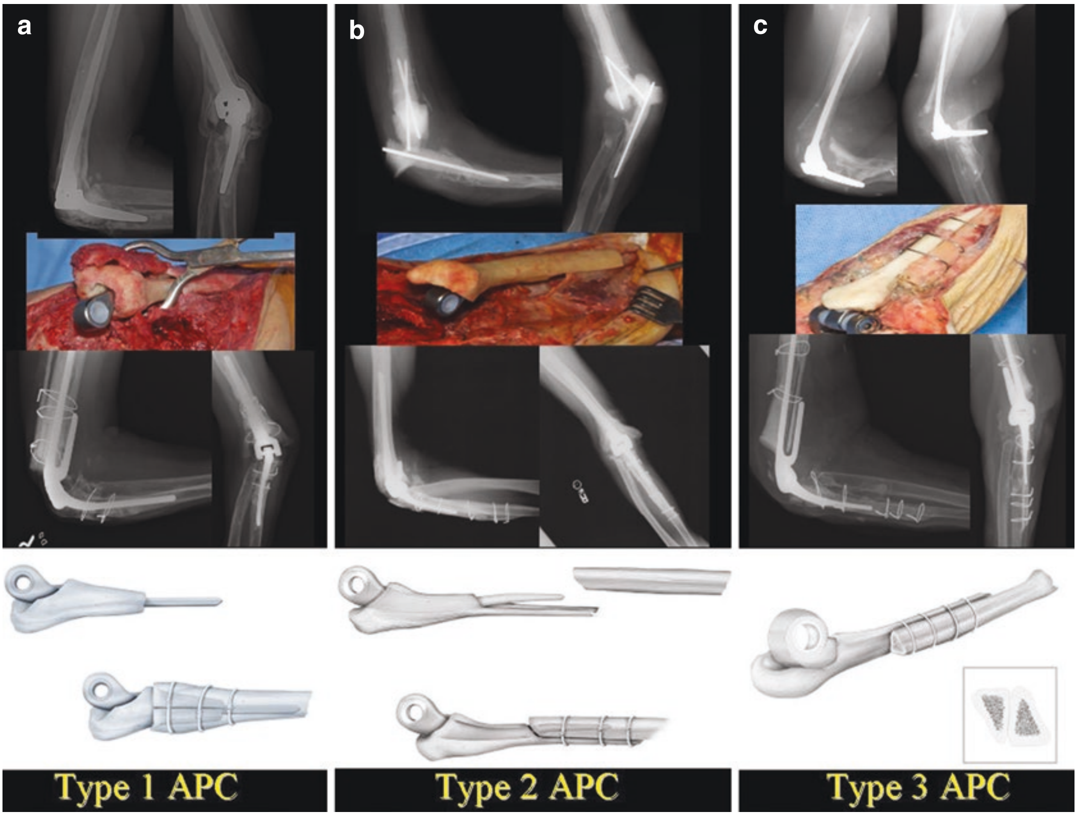

Fig. 13.14 Allograft prosthetic composite (APC) reconstruction types. Type 1 in (**a**) is an intussusception of the graft within the host bone. Type 2 (**b**) is a step cut with a long strut exterior but with the implant cemented within the patient's native bone and type 3 (**c**) is a side-to-side apposition where no part of the implant lies within the native bone

to be addressed with struts or, in the case of an absent olecranon an APC. We utilize a proximal humerus with rotator cuff attachment or an ulna with triceps attachment to allow for restoration of the extensor mechanism.

- The bone and soft tissue of the allograft allow for coverage of the implant which prevents erosion of all-soft tissue reconstructions, but the surgeon must ensure skin closure is still possible with the graft in place.
- The endosteal side of the graft is contoured to the posterior aspect of the ulna to allow for maximal host to bone contact (Fig. 13.20). By beveling the cortical edges greater apposition of the graft to host junction is achieved.
- A proximal humerus has anatomy that can mimic the ulna but the larger diameter allows for nesting of the allograft to the host for excellent apposition (Fig. 13.18).
- We utilize stainless steel wire to provisionally hold the graft in place for trialing and placement of a plate or circumferential wires around the graft and host for compression and healing. The knots of the wire should not be placed on the subcutaneous border to avoid skin irritation but placed below muscle on the lateral side of the ulna.
- A compression plate is selected which should end at a different level from the strut and stem and be two cortical diameters beyond the bone defect. The screws are directed around the stem and allow for compression of the graft to the host bone. This step is performed first to avoid cement extrusion into the graft host interface and impeded healing at the graft–host junction.
- Cementing in stages typically allows for better attention to each individual component given

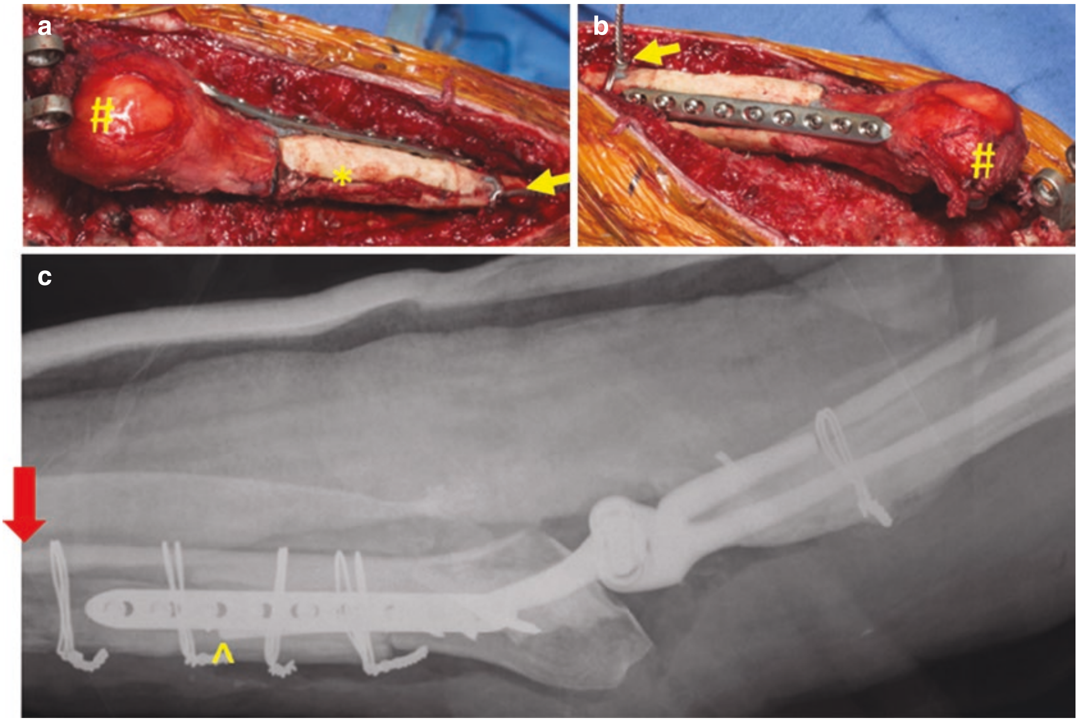

Fig. 13.15 An intraoperative photograph and postoperative X-ray of a type 2 ulnar APC. In (**a**) a posterior view shows the orientation of prior healed struts (*) to the native bone. The new allograft strut is placed on the anterior surface of the ulna as see in the radiograph in (**c**). A wire → is provisionally tightened and then a plate placed in compression along the side of the bone distal to the tip of the implant (^), but shorter than the allograft strut (⇩) to avoid stress risers. The soft tissue attachments of the rotator cuff (#) from the proximal humerus are used for anchor points to reconstruct the triceps

the importance of proper rotation and alignment during curing.

- The soft tissue reconstruction of the triceps is performed with the rotator cuff attachments to proximal humeral grafts is some native tendon remains or the triceps with ulnar grafts if it is severely retracted. Locked sutures help to distribute the forces along the entire soft tissue reconstruction. The graft can be placed below the native triceps to prevent adhesions to the posterior humerus, but if the tendon cannot be identified the graft should be placed on the superior surface to avoid branches of the radial nerve which innervate the triceps proximally.
- Finally, excess cement is removed and the implants are coupled. Hemostasis is confirmed and a thorough wash is used prior to closure. The deep wound is then closed in layers with monofilament sutures and we then routinely use an incisional wound vac.

13.12 Pearls and Pitfalls

Potential problems	Solutions
Retained cement	An arthroscope and fluoroscopy can be employed to ensure complete removal of cement in the case of infected arthroplasty when removal of all foreign material is mandatory
Retained cement plug	A threaded Steinmann pin is drilled into the plug under fluoro guidance and removed with a slap hammer
Cortical bone is softer than cement and the reamer creates a defect in the bone through the path of least resistance and stress riser	Center the entry hole in the cement mantle with a drill utilizing fluoroscopy if necessary prior to placement of a guidewire or use of reamers. Protect nerves from potential thermal damage if the cortex has been violated with a strut graft and wet glove as a dam

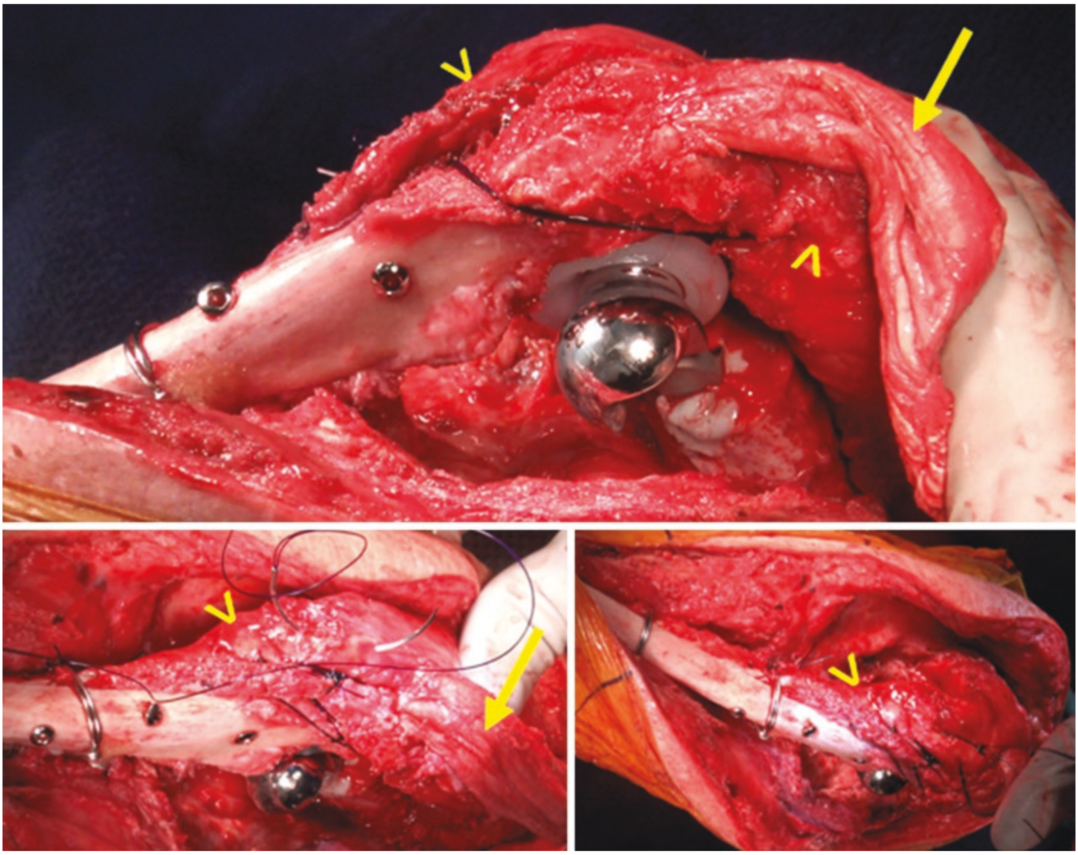

Fig. 13.16 Ulnar type 2 APC with triceps. The native triceps has been repaired medially and deep to the host (>) ulnar and the tendon of the allograft ulna (→) will be incorporated into the repair for a formal triceps reconstruction

Potential problems	Solutions
Well-fixed implant removal	Use thin pencil tip router circumferentially around the implants plasma coating and attempted using a slap hammer. If unsuccessful use an episiotomy or osteotomy for implant removal
Expanded canal	Impaction grafting. Trial during the process to ensure flange will engage anterior cortex and motion is not impeded. Collapse the bone after removing a wedge with a wire if the triceps is under undue tension
Bone incorporation/apposition	Bevel the inner cortex of the allograft for greater surface area contact
Skin breakdown	Shorten humerus to increase soft tissue compliance and decrease closure tension, avoid bulky grafts and subcutaneous wires. Use a wound vac in revision settings
Contracture and loss of motion	Assess soft tissue envelope by reducing ulna on humeral trial. Shorten the humerus to up to 2 cm for better bone stock, engagement of the flange, ease of soft tissue closure and increased motion. Test ROM and remove impinging bone

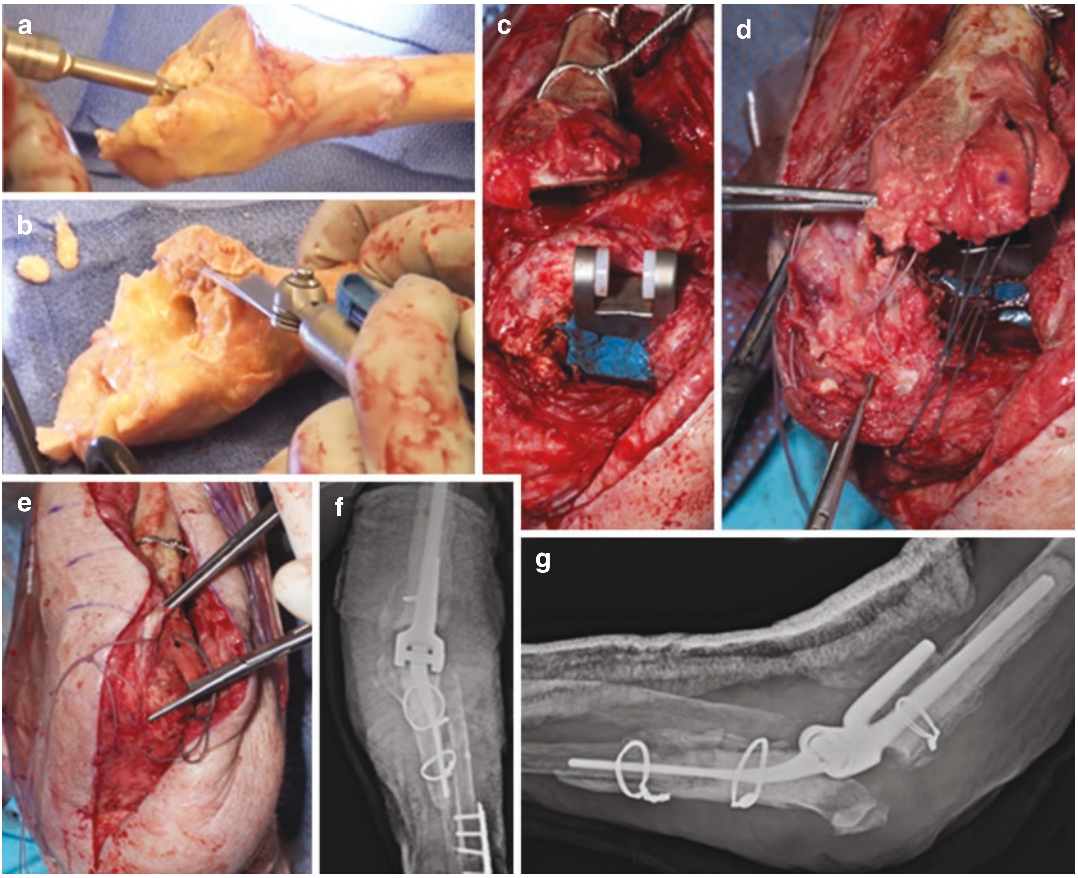

Fig. 13.17 Clinical photographs in (**a**, **b**) show the preparation of the proximal humerus for and ulnar APC. The humeral head is removed and the graft prepared to accept the ulnar component (**a**). The prominent calcar representing the coronoid analog is removed to avoid impingement in (**b**). (**c**, **d**) show a proximal humeral allograft in place over the patient's native ulna with soft tissue attachments of the allograft being used to reconstruct the triceps (**d**) and still ensure soft tissue closure (**e**). The final AP (**f**) and lateral (**g**) radiographs of the implant in place. The graft strut should have been kept slightly longer to avoid a stress riser

13.13 Bailout, Rescue, and Salvage Procedures

13.13.1 Infection

- If revision with bony augmentation is planned and unexpected infection is encountered, a static antibiotic spacer can be used to maintain the soft tissue tension, alignment, and rotation of the upper extremity while treating the infection.
- A Steinmann pin or external fixator pin is coated with antibiotic cement and placed loosely within the humeral and ulnar canals.
- The two pins are coupled with an external fixator coupler and rigidly locked in place.
- Additional cement is then added to interdigitate with the proximal and distal aspects of the bone to maintain rotation and alignment and avoid migration of the construct by allowing for rigid fixation.
- Upon revision, the Masquelet rind allows for ease of dissection and placement of the bulk allograft within the regenerate tissue created by the antibiotic spacer.
- A small the vessel-loop may be clipped loosely around the radial and ulnar nerves to allow for ease of identification upon revision.

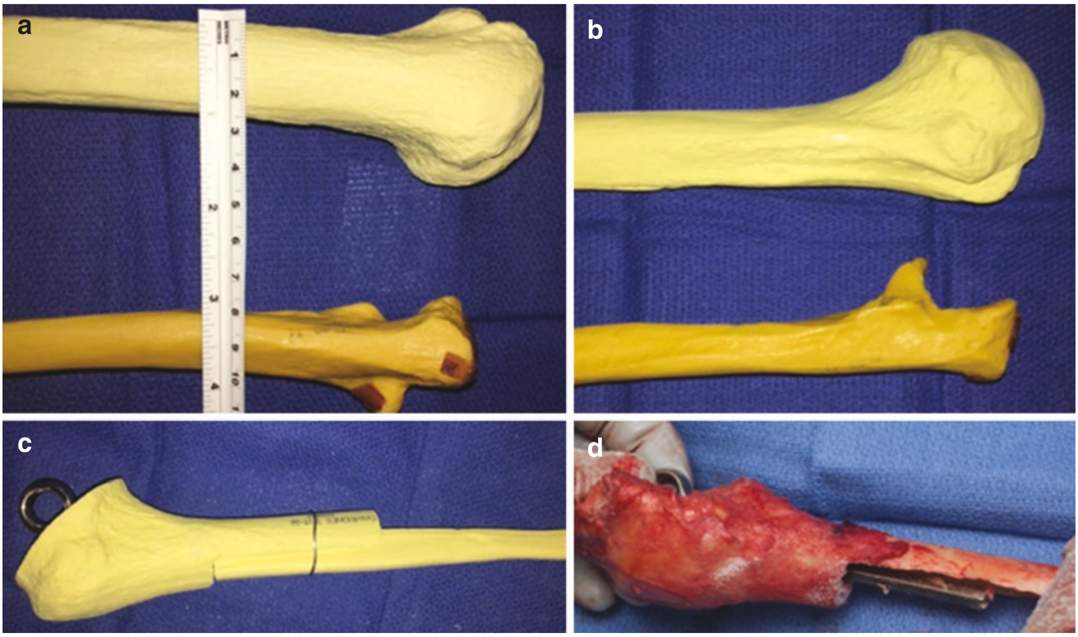

Fig. 13.18 Sawbones are used to illustrate the similar proximal geometries of the ulna and humerus comparatively from the posterior (**a**) and lateral (**b**) aspects. The ulnar implant has been placed in (**c**) within the humeral allograft and joined to the ulna. The clinical photograph in (**d**) shows the ulna and strut which, in this case, will be placed anterior on the host. The proximal humerus is slightly larger than the ulna and allows for excellent apposition and the additional strength of thicker cortices

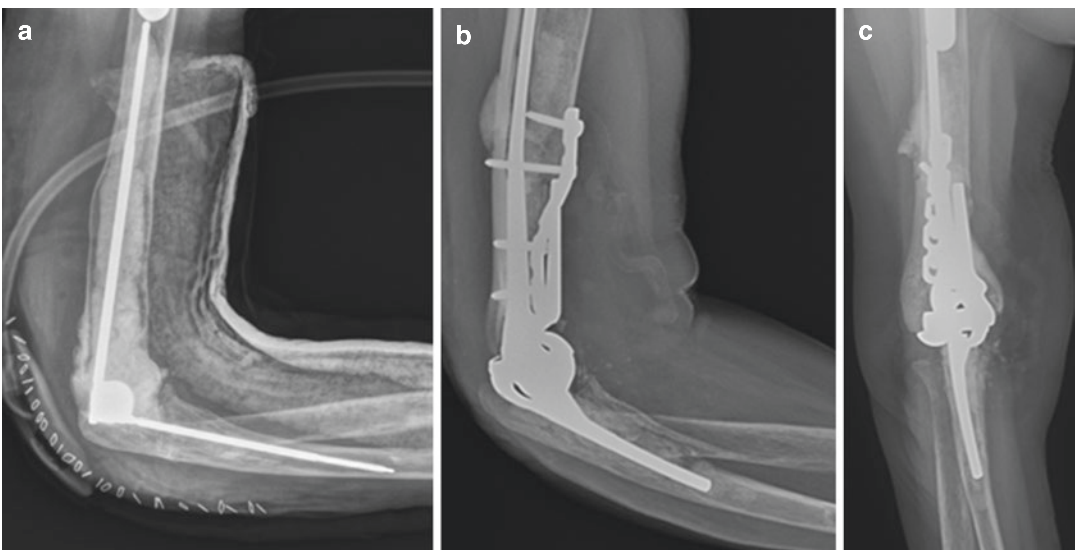

Fig. 13.19 Radiographs prior to and after humeral APC. An antibiotic spacer was used in (**a**) to stage the reconstruction with APC. A lateral (**b**) and AP (**c**) radiograph show the final reconstruction. The stem tip has been cut short to allow the stem of the elbow arthroplasty to partially overlap the stem of the shoulder arthroplasty and avoid a stress riser. The plate, in this case a pelvic recon plate, has been bent to allow for the transition from the allograft to the patient's native bone and screws placed just lateral to the stem to provide for some compression and rotational stability. The strut in this case was placed posterolaterally. A small cortical defect allowed for a path for a small amount of cement extrusion

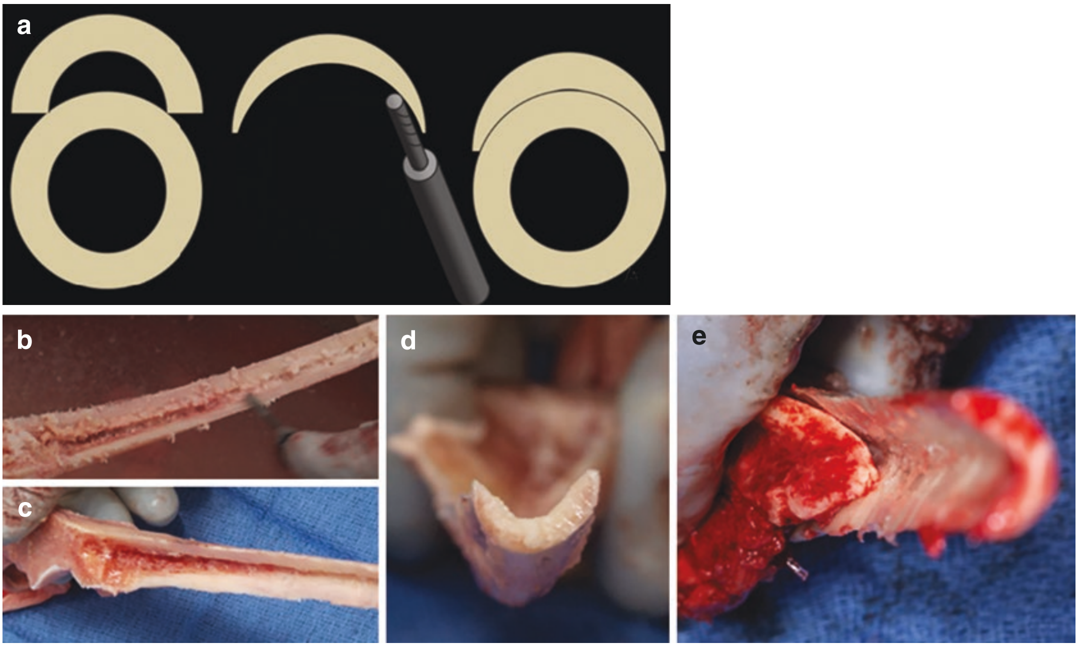

Fig. 13.20 An illustration (**a**) of beveling the cortex of the graft to achieve better apposition to the native bone. In (**b**) the graft is being beveled and the trabecular bone removed with a helicoidal bur. A clinical photograph in a longitudinal (**c**) and axial (**d**) views. The ulnar graft (*) is placed against to the host bone (>) in (**e**) to test for fit and cortex tot cortex apposition

13.14 Postoperative Care

- The wound vac is left in place for 7–10 days and the patient held near full extension an anterior splint for 1 week to fully allow for soft tissue healing.
- If the triceps was reconstructed, we place a brace with a flexion block to 30° at the first follow-up visit and increase flexion by 15° weekly until 90° at which time the brace is removed and patients are allowed activities as tolerated.

13.15 Outcomes

- Short-term outcomes show excellent functional improvements with Mayo Elbow Performance Scores (MEPS) in the 80s for APC's [8]. For impaction grafting, incorporation is reasonable with only grade-1 and 2 resorption reported which did not compromise implant stability, and mean MEPS scores also in the 80's [6, 7]. Long-term outcomes for survivorship are still to be determined as to the durability over time of these constructs, but alternatives to reconstruction in these situations which provide some function are lacking.

13.16 Complications

- Nerve injuries, intraoperative fracture, heterotopic ossification, and arterial injuries during cement extraction and dissection due to loss of normal anatomic architecture are all reported complications. The largest complication, however, is infection, particularly where staging for infection is performed. Multiple prior operations increase the risk of infection as does the operative time which is necessarily increased in these complicated cases. We are successful in treating infection with staging these techniques in about 70% of patients [8].

- Late allograft fracture can occur after reconstructions with bulk allograft and usually happens at the junction of the host to the allograft bone. Using a strut extension from the allografts and larger allografts has helped decrease this complication.

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14 Interposition Arthroplasty of the Elbow

Mark Morrey, Daniel Austin, Thomas Rogers, and Bernard Morrey

14.1 Introduction

Elbow arthrodesis is one of the most difficult and uncommonly performed reconstructive procedures at the elbow. Unfortunately, unlike arthrodesis of other joints, elbow arthrodesis tends to be a dysfunctional reconstructive option. Therefore, it is important to have the technique of elbow interposition arthroplasty in one's armamentarium as it is the only viable functional reconstructive option for the younger active patient with end stage arthritis.

14.2 Indications/Selection

In general, candidates for interposition arthroplasty are younger patients, less than 60 years old, with an activity level that exceeds the recommended restrictions imposed by the artificial elbow. There is no rigid age guideline and activity is the key determinant. The most important selection factor for interposition is whether minimal or no activity restriction is more important than reliable pain relief. As with all elective interventions, but especially so with interposition arthroplasty, it is paramount to know the patient's goals and expectations. This point cannot be overemphasized. Since the outcome of interposition tends to deteriorate with time, it is considered a temporizing or bridging procedure as an elbow replacement is highly possible in the future [1].

14.3 Contraindications

There are some well recognized contraindications to interposition arthroplasty, in addition to active infection.

1. Instability of the ulnohumeral joint [2].
   This may be considered a relative contradiction if it is possible to reliably stabilize the unstable elbow at the time of surgery.
2. Varus/valgus angular deformity greater than 10°–12°.
   Assessment includes whether the deformity can be corrected with distal humeral preparation. Rarely a staged osteotomy may be considered under the proper circumstances.

There are several relative contraindications:

1. Pain at rest. In this case, the surgeon should rule out low grade infection and psychosomatic conditions causing poor pain tolerance.
2. A painful arc of motion that exceeds 90° [2].

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14.4 History

Interposition arthroplasty is equally effective for inflammatory and post-traumatic arthritis [3]. It is important to pay attention to previous surgery for evidence of infection. Historical information to suggest possible prior infection includes prolonged drainage [4], treatment with antibiotics after prior procedures, and subsequent early additional surgery.

14.5 Physical Examination

Confirmation of joint stability is crucial. Location of prior surgical scars is likewise obvious, but important. The surgeon should always be considerate of a prosthetic elbow in the future. If there is any question about the quality of the skin involved in the surgical exposure, we obtain an opinion from a plastic or hand surgery colleague. If there is serious concern, a staged procedure is done after the soft tissue problem has been addressed. Loss of motion is characteristic of the post-trauma candidate and also is common in the inflammatory setting. Forearm rotation is usually normal or near normal. The presence of a radial head is extremely important to assess and preserve at surgery since it is a valuable component to valgus stability.

14.6 Imaging

Plain AP and lateral films are often all that is necessary. If there are concerns regarding post-traumatic distortion, then a three-dimensional computer tomographic reconstruction can be important or even critical (Fig. 14.1). If questions regarding deformity, articular distortion and instability exist even at the time of surgery, it is important to be prepared to pivot to a prosthetic replacement during the procedure. This important point should be clearly discussed with the patient.

14.7 Decision/Discussion

As with all elective procedures, the risks and benefits are carefully reviewed. It is essential that the goal of the patient is understood and revisited at the time of the decision to go forward. The clearest way to assure the needs of the patient are understood is to frame the question: "If I can only relieve pain, but with restricted activity, or allow near normal activity but with some residual pain, which of the two outcomes would you prefer?" In the risk benefit discussion, it is important to note that the complication rate is comparable to replacement. The final point in the discussion is the possibility of an unsuccessful outcome and to review the options and implications of a subsequent operation.

14.8 Preoperative Planning

Three special considerations are part of the preoperative preparation in addition to the potential need for consultation regarding the quality of the soft tissue:

1. The graft. We use an Achilles tendon allograft. It has adequate size to cover the entire distal humerus, does not require harvest, can be used to augment the collateral ligament repair (or reconstruct), and has considerable thickness allowing increased durability. If a coronoid reconstruction is anticipated, the graft includes the calcaneal attachment. The portion with the Achilles attachment is placed in a manner to articulate with the trochlea.

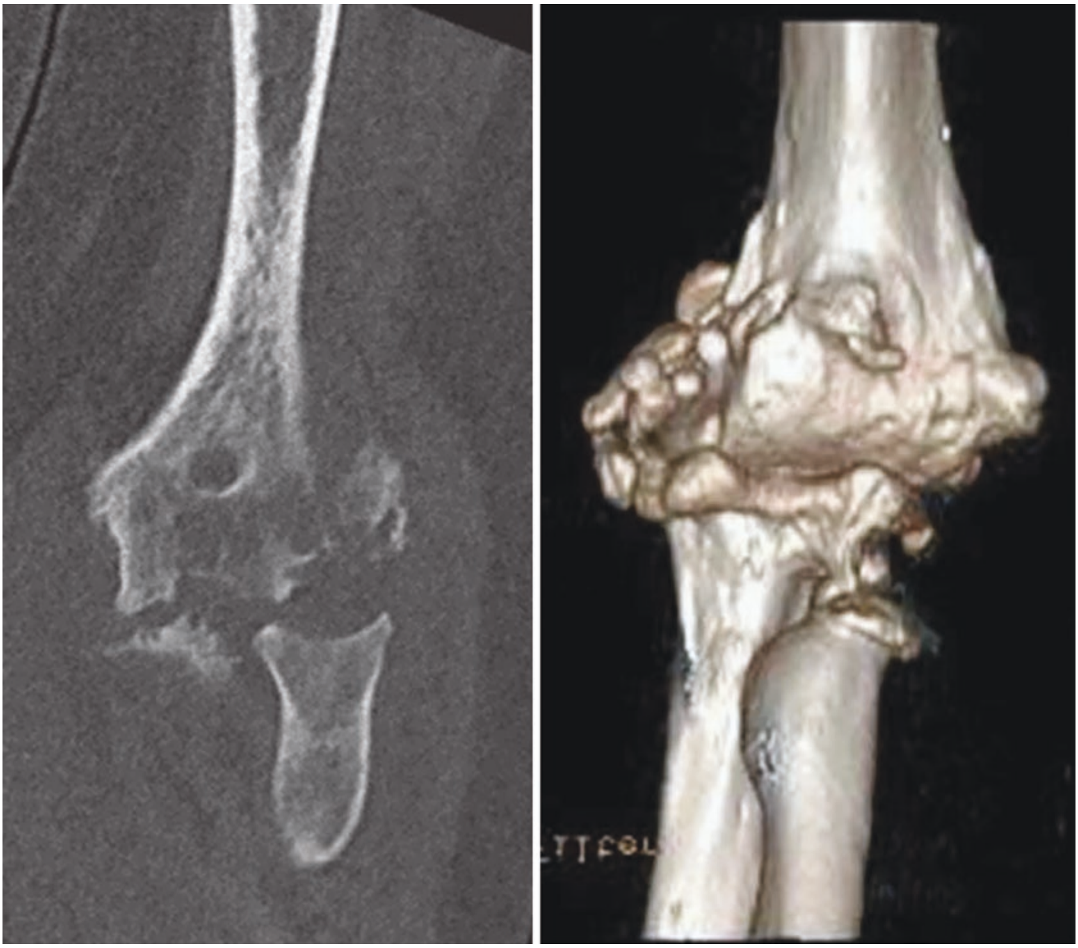

Fig. 14.1 Cystic change on the CT scan can help the surgeon understand if interposition is a viable option. Patients with cystic changes of the distal humerus are not good candidates as the subchondral support for the graft is absent which can lead to collapse and subsequent instability. The stars represent areas of cystic change including collapse of both the capitellar and the trochlear surfaces

2. External fixator. Originally, we felt the use was a key to the success of the procedure. Today we feel this is still of great value, especially in selected cases, but not necessary in every patient. However, we do have this available for all interposition procedures, as discussed below.
3. Prosthetic implant. While we do not open the surgical trays, we have a prosthetic readily available in case it is desirable to replace instead of interposing.

14.9 Procedure [5]

1. Positioning.
   We prefer supine with the sterile arm brought across the chest. Tilting the table about 10°–15° away from the operated side facilitates support and position of the arm during surgery.
2. Incision.
   We use the prior incision if possible. If a new incision must be made, we use a straight pos-

terior incision about 15 cm in length, considering the possibility of a subsequent replacement procedure.

3. Skin flaps.
   Full thickness skin flaps are raised, laterally to the lateral epicondyle and medially anterior to the medial epicondyle to assure visualization and protection of the ulnar nerve through the cubital tunnel.
4. Ulnar nerve.
   The ulnar nerve is identified proximal to the epicondyle and exposed into but not through the cubital tunnel. If the nerve is symptomatic preoperatively, it is released and transposed subcutaneously.
5. Triceps sparing exposure. We have always preferred a triceps sparing approach. Details have been well described elsewhere. For interposition the lateral collateral ligament is detached, the ulna is rolled off the humerus hinging on the preserved medial collateral ligament (Fig. 14.2). Most procedures are done for stiffness, thus an aggressive soft tissue release is performed initially to facilitate subluxation of the ulna but also achieving restoration of as much motion as possible. Great care is taken to assure the ulnar nerve is not compressed with ulnar subluxation, if so it is translocated at this time.
6. Radial head.
   The radial head is **never** resected if this can be avoided. If it is involved in the pathology, we prefer to debride and preserve as opposed resect.
7. Humeral preparation.
   An oscillating saw removes residual cartilage and sclerotic bone. An effort to maintain trochlea contour is important for subsequent articular stability.

   CAUTION—Do not remove any more subchondral bone than is necessary to have bleeding bone. Avoid covering soft cancellous bone with the graft, as this tends to resorb.

   TIP—By drawing the oscillating saw toward you, it creates a shaving or planning action. This allows control of the amount of bone removed and facilitates smooth contouring of the humeral surface (Fig. 14.3).
8. Application of the allograft.
   The Achilles tendon allograft affords a sufficient amount of tissue to cover virtually any humeral dimension. Assess the size of the graft and align with the width of the humeral articular surface. Attempt to get the thickest part over the anterior, distal humeral contour. Sutures are placed in the graft in a way to ensure the "rough" surface is applied to the

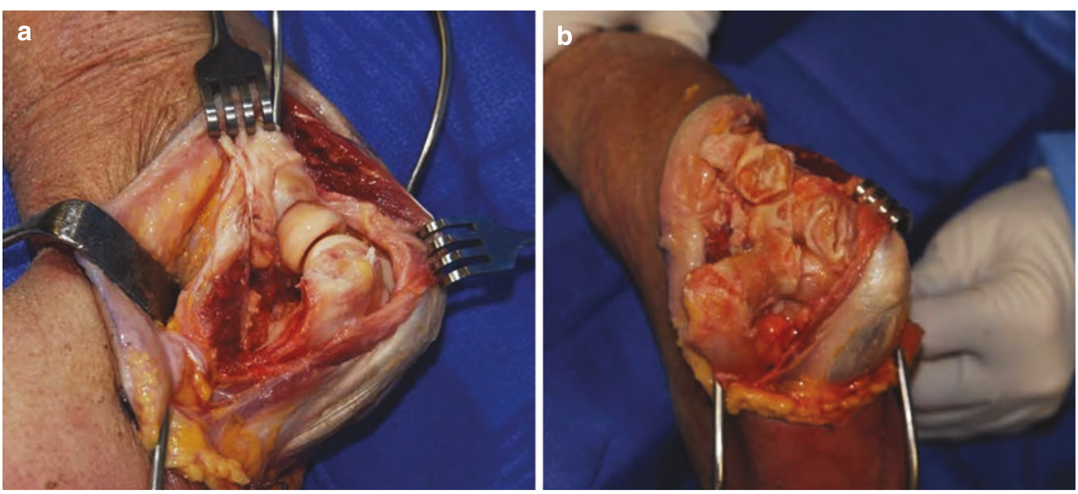

Fig. 14.2 A triceps preserving approach is favored. An extensile modified Kocher that releases the lateral collateral ligament and about 20% of the lateral triceps attachment (**a**) permits the radius and ulna to be rotated medially providing adequate exposure of the distal humerus while preserving the medial collateral ligament (**b**)

bone and are aligned with the holes placed in the humerus. Drill holes through the medial and lateral margins of the distal humerus followed by two equally spaced holes roughly mid trochlea, and at the incisura trochlearis between the capitellum and lateral trochlea (Fig. 14.4). This is a crucial step to assure the graft is stretched tightly across the medial–lateral dimension of the humerus. The graft is trimmed at the suture line after the sutures are placed in the anterior portion of the graft. With a suture inserted from posterior, the suture in the graft is retrieved and brought through the distal humerus from anterior to posterior. The graft is draped over the distal humerus and, using a free needle, the suture is passed through the posterior aspect of the graft and tied (Fig. 14.5). We prefer to first secure the medial margin then the lateral margin of the graft. The middle two sutures are then placed and tied.

Tip 1. To be sure the graft is tight over the distal humerus, tension is placed on all the free sutures to assure the anterior portion of the graft is tightly applied to the anterior aspect of the humeral articulation.

Tip 2. To further assure the graft is tightly opposed to the distal humerus the sutures are placed slightly more distally in the graft than the hole in the humerus. When tied this will tighten the graft over the distal humerus (Fig. 14.6).

Tip 3. We tie the first suture to stabilize the graft, but place all the remaining sutures without tying to facilitate graft manipulation and assure proper suture placement.

9. Collateral ligament(s). Since instability is one of the major causes of failure this also is a critical step in the procedure. If there is good tissue, the ligament is discretely repaired with a running locked stitch. However, if the tissue is inadequate, the repair is reinforced with a portion of the Achilles allograft fashioned to reconstruct the lateral complex (Fig. 14.7). If there is deficiency in both collateral ligaments, a "loop" reconstruction is performed. A medial

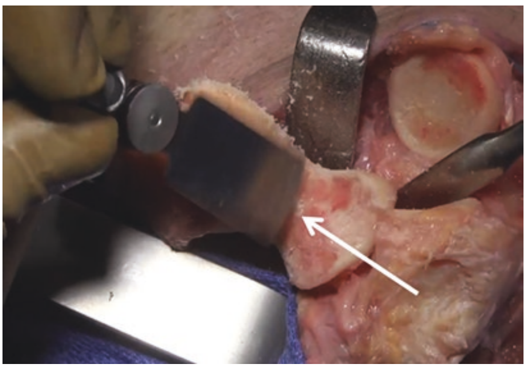

Fig. 14.3 The oscillating saw is used with a retrograde motion to allow a controlled contour of the distal humerus

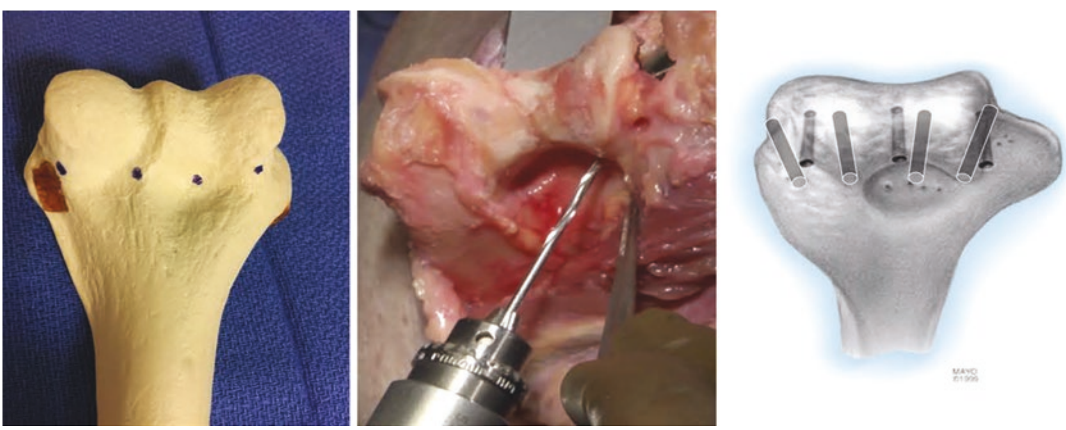

Fig. 14.4 Four drill holes are made taking care to assure the medial and lateral most tunnels diverge from posterior to anterior to assure coverage of the entire width of the distal humerus

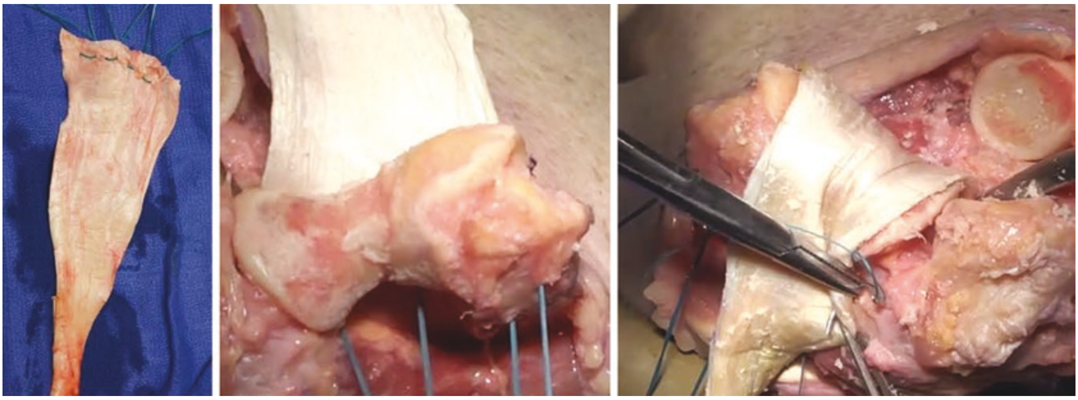

Fig. 14.5 The sutures are placed

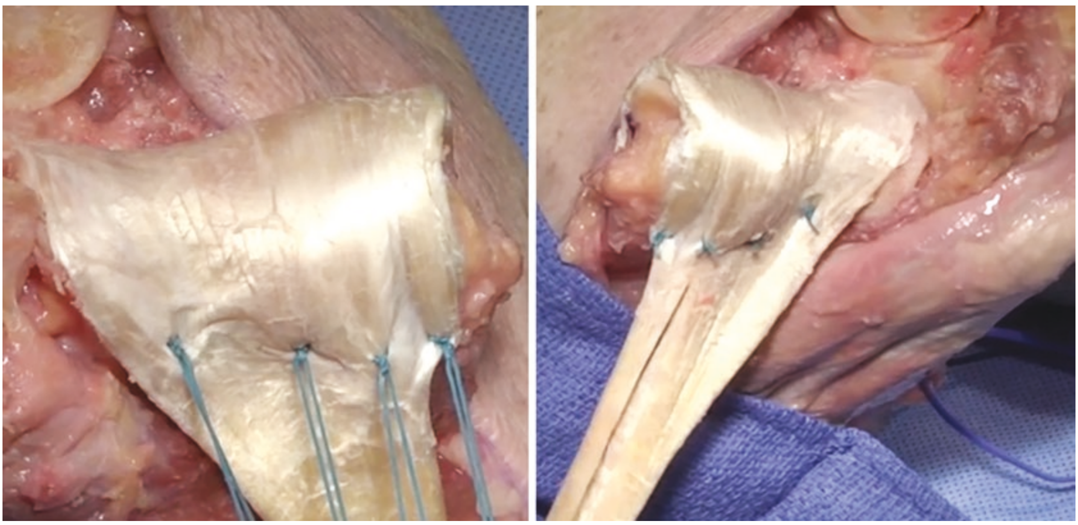

Fig. 14.6 By placing the posterior suture slightly distal to the tunnel the graft will be drawn taught when the suture is tied

and lateral strip of the residual graft is fashioned and a bone tunnel is created between the sublime tubercle medially and the crista supinatoris laterally (Fig. 14.8). Each collateral reconstruction is secured to the anatomic site of their respective humeral attachment. A running locked suture is placed in each arm of the graft and the ends of the allograft reconstruction are introduced into and pulled through the ulnar tunnel. The elbow is placed through an arc of flexion/extension to assure isometry of the humeral attachments. With the elbow perfectly reduced the sutures are secured to the humerus to restore collateral ligament integrity.

10. Articulated external fixator (ExFix). The fixator allows protection of the collateral ligament healing as well as separating the ulna from the humerus while permitting a flexion arc that is void of sheer stress on the graft or strain on the collateral ligament repair/reconstruction.
    A distinct advantage of using an ExFix is the ability to "examine" the elbow 3 weeks after surgery.

While we prefer the DJD II from Stryker for its simplicity and effectiveness (no royal-

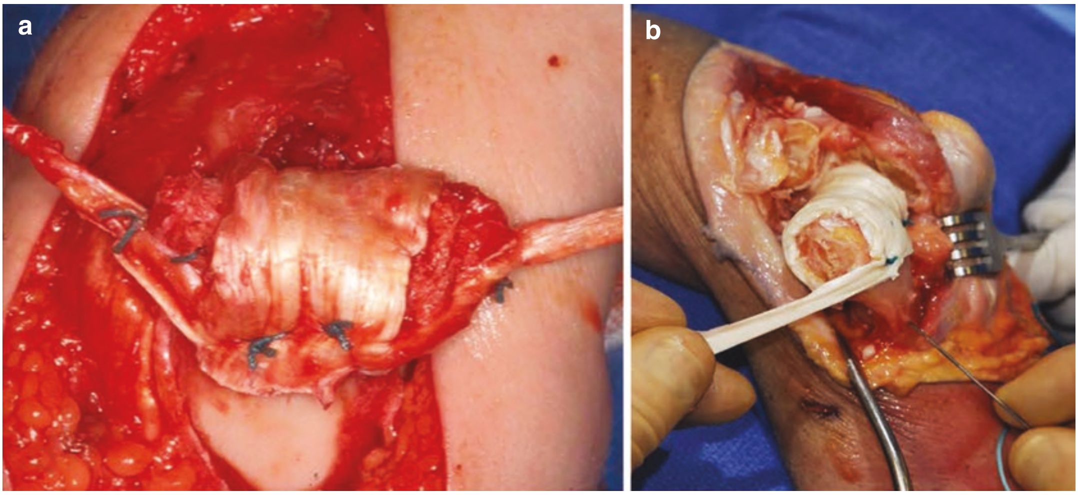

Fig. 14.7 To assure collateral integrity strips are fashioned from the excess graft (**a**) and attached to the anatomic flexion axis (**b**). The graft then reinforces the deficient collateral ligament

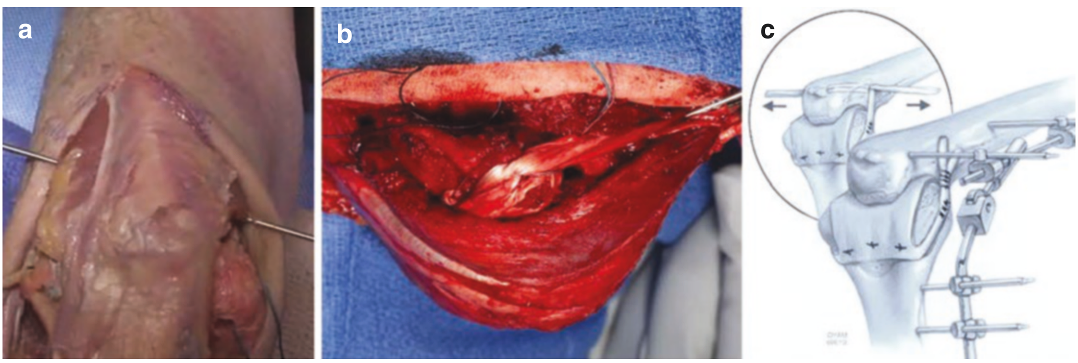

Fig. 14.8 If both sides are deficient a "sling" reconstruction is performed by creating a tunnel between the sublime tubercle medially and the tubercle crista supinatoris laterally (**a**). Each arm of the graft is secured to the axis of rotation and brought through the ulnar tunnel (**b**) and then secured to the graft material at the humerus (**c**)

ties currently received), any articulated fixator is effective.

First, the "axis pin" (a smooth Steinman pin that is the diameter of the hole of the ExFix) is tapped in place using the targeting device to assure replication of the flexion axis of the flexion/extension arc (Fig. 14.9). The outrigger of the ExFix device is placed over the axis pin. The humeral arm of the fixator is aligned with the anterior cortex of the humerus.

Next, the "proximal humeral pin" is placed under direct vision or palpation through the open wound. Anticipate pin position in the closed skin when making the puncture site for the pins. The proximal pin is placed one epicondylar axis length proximal to the flexion axis (Fig. 14.10). Anatomically, this location is 40% of the length of the epicondylar axis distal to the radial nerve [6]. A tissue protector should be used with the proximal humeral pin placement.

11. Postapplication: AP and lateral radiographs are taken to confirm joint integrity. Next, distract the elbow 2–4 mm. Examine and document the flexion arc before and after application of the ExFix.

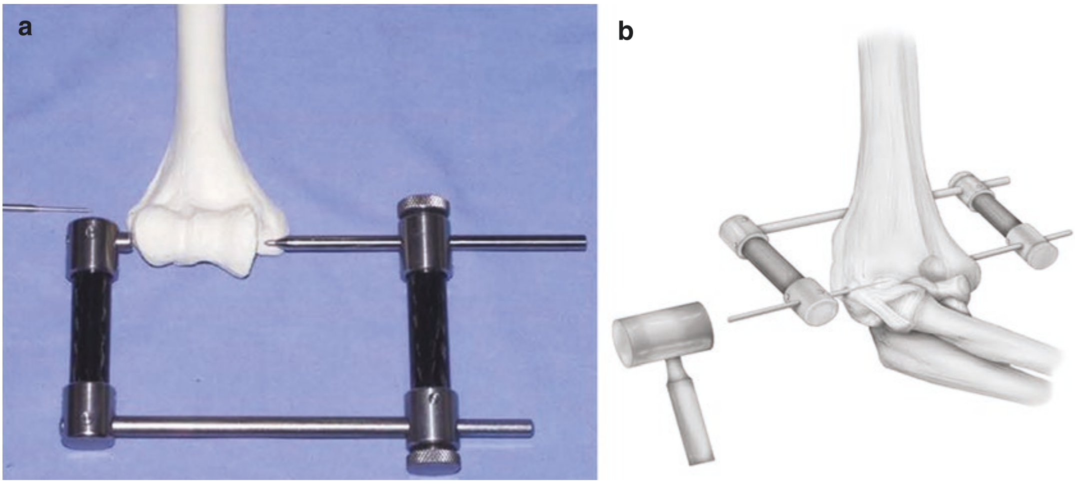

Fig. 14.9 A guide is helpful to introduce the axis pin for the articulated external fixator laterally (**a**). The stylus is inserted with a mallet, avoiding potential suture cut out caused by a drill (**b**)

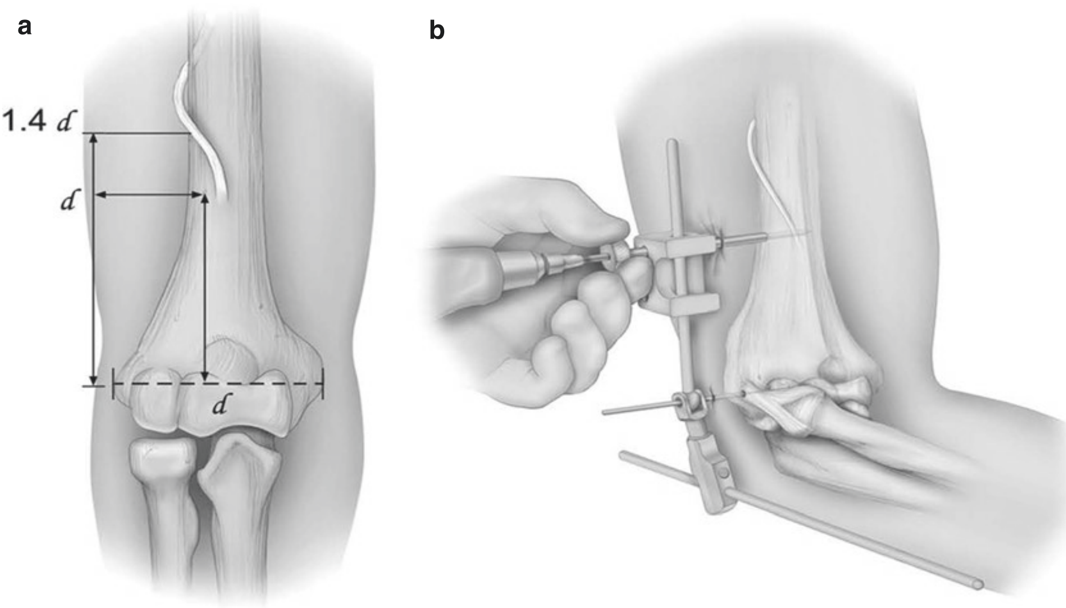

Fig. 14.10 The radial nerve is at risk if the proximal humeral pin is more proximal than 1 epicondylar width (**a**). Tissue protecting trocars are also used in the placement of the humeral pins (**b**)

14.10 Post Procedure

Simple cleaning of the pin sites with soap and water is adequate but betadine swabs are also supplied. The patient is encouraged to use the opposite extremity to assist ROM as tolerated. No effort is made to develop a functional arc if this is not readily attained. No formal therapy is prescribed except as may be needed for the hand or shoulder.

14.11 Examination Under Anesthesia

This is performed at 3 weeks post-operative. The patient is placed under sedation or a brief anesthesia. The ExFix and sutures are removed and the elbow is "examined" [7]:

1. Perform a gentle flexion/extension stretch, repetitive and gradual. Regain ROM described in the operative note.
2. Observe smoothness of the flexion arc.
3. Check for varus/valgus stability with fluoroscopy.

14.12 Further Rehabilitation

1. Activities as tolerated with Mayo elbow brace as needed.
2. Assess patient at 6 and 12 weeks post-operative with flexion arc testing. Subsequent assessment is optional. We obtain 12 and 24 month post-operative surveillance information.

14.13 Results and Expectations

Between 1996 and 2003, 69 elbows were treated with interposition arthroplasty with an Achilles tendon allograft at the Mayo Clinic [3]. Detailed surveillance was obtained at a mean of 6 years post-operative for 38 patients who were an average age of 39 years. The mean Mayo Elbow Performance Score improved from 41 before to 65 points after surgery ($p < 0.0001$). Thirteen patients had a good or excellent result, 14 had a fair result, and 11 had a poor result. The remaining seven patients had a revision. Of interest, 12 patients rated the elbow as somewhat better and 19 rated the elbow as much better. All but one of these 31 patients indicated that they would have the procedure again (Figs. 14.11 and 14.12). In 2008, Blaine documented 11 of 13 (85%) satisfactory outcomes at a mean of 9 years after total elbow salvage for a failed interposition arthroplasty. While the objective outcomes are not impressive as a salvage procedure in young patients, the fact that almost 90% said they would undergo the procedure again based on their outcome prompts the continued use of this procedure in this clinical setting. We have nothing else to offer.

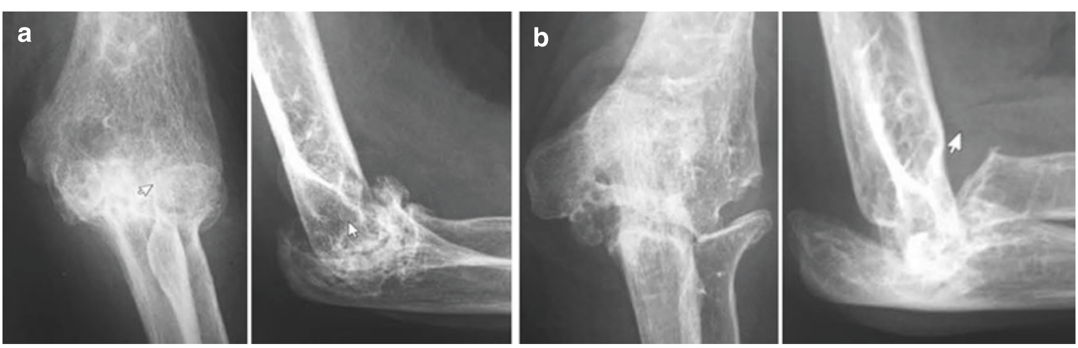

Fig. 14.11 End stage arthritis with 7/10 pain and 60–90% motion in 60-year-old patient with Wilson's disease (**a**). She requested and underwent interposition of the right elbow at age 63. Radiographs at 3 years post-op (**b**)

Fig. 14.12 Three years after surgery, the patient was without pain, reported a MEPS score of 95, and had functional motion (seen during COVID-19 pandemic)

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15 Open Treatment of the Stiff Elbow

Pierre Mansat

15.1 Description

Elbow stiffness can be classified as extrinsic or intrinsic. Extrinsic contracture typically involves only the soft tissues around the elbow, sparing the joint space. Intrinsic contracture is associated with joint articular involvement. Both can be associated as a mixed contracture. Conservative treatment can give good results if the contracture is mainly of extrinsic origin and of short duration. With failure of nonoperative treatment surgical release may be indicated. Surgical techniques will be chosen according to the type and the severity of the stiffness. Chronic extrinsic stiffness is usually managed by arthroscopic or surgical release. When less than 50% of the joint surface is involved in an intrinsic stiffness, the same treatment can be proposed with less reliable results. However, when more than 50% of the articular surface is involved, an interposition arthroplasty may be the treatment of choice in young patients, whereas in older patients a total elbow arthroplasty has been considered the desirable option.

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15.2 Key Principles

The limited open contracture release or "column procedure" provides access to the anterior and posterior capsules. It also affords exposure of the coronoid and olecranon processes as well as the anterior margins of the capitellum and trochlea and of the coronoid and olecranon fossae. It can be performed from a lateral approach or a medial approach.

15.3 Expectations

Recovery of a functional range of motion at least 30° flexion contracture and flexion to 130°. Best expectations can be reached for extrinsic stiffness.

15.4 Indications

The process is considered chronic or nonresponsive to nonoperative management at 6–12 months after injury. Indication for capsular release is very individual depending on the needs or occupation of the patient, in general, flexion contracture greater than 30° and flexion less than 110°. Surgical intervention follows only after a very careful discussion of the risks and benefits of surgery. The potential for improving motion at the

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expense of stability, strength, and pain is also specifically discussed.

15.5 Contra-Indications

Limited involvement and limited soft tissue contracture argue against this procedure. An inadequate period of an appropriate splint program is also a contraindication. Intrinsic lesions are not absolute contraindications, but a lower level of improvement has to be expected in these cases. This "simple" release cannot be done in instances requiring interposition of the joint. Interposition is used if any of the following three contraindications to the column procedure are present: (1) a significant alteration of the articular contour, (2) loss of joint cartilage (50%), or (3) pathology that requires release of one or both collateral ligaments. Additional contraindications include motor deficiency or spasticity especially involving the flexor muscles and residual impairment from closed head injury.

15.6 Special Considerations

Diagnosis of the contracture is made by identifying a characteristic history and performing a physical examination. Joint involvement is confirmed by plain radiographs. The anteroposterior view gives good visualization of the joint line, but the lateral view demonstrates osteophytes on the coronoid and at the tip of the olecranon, even when the joint space is preserved. Arthro-computed-tomography scan with three-dimensional reconstructions is especially valuable to estimate joint involvement, but also to identifying nerve involvement associated with heterotopic ossification and marginal osteophytes that may be overlooked by plain radiographs.

Extrinsic contractures almost always involve the anterior capsule and less commonly the posterior capsule and extensor mechanism. Before surgery, a decision to approach the capsule from the lateral or medial aspect is made. If the ulnar nerve is to be addressed or there is extensive medial or coronoid arthrosis, the medial approach is of value. If the radiohumeral joint is involved or if a simple release is all that is required, which is the most common situation, the lateral "column procedure" is carried out.

15.7 Lateral Column Procedure: Procedural Steps

15.7.1 Positioning and Exposure

Either general or regional anesthesia may be used. The patient is placed supine with a sandbag under the ipsilateral extremity, or the table is tilted to 10° away from the involved extremity. The arm is draped free and brought across the chest. The proximal one-half of a Kocher incision, which extends 3–5 cm proximal to and 3 cm distal to the epicondyle, is used if there is no previous incision and if there are no symptoms related to the ulnar nerve (Fig. 15.1).

Note: It is useful to palpate the "column" and the radial head to properly orient the skin incision. If there are symptoms related to the ulnar nerve and there is any thought that the patient may require an elbow replacement or interposition, the long posterior incision is used. The nerve is explored by elevating the medial flap. A limited medial exposure is acceptable, especially if subsequent arthroplasty is unlikely. If there is evidence of compression before or after the capsular release, the nerve is decompressed as necessary.

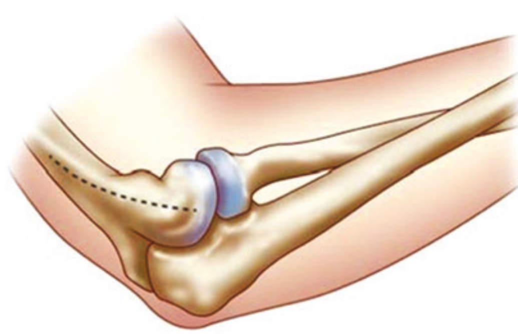

Fig. 15.1 The lateral column procedure: incision on the proximal one-half of the Kocher incision

15.7.2 Exposing the Anterior Capsule

In order to release the anterior aspect of the capsule with minimum disruption of normal tissue, the fleshy origin of the extensor carpi radialis longus (ECRL) and the distal fibers of the brachioradialis are identified. Release of the origin of the ECRL and the distal fibers of the brachioradialis from the humerus using a cutting cautery provides direct access to the superolateral aspect of the capsule (Fig. 15.2). The brachialis is swept from the anterior aspect of the capsule with a periosteal elevator.

Note: The maneuver to strip the muscle from the capsule is directed medially and posteriorly. If the dissection is directly only medially, one may slide anterior to the brachialis fibers.

The capsule is entered at the anterior radiohumeral joint, and assessment of the thickness of the capsule is noted. A retractor with a blade–shaft angle of 130° protects the brachialis, the radial and median nerve, and the brachial artery. The anterior aspect of the capsule is grasped and is excised as far medially as possible (Fig. 15.3).

The most medial aspect of the capsule can sometimes be difficult to visualize but can be palpated. This is isolated and is incised from inside out to complete the release.

Note: Proper positioning of the "special" retractor blade protects the anterior structures during this maneuver.

The elbow is extended, and any remnant adhesion is gently lysed. At this time, if there is full extension or if extension is within 10° of normal and there are no radiographically evident spurs on the olecranon, no additional release is needed. The capsule is left open, and the wound is closed.

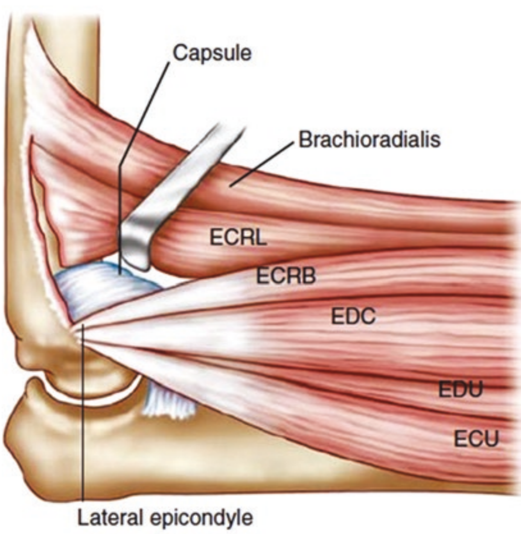

Fig. 15.2 The brachioradialis and ECRL are elevated from the humerus exposing the anterior capsule

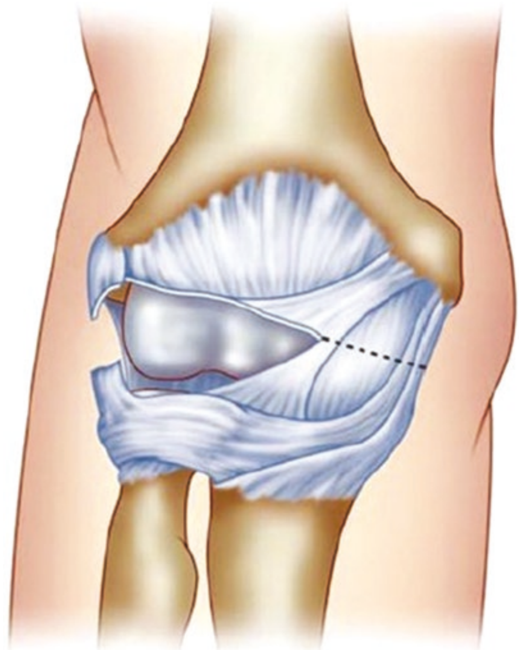

Fig. 15.3 The anterior capsulectomy is performed from the lateral side

15.7.3 Exposing the Posterior Capsule

If flexion is limited, if extension is not complete, or if posterior impingement pain is present, the posterior column is exposed. The triceps is elevated from the posterior aspect of the humerus along with the humeral attachment of the anconeus. The posterior aspect of the capsule is released, and the olecranon fossa is cleaned of soft tissue. The tip of the olecranon is removed with an osteotome if there are osteophytes. A high-speed burr removes anterior and/or posterior humeral osteophytes.

The amount of flexion and extension of the elbow is assessed. Typically, full extension is readily attained. If there is at least 130 degrees of flexion, nothing more needs to be done posteriorly. If flexion is limited, the coronoid is inspected and any osteophytes are removed.

Note: Place the index finger in the anterior and posterior capsules to assess residual capsule tightness or impingement.

If any of the concerns with the ulnar nerve are present, the ulnar nerve is inspected. It is decompressed or translocated. If simply decompressed, stability of the nerve in the cubital tunnel is assessed through the full arc of flexion and extension.

15.7.4 Postoperative Management

If the neurologic examination in the recovery room reveals normal findings, a brachial plexus block is administered. The arm is elevated as much as possible, and continuous passive motion is begun on the day of the operation. Indometacin can be prescribed (75 mg/day during 2 weeks) to decrease postoperative inflammation reaction and pain, and to lower the risk of adhesions and ossifications. The patient is dismissed the following day. If obtaining extension is a problem, a brace is used at night. Physical therapy is not used, but a detailed program of therapy with the adjustable brace, which depends on the motion before and after the procedure, is prescribed. The splint program employs the brace allowing flexion and extension torque with the same device. The program typically begins with 20 h/day for 3 weeks, then the brace is used at night for 3 months.

15.8 Medial Column Procedure: Procedural Steps

If a medial approach is chosen, same steps are described on the medial side.

15.8.1 Approach

The skin incision may be a posterior skin incision or a midline medial one. The key to this exposure is identification of the medial supracondylar ridge of the humerus. At this level, the surgeon can locate the medial intermuscular septum, the origin of the flexor–pronator muscle mass, and the ulnar nerve.

15.8.2 Exposing the Ulnar Nerve and the Medial Fascia

Once the medial intermuscular septum is identified, the medial antebrachial cutaneous nerve is identified, traced distally, and protected.

Note: If previously anterior transposition was performed, the ulnar nerve should be fully identified and mobilized before proceeding. Dissection of the nerve needs to be carried distally far enough to allow the nerve to sit in the anterior position without being kinked distal to the epicondyle.

15.8.3 Exposing the Anterior Capsule for Excision and Incision

The septum is excised from the insertion on the supracondylar ridge to the proximal extent of the wound, usually about 5–8 cm. Many of the veins and perforating arteries at the most distal portion of the septum require cauterization.

Once the septum has been excised, the flexor–pronator muscle mass should be divided parallel to the fibers, leaving roughly a 1.5-cm span of flexor carpi ulnaris tendon attached to the epicondyle.

The surgeon then returns the supracondylar ridge and begins elevating the anterior muscle with a Cobb elevator. Subperiosteally, the anterior structures of the distal humeral region proximal to the capsule are elevated to allow placement of a wide Bennett retractor. As the elevator moves from medial to lateral, the handle of the elevator is lifted carefully, keeping the blade of the elevator along the surface of the bone (Fig. 15.4).

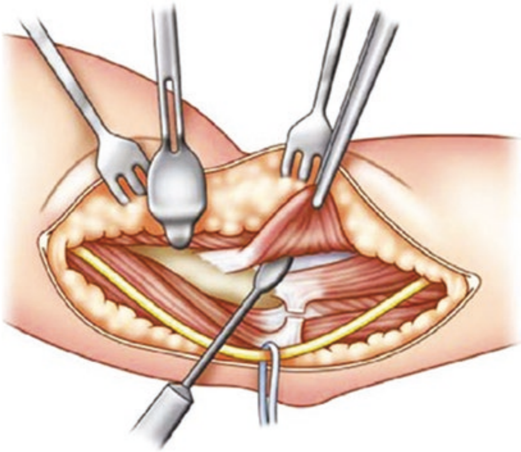

Fig. 15.4 The medial column approach: after isolation of the ulnar nerve, the capsule is approached using the interval between the FCR and PT

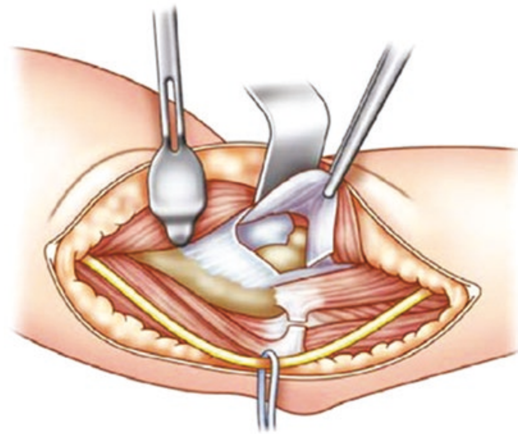

Fig. 15.5 The anterior capsulectomy is performed from the medial side

Note: A small cuff of tissue of the flexor–pronator origin can be left on the supracondylar ridge as the muscle is elevated. This facilitates reattachment during closing. A proximal, transverse incision in the lacertus fibrosus may also be needed to adequately mobilize this layer of muscle.

Once the Bennett retractor is in place and the medial portion of the flexor–pronator has been incised, the plane between muscle and capsule should be carefully elevated. As this plane is developed, the brachialis muscle is encountered from the underside. This muscle should be kept anterior and elevated from the capsule and anterior surface of the distal humerus.

Note: The dissection of the capsule from the brachialis muscle proceeds both laterally and distally. At this point, it is helpful to feel for the coronoid process by gently flexing and extending the elbow. A deep, narrow retractor is often helpful to allow the operator to see down to the level of the coronoid.

The anterior capsule should be excised (Fig. 15.5) to the extent that that is practical and safe. It is helpful first to incise the capsule from the medial to the lateral aspect along the anterior surface of the joint. Once this edge of the capsule is incised, it can be lifted and excised as far distally as is safe. From this vantage, and after capsule excision, the radial head and capitellum can be visualized and freed of scar, as needed.

In cases of primary osteoarthritis of the elbow, removing the large spur from the coronoid is crucial. Using the Cobb elevator, the brachialis muscle can be elevated anteriorly for 2 cm from the coronoid process. With the elevator held in position, protecting the brachialis but anterior to the coronoid, the large osteophyte can be removed with an osteotome. The brachialis insertion is well distal to the tip of the coronoid.

Note: The extreme anteromedial corner of the exposure deserves special comment: in a contracture release, the anteromedial portion often requires release; to see this area, a small, narrow retractor can be inserted to retract the medial collateral ligament, pulling it medially and posteriorly; this affords visualization of the medial capsule and protection of the anterior medial collateral ligament.

15.8.4 Exposing and Excising the Posterior Capsule and Bone Spurs

The posterior capsule of the joint is exposed. The supracondylar ridge is again identified (Fig. 15.6). Using the Cobb elevator, the triceps is elevated from the posterior distal surface of the humerus.

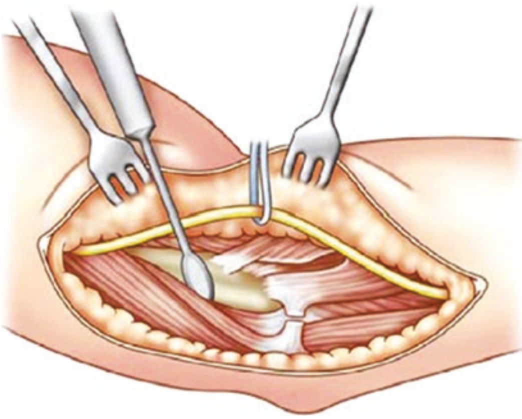

Fig. 15.6 The posterior aspect of the elbow is visualized by elevation of the triceps from the humerus

The exposure should extend far enough proximal to permit use of a Bennett retractor.

The posterior capsule can be separated from the triceps as the elevator sweeps from proximal to distal. The posterior medial joint line should also be identified, as it is often involved by osteophytes or heterotopic bone.

Note: In contracture release, the posterior capsule and posterior band of the medial collateral ligament should be excised. The medial joint line up to the anterior band of the medial collateral ligament should also be exposed and the capsule excised. This area is the floor of the cubital tunnel.

In contracture release and in primary osteoarthritis, the tip of the olecranon usually must be excised to achieve full extension. The posteromedial joint line is easily visualized, but the posterolateral side must also be carefully palpated to ensure clearance.

15.8.5 Ulnar Nerve Transposition

After being reattached to the medial supracondylar region, the ulnar nerve should be transposed and secured with a fascial sling to prevent posterior subluxation. The sling can be fashioned by elevating two overlapping rectangular flaps of fascia or by using a medially based flap attached to the underlying subcutaneous tissue. Once this maneuver is completed, the nerve must not be compressed or kinked. The joint should be flexed and extended to ensure that the nerve is free to move.

15.8.6 Closure

The flexor–pronator mass should be reattached to the supracondylar ridge with nonabsorbable braided 1-0 or 0 suture. If a large enough cuff of tissue was left on the medial epicondyle, no hole need be drilled in bone. Otherwise, drill holes in the edge of the supracondylar ridge can be made to secure the flexor–pronator mass.

15.9 Handling Difficulties

Since the original description of the technique, we have become increasingly aware of the implications of ulnar nerve irritation before surgery. The ulnar nerve is addressed surgically if (a) the patient has ulnar nerve symptoms, especially with flexion; (b) examination reveals ulnar nerve irritation or has a positive Tinel sign; and (c) preoperative flexion is less than 90°. Whether it is simply decompressed or translocated is the surgeon's preference/judgment.

If the pathology suggests that there is intrinsic involvement or that a release of the collateral ligament is necessary to obtain adequate exposure, then the surgeon should be prepared to apply the distraction device protecting the collateral ligament repair and separating the joint surfaces for approximately 3 weeks after surgery. It is uncommon to be faced with this option if the proper determination of the nature of the contracture and adequate imaging and assessment of the joint surface has occurred prior to the surgery as discussed above.

Finally, it is important for the patient to have a clear understanding of the recovery time that is required after such surgery. The emphasis on the maintenance of the splinting program for several weeks or even months following the procedure is quite important, particularly depending upon the type of occupation and the expectations that the patient may hold.

15.10 Bailout and Salvage

15.10.1 Combined Lateral and Medial Approaches

A posterior skin incision is used lateral to the tip of the olecranon. Two flaps are then elevated, one lateral up to the lateral column in order to have access to the lateral compartment and one medial to have access to the ulnar nerve and the medial column. The procedure is then performed as previously described. Fenestration of the olecranon fossa has been advocated by some authors to resect all the posterior osteophytes removing the posterior impingement with the tip of the olecranon.

15.10.2 Distraction Arthroplasty

If lateral collateral ligament has been released in cases with lateral ligament scarring or severe articular involvement, it is reattached through bone holes placed through the anatomic axis of rotation. However, this reconstruction is protected with a distraction device. Two to 3 mm of distraction is usually performed. The elbow is moved to assure smooth motion with no impingement of the articular surfaces. At surgery, depending on the problem being treated, motion of at least 50°–110° is possible with the distraction device. After 4 weeks, the patient is placed under anesthesia, and the device is removed. Adjustable splints are then prescribed for a minimum of 6 weeks and often up to 3 months.

15.10.3 Interpositional Arthroplasty

If more than 50% of the articular surface has been violated and is not covered with hyaline cartilage, if significant adhesions cause avulsion of 50% of the articular surface at surgical release, or if a malunion causes a refashioning of the articular surface, then interposition arthroplasty is indicated in the young patient, whereas a total elbow arthroplasty may be an option for older patient. The use of a distraction fixator allowed better healing of the collateral ligaments as well as a distraction of the joint surface to protect the interposition graft and to allow immediate passive motion. Achilles tendon allografts are commonly used as interposition materials to resurface damaged joints. The joint is exposed through a Mayo modified Kocher approach with a midline posterior skin incision. The lateral collateral ligament is detached from its humeral origin, which allows for exposure of the joint. The radial head is preserved if the proximal radioulnar joint is intact. Minimal bone resection is performed with the goal of contouring the distal humerus to accept the graft. The graft is secured to the bone with trans-osseous nonabsorbable number 5 sutures. Part of the graft can be used to reconstruct the collateral ligaments. A distraction fixator is then applied, and the lateral ligament is repaired through drill holes in the lateral epicondyle (Fig. 15.7). A continuous axillary catheter is used to give good postoperative analgesia, and a continuous passive motion machine is used for 4 days. The external fixator is usually removed between 4 and 6 weeks postoperatively. An articulated splint is maintained during 3 months.

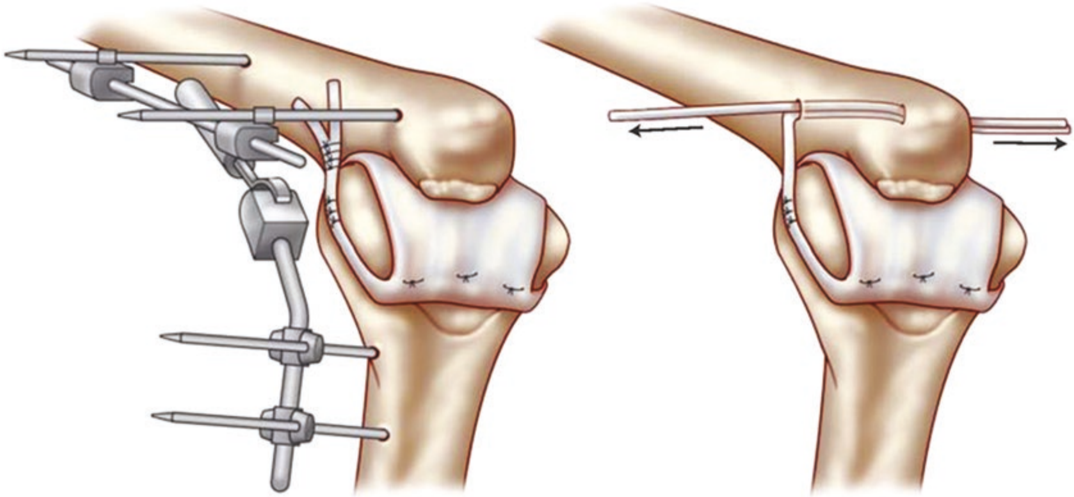

Fig. 15.7 Interpositional arthroplasty protected with an articulated external fixator

Suggested Readings

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16 Total Elbow Replacement

Roger van Riet

16.1 Description

The indication for total elbow arthroplasty (TEA) has evolved over recent years. Acute trauma and posttraumatic conditions have become more common indications, while inflammatory conditions have become less prevalent due to improved medical treatment.

Design has also improved, and we now have several options, depending on the indication. The elbow can be replaced with a "linked" (Fig. 16.1) or an "unlinked" (Fig. 16.2) articulation [1] and in some selected cases, a hemiarthroplasty (Fig. 16.3) can be used to replace the distal humerus only [2].

Fig. 16.1 3D CT scan showing an example of a linked total elbow arthroplasty

16.2 Key Principles

Bone and soft tissue balancing of the joint determine the longevity of the TEA. In cases with adequate bone and soft tissue, an unlinked design can be used. Ligament integrity or repair is paramount for the success of an unlinked prosthesis. Stability needs to be tested during surgery and when bony and soft-tissue stabilizers provide a stable joint during the arc of motion it is not necessary to link the

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Fig. 16.2 Lateral radiograph showing an unlinked total elbow replacement. Note the shorter stem of the ulnar component as traction on the component is not an issue

joint. In other cases, the humeral and ulnar components need to be physically linked. All available designs allow some varus-valgus movement to decrease articular stresses during flexion and extension. Linking the prosthesis may induce some traction forces on the ulna component and theoretically increase the risk of loosening. The main disadvantage of an unlinked prosthesis would be potential instability.

16.3 Expectations

TEA offers significant pain relief with a functional range of motion. Lifting over 5 kg should be avoided. Complications are not uncommon and patients should be counseled on the problems that could arise, including but not limited to infection, stiffness, ulnar nerve symptoms, and failure of the implant.

Fig. 16.3 Anteroposterior radiograph of a distal humeral replacement, hemiarthroplasty

16.4 Indications

- Comminuted distal humerus fractures in patients over 65 years old.
- Post-traumatic arthritis.
- Rheumatoid arthritis and other inflammatory diseases.
- Osteoarthritis.

16.5 Contraindications

- Absolute: Active infection.
- Relative: Poor neurological control, younger age, poor compliance.

16.6 Special Considerations

Complications are not uncommon, and patients should be made aware of this. Infection, wound problems, triceps insufficiency, ulnar neuropathy, heterotopic ossification, are some of the potential complications. Postoperative guidelines for patients include no lifting over 5 kg and no repetitive lifting over 1.5 kg. If patients are unable or not willing to adhere to these guidelines, early failure may occur. Other reasons for failure include: loosening, infection, periprosthetic fractures, instability, wear of the articulation, fracture of components.

16.7 Special Instructions, Positioning, and Anesthesia

- General anesthesia, combined with a regional block.
- Supine position, arm over the thorax or over a Mayo table.
  - Prone or lateral decubitus are possible.
- Assess range of motion and elbow stability.
- Tourniquet.
- Surgical skin preparation and draping.
- Palpation of the ulnar nerve prior to incision.
- High speed burr available.
- Fluoroscopy available.
- Make sure prosthesis and specific instrumentation are present and sterile.

16.8 Tips, Pearls, and Lessons Learned

- The articulation can be approached in several ways. A lateral para-olecranon approach [3] is preferred to decrease the risk of postoperative triceps insufficiency, while allowing early mobilization.
- Sharply detach the ligaments and mark them. Conserve them for later reattachment.
- Removing fracture fragments early in the procedure as this facilitates the approach.
- Minimum 5 mm of fascia should be left on the ulna on either side, so it can be closed at the end of the procedure.
- Reduction of the elbow with the components in place is sometimes difficult with the triceps on technique. Find the best method during trial reduction before the definitive components are cemented in place.
- Verify rotational alignment by taking the elbow though a full range of flexion–extension with the trial components in place. Any bony impingement observed should also be dealt with at this time.
- Cement stops, viscous cement, and a cement gun with a narrow nozzle should be used to assure adequate cement fixation of both components.
- Hemostatic gelatin sponge can be used as a cement stop with the advantage that it will dissolve over time.
- Place the definitive ulnar component first as the humeral component can obstruct a direct path to the ulna if this is placed first.
- Use copious irrigation and strict hemostasis to decrease the chance of postoperative bleeding, heterotopic ossification and infection.

16.9 Difficulties Encountered

Difficulties encountered are somewhat specific to the indication for TEA and the number of previous surgeries. The ulnar nerve may be embedded in scar tissue. Elbow stiffness can make it very difficult to release and dislocate the joint. It may be necessary to take down the triceps to achieve an acceptable view. Correct orientation and height of the components may be difficult to determine in acute fractures or cases with bone loss.

16.10 Key Procedural Steps

A straight posterior incision is used. The ulnar nerve is dissected and protected throughout. If an anterior transposition is planned, the subcutaneous pocket could be created at this point. This will allow the surgeon to keep the nerve out of the way, without pulling on the nerve (Fig. 16.4).

The medial approach is continued through the bed of the ulnar nerve.

Open the posterior capsule and detach the medial collateral ligament complex inside out (Fig. 16.5). Mark the ligament with a suture for possible repair later in the procedure.

Continue the dissection by cutting the posterior and anterior capsules. The lateral fascia is incised 5–10 mm lateral to the subcutaneous border of the ulna (Fig. 16.6). The incision is continued proximally onto the triceps fascia and lateral one third of the tendon. The lateral side of the medial head of triceps is split, offering a great view to lateral capsule. The anconeus is partly released from the ulna from posterior to anterior (Fig. 16.7), making sure the LCL insertion on the ulna remains intact. The capsule is incised, and the lateral collateral ligament (LCL) complex is released inside out (Fig. 16.8) and marked with a suture. The elbow joint is then dislocated. Preparation of the humerus and ulna depends on the system used. Specific cutting guides and reamers are used.

The humeral component should be 15° internally rotated from the flat portion of the posterior humeral cortex, alternatively the anterior cortex can be used to aid in rotational alignment (Fig. 16.9). The alignment of the ulnar component is determined by the posterior cortex of the olecranon. It is imperative to test and correct rotational alignment with the trial components

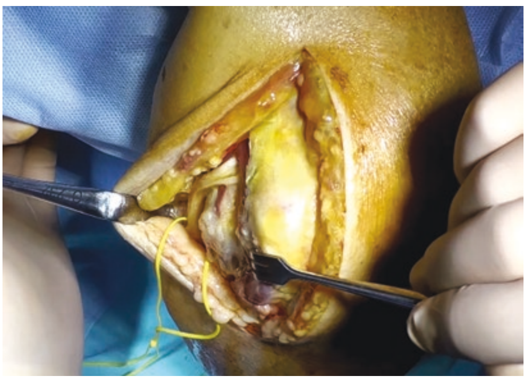

Fig. 16.4 The ulnar nerve is released and protected throughout the procedure

Fig. 16.5 The medial collateral ligament complex is released from the bone. It needs to be reattached at the end of the procedure when an unlinked design is used

Fig. 16.6 Incision of the fascia in the lateral paraolecranon approach

Fig. 16.7 The anconeus is released from the ulna, while the ulnar insertion of the CL is protected

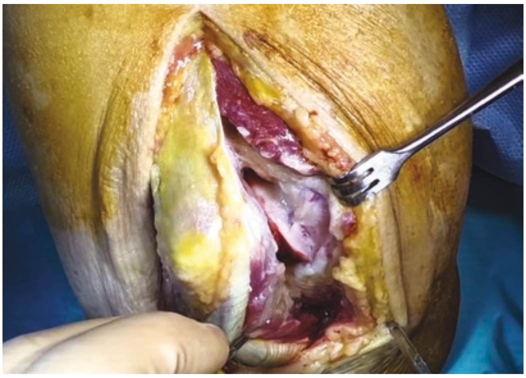

Fig. 16.8 The capsule is incised and this provides an excellent view of the lateral elbow (Courtesy of MoRe foundation)

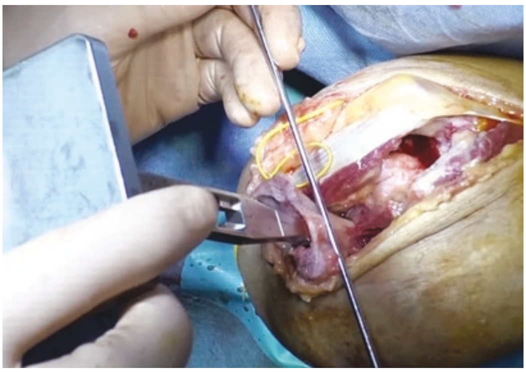

Fig. 16.9 Lateral and medial columns are often resected in patients with a distal humerus fracture. Rotation of the humeral component is then determined by the anterior and posterior cortices of the humerus

(Fig. 16.10). The position of the anterior flange dictates the size of the bone graft placed between the flange and the anterior humeral cortex.

Trial components are removed once the position has been determined and any bony impingement has been dealt with. Cement stops are placed in the intramedullary canal of both the ulnar and humeral intramedullary canal. Cementing is performed using a narrow nozzle and a cement gun. Both ulna and humerus are cemented at the same time. The ulnar component is inserted first, after which the humeral component is inserted (Fig. 16.8). The elbow is then reduced, rotational alignment is verified, and the elbow is fully extended for the cement to harden.

The next steps depend on the prosthesis used. A radial head component can be inserted,

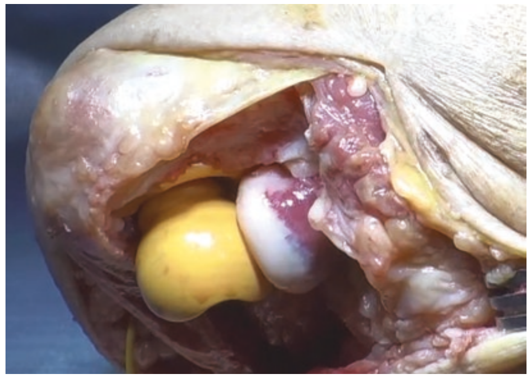

Fig. 16.10 Trial ulnar and humeral components are in place and position of the components ulnohumeral tracking and range of motion are tested

humerus and ulna can be left unlinked or can be mechanically linked. Soft tissue balancing is important, irrespective of the implant used. MCL and LCL are reattached together with the flexor–pronator and extensor insertions. The ulnar nerve is transposed anteriorly and the skin is closed in layers. A protective bandage is used for 2 weeks and the patient is allowed to mobilize the elbow immediately.

16.11 Bailout, Rescue, and Salvage Procedures

- A cerclage wire can be placed around the humerus or ulna if a fissure should occur in the bone during the bony preparation.
- If the cortex is perforated during reaming or because of the removal of hardware, bone graft from the humeral osteotomy can be impacted in the defect, to close the gap and prevent cement from extruding out of the canal.
- An intraoperative olecranon fracture can be pinned prior to cementing.
- Structural bone grafting techniques can be used, in conjunction with longer stem arthroplasty, in the case of severe bone loss.
- Achilles tendon graft can be used to reconstruct a chronically ruptured triceps tendon with poor tissue quality.

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17 Revision Total Elbow Replacement

Matthew Ricks, Andrew Keightley, and Adam C. Watts

17.1 Background of Revision Elbow Arthroplasty

Elbow replacement has been shown to give good improvement in pain and function [1, 2]. In the UK the National Joint Registry recorded 2640 primary total elbow replacements from 2012 to 2018 in keeping with the published incidence of 1 per 10^5 population per annum [3]. The 16th Report of the NJR (2019) documents 123 revisions of primary elbows recorded in England and Wales with an estimated cumulative revision rate of 6.1% at 5 years (95% CI 5.0–7.4) [4]. This low volume gives unique challenges, with most surgeons having little experience in dealing with the problems particular to revision elbow arthroplasty [5]. As in other countries the majority of patients undergoing arthroplasty are female (70%) with the greatest incidence in the seventh decade [4, 6]. Inflammatory arthritis was historically the major indication for primary elbow arthroplasty but improvements in medical management have seen rapid declines for this in most countries with an increasing number of arthroplasty's being performed for trauma in the treatment of distal humeral fracture. Failure of an implant is hard to define. Pain, mechanical symptoms, swelling, and loss of function are all clinical indications to consider implant revision but many patients with a failing implant will be asymptomatic and regular radiographic surveillance is required to detect silent failure.

17.2 Modes of Failure of a Total Elbow Replacement

17.2.1 Aseptic Loosening

As with other joint replacements aseptic loosening can affect the implant survivorship which in turn can lead to a periprosthetic fracture or pain and loss of function (Fig. 17.1). The loosening can occur between the implant–cement interface, cement–bone interface or in the absence of a sufficient cement mantel the implant–bone interface. Total elbow replacements whether linked or unlinked allow have limited varus, valgus motion and internal and external rotation in addition to the main flexion extension axis. This freedom of movement, often referred to as a "sloppy hinge" is to allow energy to be absorbed by the soft tissues decreasing strain at the interfaces between implant, cement and bone.

One must take into consideration the coating of the stem when planning a revision. These implants are commonly cemented into the bone; however, the coating of the humeral and ulnar components does vary between manufacturers.

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Fig. 17.1 Zones of aseptic loosening (from Hearnden AJ, Desai AS, Harrison JW, Dramis A, Hayton MJ, Trail IA, Stanley JK. Outcome of revision total elbow replacement using the Acclaim prosthesis. Shoulder & Elbow. 2009 Jul;1(2):99–103)

These vary from a smooth surface to a hydroxyapatite or rough surface finish. These are designed to provide a rough surface for osteointegration. Some surfaces are also osteoconductive providing a surface that stimulate stem cell development into osteoclasts and bony ingrowth.

With constant cycling of the implant through movements this in turn can lead to torsional or distractive forces being applied to different aspects of the implant. The linking devices are commonly a screw system and a torsional force converted to a longitudinal pull over time and many cycles can lead to decoupling or disassembly of the implants which in turn leads to the failure.

It is well known within the hip that polyethylene particles generation can create a cycle of macrophage activation and in turn bone resorption between the cement–bone interface. Goldberg et al. within their study demonstrated

Fig. 17.2 Silent aseptic loosening of the Souter-Strathcylde elbow arthroplasty. (Image copyright Adam Watts)

through tissue sampling of revision elbow replacements that the cellular response to particle wear was similar in most of the cases with an increase in a number of multinucleated giant cells. The tissue showed chronic inflammation, fibrosis, and necrosis with particle infiltration. The theory is that the cyclical movement of the elbow circulates the fluid, containing polyethylene wear particles, driving them between the developing bone–implant interfaces which self-perpetuates implant loosening (Fig. 17.2).

17.2.2 Infection

Infection is a catastrophic complication and although risk can be minimised through the use of antibiotics, aseptic techniques, and laminar flow it cannot be fully eradicated. Infection remains the second most common cause of revision and is higher than for most other joint replacements [4]. Periprosthetic joint infections (PJI) can be caused by direct inoculation at the time of surgery or after or haematogenous spread. It has been hypothesised that the direct inoculation at the time of surgery can produce two categories depending on the length of time from infection: if presenting within 3 months it is more likely a highly virulent organism, whilst those that present from 3 to 24 months are of a lower virulence [7]. Haematogenous spread is suspected in later presentation and particularly in those with a clear source of infection elsewhere that could have led to septic seeding.

Making the diagnosis can be challenging, particularly where a low virulence pathogen is responsible [8]. It has been shown that low grade infections can present with no derangement in inflammatory markers [9].

The management of a suspected PJI in the Wrightington unit is managed within a multidisciplinary unit working closely with radiologists, microbiology consultants, and a number of revision consultant elbow surgeons. Each suspected infected case is discussed at a multidisciplinary team meeting and up to date imaging in the form of radiographs or CT images are acquired. Serum blood markers for infections are taken, however, normal values do not exclude an infection. Tissue samples are acquired from around both the humeral and ulnar components and are sent for prolonged tissue culturing, polymerase chain reaction testing and histology. A total of 7 samples are taken with 5 sent for microbiology and 2 sent for histology.

17.2.3 Wear

The elbow is a load bearing joint with up to three times body weight crossing the relatively small surface area when loading through the hand. Long lever arms either side of the joint multiply forces applied and short moment arms for restraining soft tissues can mean that peak torques across interfaces are high. This can lead to implant loosening, wear, dislocation or even implant fracture. Modes of wear have been categorised by McKellop et al. as shown in Table 17.1 [10].

Goldberg et al. looked at the different modes of failures of the elbow replacements and highlighted that all of the retrieved components demonstrated multiple modes of wear. Mode 1 and mode 3 wear was demonstrated on all of the implants removed. Type 2 mode was demonstrated in only a proportion of the removed implants. They demonstrated a degradation of the polyethylene bushings which led to accelerated wear as this exposed contact between non-bearing surfaces. Mode 4 wear was demonstrated due to wearing of the bushing and proximal migration of the ulnar component [11].

Table 17.1 Modes of wear for bearing surfaces

Modes of wear	
Mode	Contacting surfaces
1	Bearing versus bearing
2	Bearing versus non-bearing
3	Bearing versus bearing versus third-body particles
4	Non-bearing versus non-bearing
Third bodies including metallic, bone cement and bone particles between the bearing surfaces	

(McKellop HA. The lexicon of polyethylene wear in artificial joints. Biomaterials 2007;28(34):5049–5057)

17.2.4 Periprosthetic Fracture

There is extensive literature written about periprosthetic fractures around the hip and the knee but little around the elbow. Periprosthetic fractures around a total elbow prosthesis are an increasing burden and remain a significant challenge due to the subcutaneous nature of the ulnar, poor bone quality, and limited bone stock. Shawn O'Driscoll and Bernard Morrey have created a classification and treatment algorithm for periprosthetic fractures around a total elbow replacement. This was based on the Mayo clinic experience of over 1000 total elbow arthroplasties with an incidence of 5% of periprosthetic fractures. They consider three main factors when assessing a periprosthetic fracture and these include location of the fracture in relation to the stem, the security of the fixation of the stem, and the bone quality (Fig. 17.3) [12].

The O'Driscoll and Morrey classification applies to both the humeral and ulnar components. The region is broken up into A—Periarticular, B—around the shaft or tip of the stem, and C—beyond the tip of the stem. There are further three subclassifications; 1—Well fixed, adequate bone stock, 2—Loose with adequate bone stock, and 3—severe bone loss or osteolysis. They go on to highlight two further factors including the degree of displacement and the timing, both of which can impact upon the choice of intervention. The degree of displacement is important as if it is a small un-displaced fracture line around the stem this can potentially have a different management plan to a large fracture that is grossly displaced (Fig. 17.4) [12].

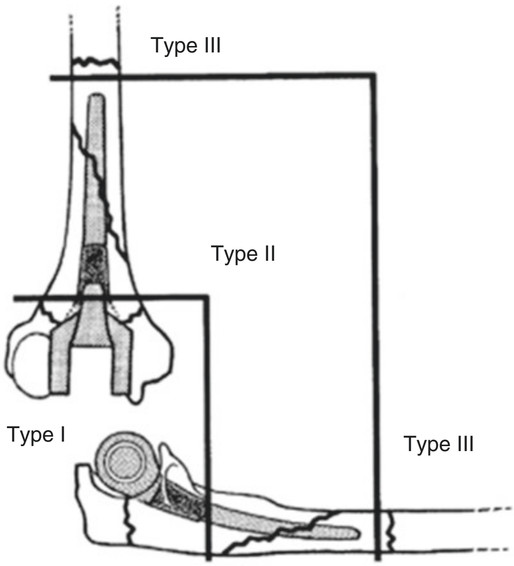

Fig. 17.3 Classification of periprosthetic elbow fractures (from O'Driscoll SW, Morrey BF. Periprosthetic fractures about the elbow. Orthopedic Clinics. 1999 Apr 1;30(2):319–25)

17.3 Assessment

17.3.1 Diagnosing Infection

The diagnosis of infection can be challenging in elbow arthroplasty. With no clear definition of infection the Musculoskeletal Infection Society (MSIS) criteria are widely adopted (Table 17.2).

The patient may report increasing pain or stiffness of the elbow. They may report swelling and warmth. Clinical assessment includes examination of the elbow for swelling, erythema, sinus, and oedema. The patient heart rate, blood pressure, and temperature should be documented and blood sent for full blood count, erythrocyte sedimentation rate, and C-reactive protein. Aspiration of the joint can be undertaken in a sterile environment but may not progress decision making as a negative culture does not exclude infection and a positive culture could be a contaminant. Advanced imaging with MRI, white cell labelled bone scan, SPECT scans, and even PET scans

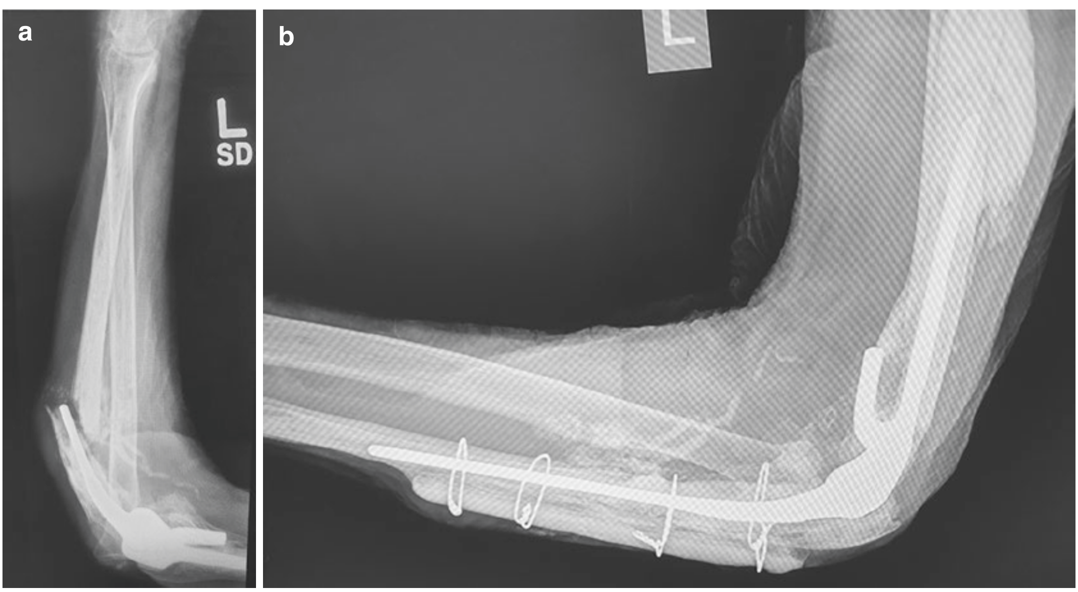

Fig. 17.4 Type 2 periprosthetic elbow fracture treated with revision of the ulna stem and cortical strut allograft. (**a**) pre-operative lateral radiograph (**b**) post operative lateral radiograph. (Image copyright Adam Watts)

Table 17.2 Diagnosis of elbow arthroplasty infection (from Watts AC, Duckworth AD, Trail IA, Rees J, Thomas M, Rangan A. Scoping review: Diagnosis and management of periprosthetic joint infection in elbow arthroplasty. Shoulder & elbow. 2019 Aug;11(4):282–91)

1. There is a sinus tract communicating with the prosthesis; or
2. A pathogen is isolated by culture from at least two separate tissue or fluid samples obtained from the affected prosthetic joint; or
3. Four of the following six criteria exist:
1. Elevated serum erythrocyte sedimentation rate (ESR) and serum C-reactive protein (CRP) concentration,
2. Elevated synovial fluid leukocyte count (>1100/μl),
3. Elevated synovial fluid neutrophil percentage (>65%),
4. Presence of purulence in the affected joint,
5. Isolation of a microorganism in one culture of periprosthetic tissue or fluid, or
6. Greater than five neutrophils per high-power field in five high-power fields observed from histologic analysis of periprosthetic tissue at ×400 magnification.

have not been shown to be specific or sensitive enough to provide a conclusive diagnosis. Where clinical suspicion is high open biopsies from implant tissue interfaces are required, with a minimum of five tissue samples for extended microbiology culture, and two for histology.

17.3.2 Assessment of Loosening, Fracture, and Bone Stock

Imaging is required before undertaking revision arthroplasty. Plain radiographs are commonly used to make an initial assessment of bone stock, implant loosening, polyethylene wear, and implant failure. CT scans may give a more detailed information, identifying periprosthetic fracture not seen on radiographs or lucency around the implant, and can aid pre-operative planning in the case of massive bone loss. Consideration also needs to be given to bone quality in this patient population with a large proportion of patients with inflammatory disease, advanced age and other comorbidities.

17.3.2.1 Additional Considerations

Pre-operative assessment should include an assessment of the soft tissue envelope around the elbow that may compromise surgical outcomes, neural compromise, vascular compromise, triceps extensor function, and health status [13].

17.4 Surgical Options

17.4.1 Debridement, Antibiotics, and Implant Retention (DAIR)

Periprosthetic joint infection is a potentially catastrophic complication. The diagnosis and management should be as part of a shared decision making process with the patient involving a multidisciplinary team approach and standardised algorithms to allow effective treatment and assessment of efficacy.

Debridement, Antibiotics, and Implant Retention (DAIR) has been used within the acute phase when organism aggregation is immature without production of a glycocalyx biofilm. This acute PJI phase is said to be less than 6 weeks from the original surgery or within 3 weeks of the onset of symptoms and signs of infection. If the components remain stable and the organism is known or identifiable, then DAIR can be considered.

The procedure should be conducted through an open approach. Arthroscopic washout and debridement is not supported within the literature. Antibiotics should be withheld until all biopsies are obtained using a standardised technique (BESS guidelines) for microbiology and histology. A thorough debridement is conducted with a 6-L washout of the joint and all modular components should be exchanged.

Best guess antibiotics are given post operatively based on local micriobiology/MDT advice until an organism can be isolated, then specific antimicrobial therapy started. BESS guidelines suggest that upper limb PJI should receive 3–6 months antibiotic therapy, with guidance from local microbiological MDT bases upon organism cultured, sensitivities, and clinical response to treatment. Extension of antibiotic duration to lifelong suppressive regimes is possible for non-responsive patients not suitable for ongoing surgery.

17.4.2 Single Stage Revision

In the presence of infection, single stage revision arthroplasty can be indicated with a known organism of low virulence with effective cure. This should again take place within an established microbiology MDT approach.

Antibiotics should be withheld until all standardised biopsies are taken for microbiology and histology. Prosthetic components should be removed completely, including all cement where appropriate. Thorough debridement and washout and systemic antibiotics precede revision component implantation. Further local antibiotics can be contained within any cement or into joint spaces. Post-operative antibiotic regimes should be guided by MDT microbiology advice.

When infection can be disproved then single stage revision is more readily accepted. However, the same protocol of intraoperative biopsy sampling should take place to disprove coexisting infection.

17.4.3 Two-Stage Revision

Two-stage revision is performed in the presence or suspicion of infection. The initial surgery is performed with implant/cement removal, thorough debridement, washout and sampling for microbiology, and histology biopsies prior to systemic antibiotic administration. Locally eluting spherical antibiotic spacers maybe inserted as a temporising measure. Empirical antibiotics are commenced on MDT microbiology advice and then changed to specific regimes dependent on cultured organisms.

Treatment schedules are unique to each patient and the organisms identified but usually are 6 weeks in duration. Following this, a period without antibiotics of 6 weeks is used to monitor clinical symptoms and inflammatory markers. If the patient remains asymptomatic with inflammatory markers in a range expected for the patient, then the second stage of revision prosthesis implantation can proceed. If there is doubt or uncertainty, further arthroscopic or open biopsies can be obtained together with further debridement if required.

17.5 Technical Considerations

17.5.1 Implant Removal

Removing well fixed implants can be necessary for the successful treatment of infection or implant failure. Careful use of osteotomes to remove cement around the implant and slap hammers to dis-impact the prosthesis may be successful but do risk increasing compromise of the bone envelope. Recanalisation of the humerus and the ulna is best performed with sequential rigid drills starting with 2.5 mm and increasing in 1 mm intervals. Flexible reamers are not always helpful as they will preferentially remove soft bone over hard cement and increase the risk of canal fenestration. In some cases a controlled osteotomy may be preferred. A window may be created dorsally in the distal humerus as described by Stanley to preserve the important bone bridge at the dorsal distal humeral metaphysis (Fig. 17.5a). On the ulna side an extended olecranon osteotomy can be helpful (Fig. 17.5b). Arthroscopes can be used to aid cement removal (Fig. 17.6). The Orthosonics OSCAR 3 ultrasonic arthroplasty revision instrument is helpful for removal cement from the humerus but there is a risk of thermal injury to the radial nerve. The device should be used in short pulses with copious lavage. The senior author always elevates the radial nerve away from the humerus and places a finger between the nerve and the bone when using OSCAR.

17.5.2 Management of Bone Loss

When the implant is loose, and accompanied by poor bone stock, revision arthroplasty needs to

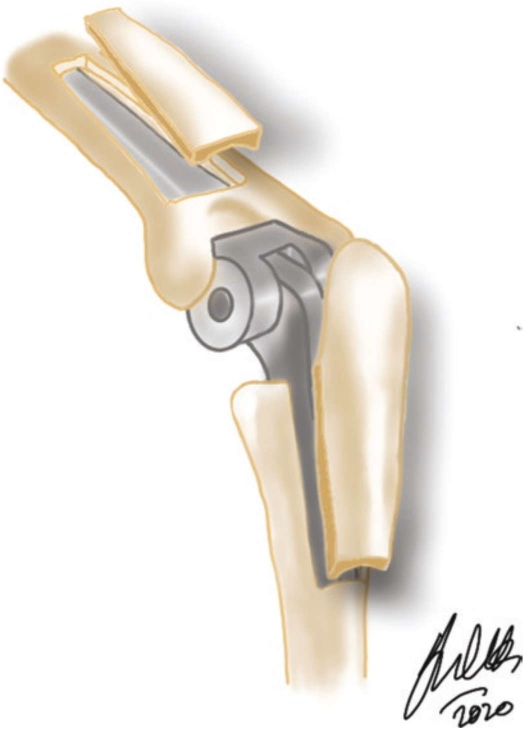

Fig. 17.5 Controlled osteotomy can be used to remove well fixed implants from the humerus and ulna. (Image copyright Adam Watts)

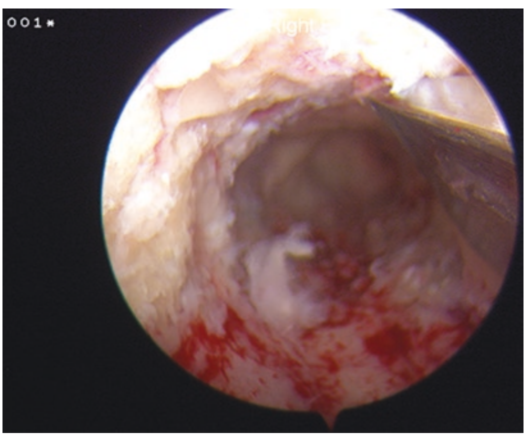

Fig. 17.6 A 4 mm arthroscope can be used to remove cement from the humeral canal with graspers or a burr. (Image copyright Adam Watts)

be combined with augmentation or a bone reconstruction procedure. Significant bone loss may be present with both septic and aseptic loosening [14]. Strategies to manage the bone loss are as follows:

– Revision with standard implant.
– Revision with customised implant.
– Revision with impaction bone grafting and standard/custom implant.
– Revision with allograft and standard/custom implant.

The proportion and location of bone loss will influence the implant and bone graft available to manage the issue. A grading system for bone loss has been developed by Mansat et al.

For the humerus:

- Grade I involves bone around the articular part of the prosthesis up to the olecranon fossa.
- Grade II involves the distal third of the humerus around the stem of the prosthesis.
- Grade III involves the humerus proximal to the stem of the prosthesis.

For the ulna:

- Grade I involves the olecranon process including the triceps tendon attachment.
- Grade II involves the proximal third of the ulna around the prosthesis.
- Grade III involves the ulna distal to the prosthesis.

Bone loss can also be categorised as contained and uncontained defects which can determine the grafting options. A contained defect may be amenable to impaction graft or cortical strut graft. Uncontained defects when large are likely to require reconstruction with an allograft prosthesis composite (APC) or megaprosthesis.

17.5.2.1 Autograft

The Mayo Clinic in 2005 showed good results with impaction bone grafting of contained defects which have been replicated in other studies [15, 16]. This aims to restore bone stock to acceptable levels prior to definitive implantation of prostheses.

17.5.2.2 Allografts

Uncontained defects, that cannot be impaction grafted satisfactorily, need restoration of structural integrity. Urbaniak and Black introduced the use of allografts in elbow arthroplasty to bridge uncontained bone loss defects [17]. Allografts can be in the form of strut grafts or hemi or whole joint allografts with step cuts made in the interface to augment potential graft integration (Fig. 17.4). This can re-establish enough skeletal congruity to allow further impaction bone graft accompanied by standard or even custom implant insertion.

17.5.2.3 Allograft Prosthesis Composite (APC)

An APC refers to a whole circumferential allograft, used to reconstruct an entire distal humerus or proximal ulna (Fig. 17.7). The implant is cemented into the allograft extending into the native bone. APCs are indicted when there is not enough native bone to support the proposed revision implant. This translates to significant levels of bone loss and Morrey proposes that this should exceed 8 cm for the distal humerus [18].

The fixation of APCs to native bone can take the form of

1. Telescoping—where the allograft is burred and bevelled to be circumferentially incorporated within the expanded host docking site.
2. Distal stem insertion of the implant within the host bone and continuation of strut allograft externally (Fig. 17.6).
3. Side to side—the entire allograft construct is fixed adjacent to the native bone in situations of significant bone loss and malalignment.

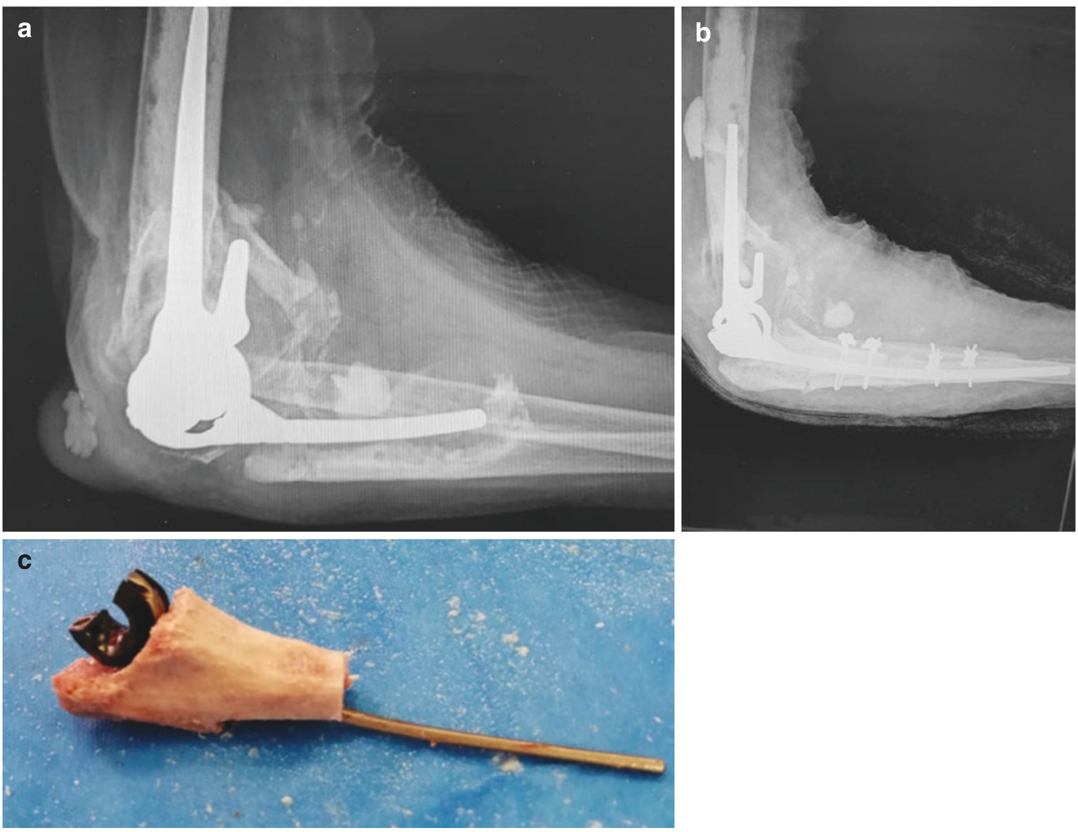

Fig. 17.7 Proximal ulna reconstruction with allograft prosthesis composite (APC). (**a**) pre-operative lateral radiograph showing significant anterior cortex bone loss from the ulna. (**b**) Allograft prosthesis construct (APC) reconstruction of the proximal ulna with long step cut to promote integration. (**c**) Allograft preparation with trial prosthesis. (Image copyright Adam Watts)

17.5.2.4 Megaprosthesis

Initially developed for neoplastic involvement of the elbow, these implants have been adapted and adopted for use in massive bone loss scenarios. These non-biological implants aim to restore function in situations of significant bone paucity but early complications have been reported and lead to a degree of reservation.

17.6 Unit Experience

The Wrightington Unit has been carrying out total elbow replacement since 1981 and has published the survival data for a number of implants used in the department. Revision total elbow replacements have been performed since 1986 and in 2001 a series was published on the Souter-Strathclyde prosthesis having been used in 52 revisions in 45 patients with a mean follow-up of 53 months. The majority of patients' pathology prior to replacement was rheumatoid arthritis in 39 cases, osteoarthritis in 3 and post-traumatic arthritis in 3 patients. The main cause of revision in this series was of pain mainly due to aseptic loosening. In 21 patients both the humeral and ulnar components were loose. 14 of the patients had loosening of the humeral component and 3 of the ulnar component. 3 of the patients had periprosthetic fractures. 11 of the revisions were for instability or dislocation. The revisions were performed with a combination of long stems and revision stems. The length of the stem used in the revision was dependent upon the quality of the diaphysis proximal to the area of loosening, perforations and fractures. The aim of the revision was to secure fixation to at least two diaphyseal widths proximal to the defect. Seven patients had a perforation of the cortex, with seven small fractures and one nerve injury.

In this series the unit showed that the level of pain was improved significantly in this patient group. The range of movement was not statistically significantly improved with marginal improvements seen in flexion, extension, supination, and pronation. The series showed a good improvement in relief of pain. However, it also demonstrated a relatively high complication rate including ulnar nerve problems infection and instability [19].

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18 Radiocapitellar Replacement

Christian Spross and Roger van Riet

18.1 Description

The clinical condition of isolated radiocapitellar arthritis is relatively rare but may be disabling due to pain. The radiocapitellar joint bears up to 60% of the forces through the elbow joint in extension and pronation. Patients are often relatively young men with a history of previous trauma with or without subsequent surgery of the radial head or patients with heavy manual labor. The capitellum may be damaged by the primary trauma or by an arthritic radial head. Pain on the lateral elbow during forceful activities (e.g. tightening a screw with a screw driver) is a leading symptom, when the radiocapitellar joint is affected. Not many elbow surgeons favor a simple radial head excision due to its changes to elbow biomechanics (more load through the ulnohumeral joint; possible proximal migration of the radius) and isolated radial head replacement is not been accepted as an option with an arthritic capitellum. These circumstances led to the development of prosthetic radiocapitellar replacement.

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18.2 Key Principles

The principle of a radiocapitellar prosthesis is to replace the arthritic lateral elbow compartment (Fig. 18.1) with limited involvement of the ulnohumeral joint, preserving normal biomechanics of the elbow joint.

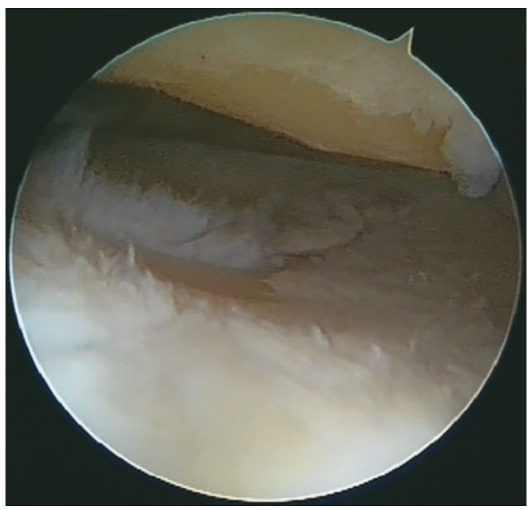

Fig. 18.1 Arthroscopic view of the lateral elbow with complete loss of the articular cartilage on both the radial head and the capitellum. (Courtesy of MoRe Foundation)

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18.3 Expectations

Conservative treatment strategies such as an adjustment in the work environment or profession of the patient should be the first line of treatment. Analgesic medication or non-steroidal anti-inflammatory drugs, as well as an intra-articular corticosteroid injection will decrease symptoms and physiotherapy may be useful in maintaining mobility and function of the elbow. However, if these measurements fail, a surgical intervention may be considered. Arthroscopic synovectomy and removal of osteophytes will often have excellent results, with regards to pain relief and increase in range of motion. Arthroscopic or open radial head resection with or without an interposition may be successful. If all fails, a prosthetic replacement may be indicated. As mainly younger patients are involved, expectations are usually high. The aim of this procedure is to restore normal function and load-bearing capacity of the elbow, with good longevity of the components.

18.4 Indications

- Isolated, primary, or post-traumatic arthritis of the radiocapitellar joint.
- Secondary capitellar erosion due to a previously placed radial head prosthesis.
- Delayed treatment of longitudinal radioulnar instability.

18.5 Contraindications

- Active infection.
- (Severe) Arthritic involvement of the ulnohumeral joint.
- Medial or lateral ligament insufficiency.

18.6 Special Considerations

18.6.1 Clinical Examination

The physical exam may demonstrate a decreased range of motion, and often a hydrops palpable in the soft spot. Passive pronation and supination are typically not painful, but the “grip-and-grind” test is positive. In this test, the patient is asked to grip two fingers of the examiner. This loads the radiocapitellar joint. The patient is then asked to rotate the forearm while maintaining the load on the radiocapitellar joint. Pain and crepitus are found in a positive test.

18.6.2 Radiographic Examination

- Plain radiographs may show narrowing of the radiocapitellar joint space (Fig. 18.2).
- CT scanning and 3-D reconstructions are routinely done to assess the bony structures for planning the prosthetic replacement.
- Magnetic resonance imaging (MRI) may be used to rule out any ligament damage or ulnohumeral cartilage damage (Fig. 18.3).
- Technetium (Tc-99) bone scans or SPECT scans may also be used to confirm the isolated

Fig. 18.2 Anteroposterior plain radiographic view showing narrowing of the radiocapitellar joint. (Courtesy of MoRe Foundation)

Fig. 18.3 Magnetic resonance image showing radiocapitellar arthritis. (Courtesy of MoRe Foundation)

involvement of the radiocapitellar joint without or with minimal increased uptake in the ulnohumeral joint.

18.7 Special Instructions, Positioning, and Anesthesia

- Prone position with the arm on a hand-table.
- Both, general and locoregional anesthesia with an ultrasound guided supraclavicular block are possible.

18.8 Tips, Pearls, and Lessons Learned

In our experience patients experience excellent pain relief following radiocapitellar replacement surgery and the majority of patients will achieve a functional range of motion, while stability is maintained or approved [1]. At the moment, only one standard radiocapitellar design [2] is available in some countries (Lateral Resurfacing Elbow, LRE systems Ltd, UK). For this design to be used, the patient needs an intact radial head as the radial head component acts as a resurfacing. It does not offer a solution for patients with instability or proximal migration following a radial head resection or patients with severe radial bone loss after a fracture. In these patients other options, including: (anconeus) interposition arthroplasty, ligament reconstruction, radial head replacement or custom made radiocapitellar replacement may be indicated. 3-D print technology (CADskills, Ghent, Belgium) may prove to be a valuable option in the near future (Fig. 18.4).

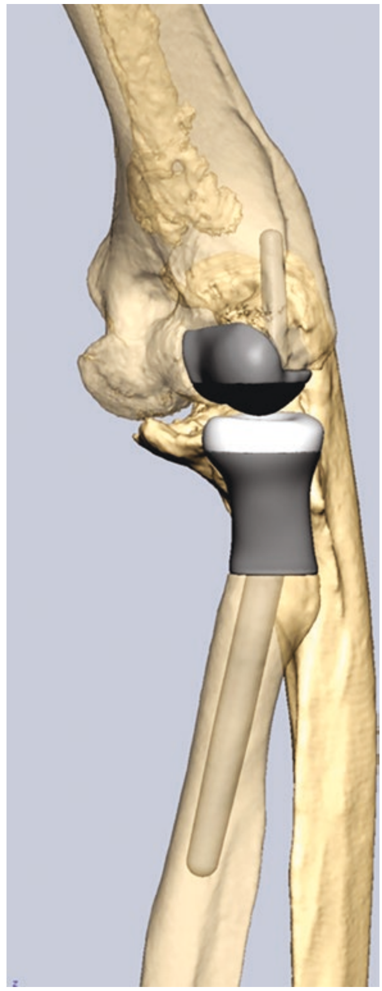

Fig. 18.4 Patients specific planning of a radiocapitellar replacement in a patient with radial bone loss. (Courtesy of CADskills, Ghent, Belgium)

18.9 Difficulties Encountered

- Orientation of both components should be perfect. We therefore prefer to release the LCL sharply at the beginning of the procedure.
- The subchondral bone becomes more dense towards the trochlea, the osteotomy should not be done beyond this point as this would damage the ulnohumeral joint.

18.10 Key Procedural Steps

The lateral epicondyle and lateral collateral ligament are palpated and a straight incision is made, starting at the lateral epicondyle. Our preferred approach is the EDC split. To gain access to the joint, the extensor tendons are split and the annular ligament is incised. The approach can be extended distally into the supinator, with the arm in full pronation to avoid injury of the posterior interosseus nerve (PIN). Care is taken to stay on the bone. We do not recommend the use of Hohmann retractors. The anterior capsule is released to increase exposure to the radiocapitellar joint. Although it is possible to place the radiocapitellar prosthesis with the LCL intact, it is much easier if the LCL is released sharply from its proximal insertion at this point (Fig. 18.5). This increases visibility and allows for easier access to the lateral elbow (Fig. 18.6). The LCL is marked for later reinsertion.

Both radial head and capitellum are then prepared. The technique depends on the system used. The radial head is resected at the head-neck junction and the intramedullary canal is rasped to size. The height of the radial head component is evaluated relative to the lesser sigmoid notch of the ulna [3].

When preparing the capitellum, it is crucial not to extend the cut into the trochlea. The capitellar osteotomy is done with an oscillating saw until a more area of bone is encountered. A direct view of the trochlea is possible as the anterior capsule has been released at an earlier stage in the procedure (Fig. 18.7). A narrow osteotome is used to elevate and remove the capitellar bone from the humerus (Fig. 18.8).

The joint is rinsed thoroughly to wash out any bone debris.

The size of the implant is determined by using the resected radial head and capitellum.

Most capitellar components require cement for its fixation. The radial head may need to be

Fig. 18.5 The joint is approached through an extensor tendon split. The lateral collateral ligament complex is released sharply, to protect the ligament and to increase the view on the lateral humerus. (Courtesy of MoRe Foundation)

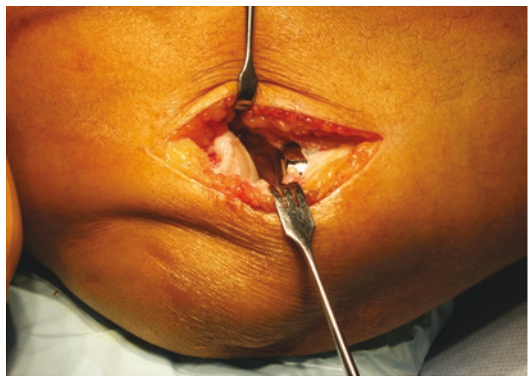

Fig. 18.6 Lateral intraoperative view of the elbow. Note the previously placed radial head prosthesis that caused capitellar erosion. (Courtesy of MoRe Foundation)

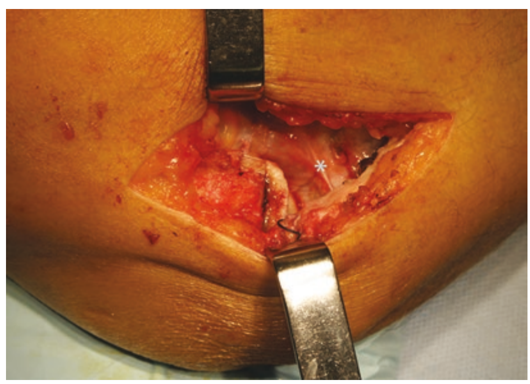

Fig. 18.7 Lateral view of the elbow after removal of the radial head and capitellar osteotomy. Note the intact trochlea and good condition of the ulnar cartilage. The lesser sigmoid notch (*) is used as a reference for the height of the radial head component. (Courtesy of MoRe Foundation)

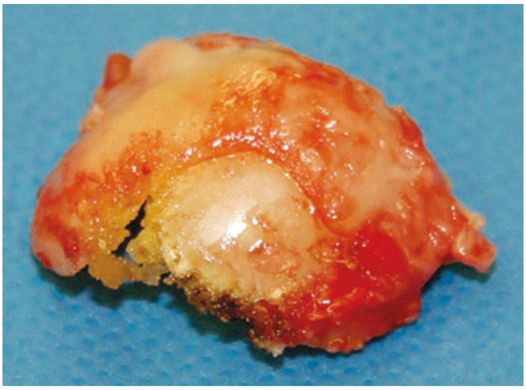

Fig. 18.8 Capitellar articulating surface. (Courtesy of MoRe Foundation)

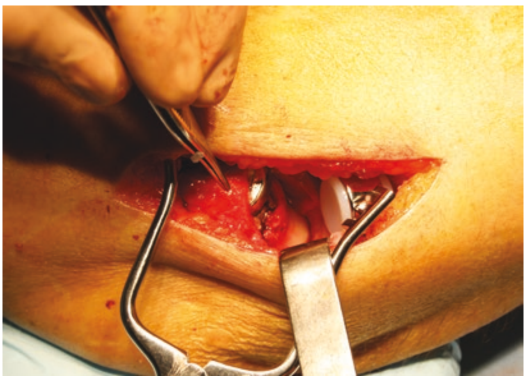

Fig. 18.9 Both the radial and capitellar components are in place. Note the height of the radial head component. The elbow is still subluxed and will be stabilized by reinsertion of the LCL complex and closure of the capsule and extensor tendon split. (Courtesy of MoRe Foundation)

cemented or can be placed press-fit depending on the system used (Fig. 18.9).

Once components are fixed, closure starts with a reattachment of the LCL to its insertion (Fig. 18.10). This can be done with a bone anchor or through bone tunnels. The extensor tendon split is closed with a running suture.

Postoperatively, a removable splint is applied for comfort (eXo Elbow, Jake Design, Antwerp, Belgium) and the patient is allowed to mobilize the elbow immediately. A dynamic brace can be used to protect the LCL repair, but this depends on the surgeon's preference.

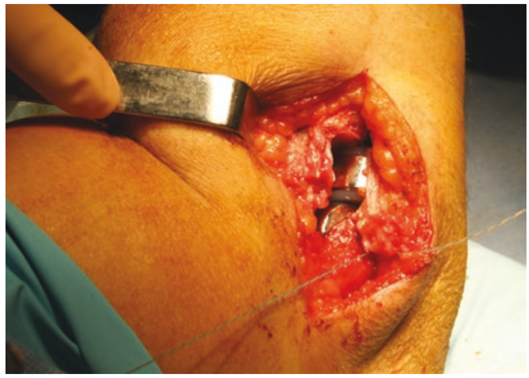

Fig. 18.10 An anchor has been used to reinsert the LCL complex restoring congruency and stability of the elbow. (Courtesy of MoRe Foundation)

18.11 Bailout, Rescue, and Salvage Procedures

In case of problems, different solutions are available.

- Instability can be treated with ligament repair or reconstruction.
- Revision of one or both of the components can be possible in case of failure.
- Components can be resected if stability allows.
- Total elbow replacement can be indicated if ulnohumeral degeneration occurs.

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19 Hemiarthroplasty of the Elbow

Lars Adolfsson

19.1 Description and Key Principles

Elbow hemiarthroplasty generally means replacement of the distal humeral joint surface by a prosthetic implant closely resembling the normal skeletal anatomy. The distal humeral condyles and collateral ligaments are repaired around the implant to restore elbow joint stability.

19.1.1 Key Principles

Restoration of elbow stability with preserved potential of normal motion and congruence with the uninjured proximal ulna and radius.

19.1.2 Expectations

Functional range of motion with normal stability and absence of pain.

19.1.3 Indications

Distal humeral fractures with significant fragments of the articular surface with compromised vascularity or fragments impossible to reliably fix with conventional osteosynthesis (Fig. 19.1). Particularly in patients for whom load restrictions ensuing a linked implant would create severe limitations.

19.1.4 Contraindications

- Previous symptomatic arthritic changes.
- Chronic instability.
- Non-reconstructable elbow stability due to ligament or condylar defects.
- Dysplasia following previous injuries or congenital deformity.
- Forearm instability.
- Defects of the ulnar articular surface.
- Absence of the radial head.

19.2 Special Considerations

Detailed preoperative assessment of osseous, neurologic, and vascular anatomy is critical to success. Computed tomography (CT) needed for complete understanding of the fracture morphology and planning for restoration of elbow joint stability.

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Fig. 19.1 Example of case treated with a hemiarthroplasty. A 72 year-old woman injured by a fall in the same plane. Because of several large fragments of the articular surface without soft tissue attachment ORIF was considered an unreliable alternative

Fig. 19.2 Postoperative result illustrating the typical mode of condylar fixation with cerclage wires medially and osteosutures in the lateral condyle

19.3 Positioning and Anaesthesia

The lateral decubitus position is preferred with the arm over an arm rest. As a rule, the procedure is performed under general anaesthesia complemented with a plexus block when possible. Interscalene local anaesthesia and sedation has proven a viable alternative if general anaesthesia is not feasible.

19.4 Tips, Pearls, and Lessons Learned

19.4.1 Condylar Fixation

Refixation of condyles and collateral ligaments is an absolute prerequisite. The refixation is performed with any necessary hardware but usually cerclage wires, K-wires, and osteosutures are sufficient (Fig. 19.2).

19.4.2 Prosthetic Placement

Currently, the only available humeral prosthesis with an anatomical design has an intramedullary stem and is fixed with conventional cementing technique. The size of the anatomical humeral spool is chosen to be as close to the original anatomy as possible in order to match the articular surfaces of the proximal ulna and radius. The correct position is finally determined by assessing good reduction of the condyles and tension of the collateral ligament complexes.

19.5 Key Procedural Steps

Exposure of elbow is usually through a posterior incision, laterally curved around the olecranon to avoid the delicate skin over the olecranon tip (Fig. 19.3). No torniquet is used. The incision is continued down to the fascial plane and the bone over the olecranon in order to raise the skin flaps together with the subcutaneous tissue preserving the circulation of the skin. The ulnar nerve is identified proximal to the medial epicondyle and followed distally to the medial joint line, separating the two heads of the flexor carpi ulnaris muscle and cutting its deep fascia to fully decompress the nerve and avoiding it from undue tension during dislocation of the joint (Fig. 19.4). The nerve is left in place but protected during the procedure.

The joint and fracture is usually approached through a 5 cm longitudinal split of the most lateral part of the triceps tendon and continued distally around the proximal lateral corner of the olecranon, subperiosteally releasing the anconeus muscle in continuation with the deep triceps fibres (Fig. 19.5). The release is continued down to the annular ligament and radial head. The joint capsule is released from the proximal olecranon deep to the still attached, medial part of the triceps tendon. If the condyles are fractured the joint can then be dislocated by bringing the ulna into supination, valgus, and ulnar translation. In case of a coronal shear fracture the condyles and

Fig. 19.3 Standard skin incision. Patient in the lateral decubitus position

Fig. 19.4 Raised skin flaps and release of the ulnar nerve

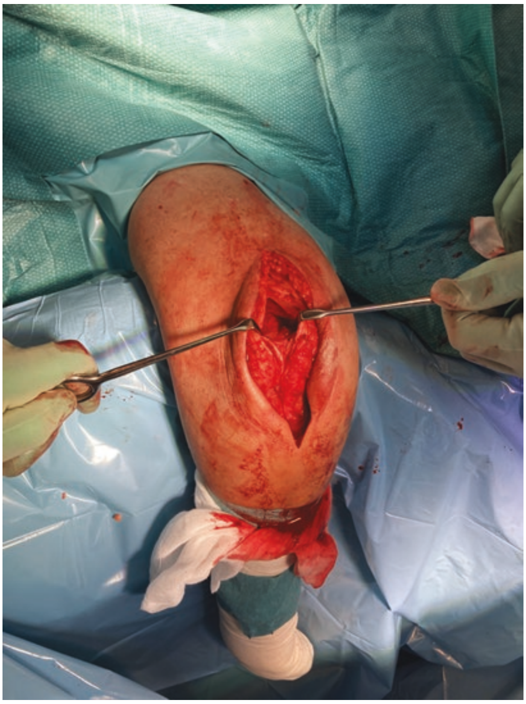

Fig. 19.5 Approach via a lateral triceps split and mobilisation of the anconeus muscle

Fig. 19.6 The joint dislocated by bringing the forearm medially and in supination. The fractured articular parts can be removed

Fig. 19.7 Preparation of the humeral shaft before introduction of the prosthesis

collateral ligaments may be intact and the collateral ligaments need to be released in order to allow dislocation of the joint. The ligament complexes are then preferably released from the humeral insertion and tagged with sutures for later repair with osteosutures. On the medial side incision of the posterior part of the MCL complex and joint capsule by careful reflection of the ulnar nerve, may improve access.

Following dislocation of the joint, all parts of the humerus covered by cartilage are removed (Fig. 19.6). Fractured pieces can easily be taken out while parts still in continuity with the humerus are sawed off immediately adjacent to the cartilage and excised (Fig. 19.7). The removed parts are assembled on the instrument table to assess size of the trochlea (Fig. 19.8). A trial humeral spool is then used to definitively determine appropriate fit with the ulna. The humeral spool size also determines the size of the humeral stem in the presently only available prosthetic system for hemiprostheses. The medullary canal is prepared with the specific instruments for the implant up to the determined size. A trial prosthe-

Fig. 19.8 Articular fracture fragments assembled for size assessment

sis is inserted, and correct position determined by reduction of the joint and the possibility to bring the condyles and ligaments are back to their correct positions. At this stage an image intensifier may be used to assure proper placement and reduction. In case of fractured condyles, these are then reduced, and cerclage wires or other modes of fixation are placed but not tied or completely introduced. After placing a proximal cement restrictor in the medullary canal cement is introduced with the definitive implant. The condyles are reduced and fixed, ideally before the cement has hardened. If needed, the condyles can also be sutured to the prosthesis for extra stability. The joint is then reduced, and the triceps split repaired by interrupted, usually resorbable, sutures.

19.6 Postoperative Management

In the first two days the arm is resting in a posterior plaster slab. The second day after surgery range of motion exercises are begun with passive extension and active flexion with 8–10 repetitions, 4–6 times per day. A static, removable splint with 45–60° of flexion is used for rest and protection between exercise sessions. At 4 weeks the arm should be used in light everyday activities such as feeding and personal hygiene and the splint is discarded. At 6 weeks light strengthening is commenced. Unrestricted load usually allowed after 3 months.

19.7 Difficulties Encountered

The injury may have caused open wounds and soft tissue defects and the approach may have to be adjusted to such conditions. Adequate skin coverage is essential and consultation with a plastic surgeon may be considered.

A simultaneous olecranon fracture does not preclude treatment with a hemiprosthesis. The fracture is then used as approach to the distal humerus and the olecranon fracture is treated with plate fixation.

In young patients with open injuries and skeletal defects a hemiprosthesis may be an alternative and in such cases acute ligament reconstruction with a tendon graft may be needed.

19.8 Bailout, Rescue, and Salvage Procedures

Pitfalls

R

- In case of encountered difficulties of access a partial or complete, release of the triceps tendon from the olecranon will allow an easier dislocation of the joint but will impose postoperative restrictions of load and motion. An olecranon osteotomy should be avoided, particularly in the event that a total replacement would be become needed.
- If case of intraoperative findings of markedly damaged joint surfaces of the ulna, the option of a total, linked or unlinked prothesis should always be available.

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20 Arthroscopic Management of the Stiff Elbow

Jae-Man Kwak and Shawn W. O'Driscoll

20.1 Description

Loss of elbow motion due to trauma or arthritis is common and significantly compromises functional capabilities of the upper extremity. Arthroscopic osteocapsular arthroplasty (OCA) of the elbow is a procedure involving three-dimensional reshaping of the bones, removal of any loose bodies, and capsulectomy to restore motion and function as well as to reduce or eliminate pain [1, 2]. This technique has become a more common procedure in recent years since it is generally believed to provide results that are at least comparable to those of traditional open procedures [3], but it allows better visualization of intra-articular lesions, a quicker recovery, and better cosmetic results. Although there is little doubt regarding the efficacy of arthroscopic contracture release, the procedure is technically challenging and there are serious concerns about the risk of nerve injury [4–6].

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20.2 Key Principle

(1) Use a step-wise, safety-driven, and standardized technique. (2) Perform a prophylactic ulnar nerve decompression to avoid delayed-onset ulnar neuritis [7, 8]. (3) Constantly control the fluid inflow to avoid swelling. (4) Remove the bone in order to recreate conforming joint surfaces. (5) Remove the capsule. (6) Use retractors. (7) Stay under your learning curve.

20.3 Expectation

The expected outcomes of the procedure are to reduce or eliminate pain and to restore motion.

20.4 Indication

The typical indication for arthroscopic osteocapsular arthroplasty is functional loss of elbow motion caused by trauma, heterotopic ossification (HO), malunion, arthritis, osteochondritis dissecans, neurologic imbalance, or prior surgery. For patients with a functional arc of motion, defined as flexion from 30° to 130° preoperatively [9], the indication for surgery is painful impingement and/or functional impairment due to the need for terminal elbow extension. This indication is not, however, applicable to all patients. Although most people can in fact lead

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normal lives with a functional arc of motion of the elbow, young and high-demand patients (usually athletes) cannot tolerate lesser degrees of contraction. For these patients arthroscopic OCA can be indicated to treat even less severe contractures [10, 11].

20.5 Contraindication

Contraindications to arthroscopic osteocapsular arthroplasty include (1) heterotopic ossification that is inseparable from a nerve, (2) the need for implant removal. Prior submuscular transposition of the ulnar nerve may be a selective contraindication depending on surgeon experience. A relative contraindication is substantial distortion of anatomy or anatomic landmarks. Dislocation or prior subcutaneous transposition of the ulnar nerve, failed prior contracture release, and/or extensive scarring from skin grafts or flaps are not contraindications.

20.6 Special Consideration

20.6.1 Preoperative nerve imaging in HO

Surgical excision of HO can be complex especially in HO that is extensive or close to a major nerve that could increase the risk of nerve injury [12–14]. Computed tomography (CT) images permit the tracing of the path of the nerves for surgical planning [15].

Before looking at the nerves themselves, the observer should dynamically rotate the 3D surface renderings of the elbow in the transverse and sagittal planes multiple times to mentally register a 3D image of the HO in relation to the bone landmarks. Based on familiarity with the anatomic location of the radial and median nerves, the observer then scrolls through the CT axial and sagittal images manually, or views them in cine mode, to create a visual impression of the paths of the nerves before taking measurements (Fig. 20.1). In some cases, a nerve "disappears" in 1 or more consecutive slices. In such cases, a potential space outlined by the perineural fat tissue is usually seen. Because this hypodense material has a larger volume than the nerve itself, it is useful for defining the pathway.

20.6.2 Simple Vs. Complex Contracture

Initially, arthroscopic OCA was performed only to manage "simple" elbow contractures [16], which involved (1) an arc of motion of ≥80, (2) no or minimal prior surgery, (3) no prior ulnar nerve transposition, (4) no or minimal internal fixation or hardware in place, (5) no or minimal heterotopic ossification, and (6) normal osseous anatomy. With greater experience, increasingly complex contracture releases have been performed arthroscopically.

Patients with complex contractures (i.e. those who fail to meet all of the criteria for a "simple contracture") are probably best referred to a surgeon with special training and expertise in elbow surgery, both open and arthroscopic. For safety reasons, arthroscopic treatment, if it is a consideration in a patient with a complex contracture, should only be performed by a surgeon with a substantial volume of experience in arthroscopic techniques of contracture release.

20.6.3 Optimal Timing to Remove HO

In determining the optimal timing for removal of heterotopic ossification, there are two factors to be considered. The first is the maturity of the heterotopic bone, as indicated by a smooth well-demarcated cortical margin and defined trabecular markings. These are best appreciated by comparing sequential radiographs. The second factor is the time since onset. Usually bone is mature enough to be removed by 3 months following its appearance and there is no reason to wait longer than 6 months.

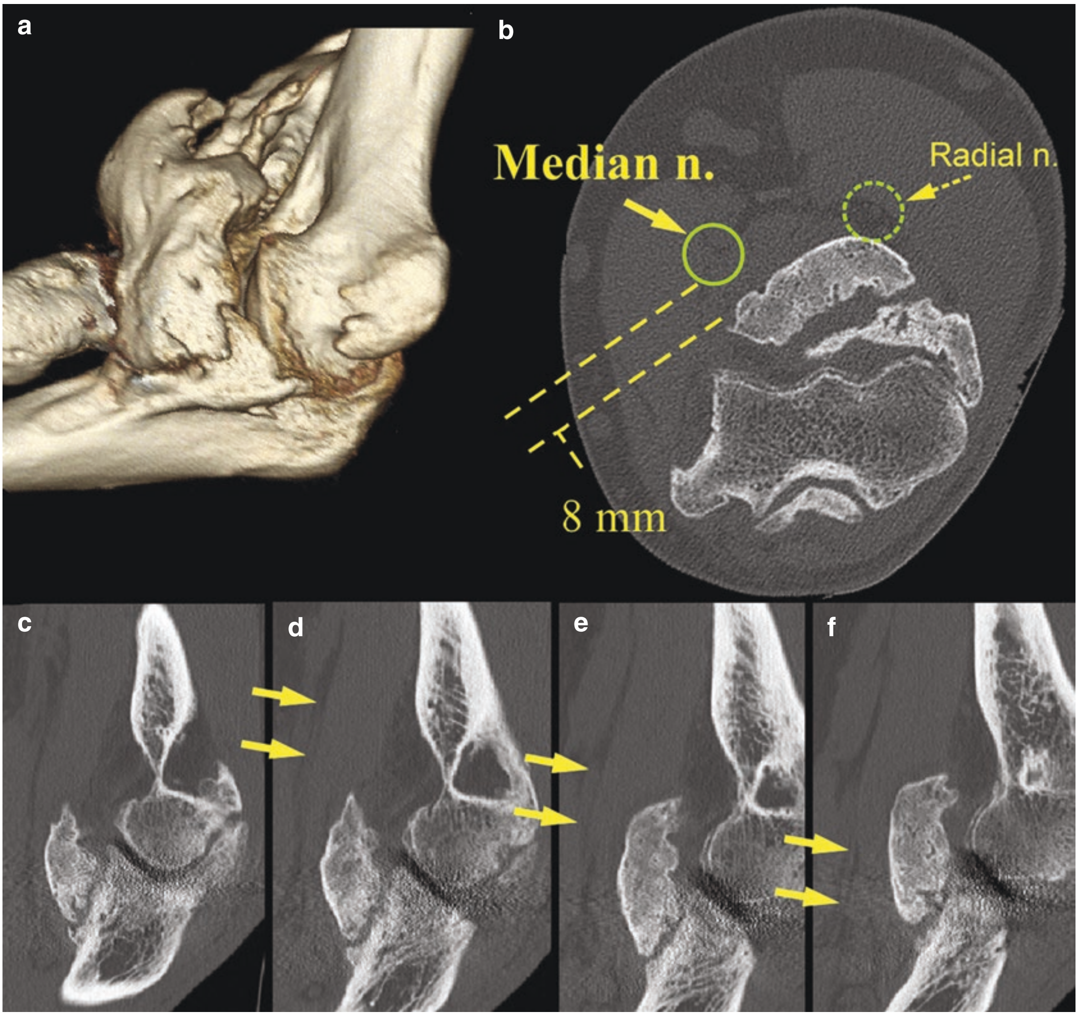

Fig. 20.1 (**a**–**f**) Elbow with extensive anterior HO. (**a**) The 3D reconstruction shows substantial replacement of muscle by HO. (**b**) Axial reconstruction on which the shortest distance between the HO and the median nerve can be measured. (The nerves lie inside the circles.) (**c**, **f**) Sequential sagittal reconstructions from lateral to medial showing ulnar landmarks (**c**) and the path of the median nerve (arrows) proximally (**d**), at the level of the joint (**e**), and distally (**f**). Sequential sagittal cuts must be viewed to follow the nerve because it is out of plane. Used with permission of Mayo Foundation for Medical Education and Research.

20.6.4 Loss of Supination-Pronation in HO [17]

There is a potential for HO at the elbow to limit not just flexion and extension but also pronation and supination. Such loss of forearm rotation occurs in about one-quarter (24%) of elbows with post-traumatic HO due to HO extending into the forearm. However, there are a few reports about this topic and no report of clinical outcomes for restoring loss of supination-pronation arthroscopically [18–20].

20.7 Special Instructions, Positioning, and Anesthesia

20.7.1 Patient Positioning Is Important

General anesthetic is administered and the patient is placed in the lateral decubitus position with the arm resting on a custom-made arm holder specifically designed for elbow arthroscopy. Wrap a tourniquet around the arm such that the tourniquet, rather than the skin, rests on the arm holder.

Fig. 20.2 Patient in the lateral decubitus position with the right arm in an arm holder (black arrow) and a nonsterile tourniquet applied (white arrow). Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved

The shoulder is flexed to between 90° and 100°, and the elbow rests at 90° of flexion (Fig. 20.2). In cadaveric studies, the distance from the portal to the nerve was reported to range from 0 to 30 mm [21–24]. The radial nerve shifts medially (further from the portal) during flexion and laterally during extension [25]. This distance is the lowest with the arm in extension and mid-pronation and greatest in 90° of flexion and pronation. For osteocapsular arthroplasty, patient positioning is critical so that adequate access to the coronoid and coronoid fossa is possible without the working instruments hitting the chest of the patient. Specifically, elevate the shoulder forward at least 90°, and keep the elbow as high as, or higher than, the shoulder.

20.7.2 Safely Creating the Anterolateral Portal

The anterolateral portal is at the level of the radiocapitellar joint articulation. At that level in the arm, the radial nerve lies anterior to the center of radial head. Radial and posterior interosseous nerve injuries caused by placement of the anterolateral portal have been reported. We recommend the "needle-and-knife technique" for safe anterolateral portal placement [26].

While viewing the lateral capsule and radiocapitellar joint with the arthroscope in the proximal anteromedial portal, a spinal needle is inserted through the skin incision for the anterolateral portal and into the joint (Fig. 20.3). Generally, no attempt is made to feel for bones with the needle. However, in tighter spaces, we routinely aim slightly posteriorly to hit the side of the capitellum and "walk forward" onto the capsule. The orientation of the needle is adjusted until it lies directly anterior to the radiocapitellar articulation, pointing toward the tip of the arthroscope. The assistant holds the needle to maintain that position and orientation.

At this point, the surgeon shifts their focus to the outside view of the needle and places a scalpel with a No. 15 blade adjacent and parallel to the needle outside the elbow, with the blade rotated into the sagittal plane and the sharp edge oriented proximally. After confirming that the position of the needle inside the joint is still correct, the operating surgeon then mentally fixes, in three-dimensional space, the precise position and orientation of the needle. On command, the assistant withdraws the needle straight out of, and away from, the elbow in line with its original direction. The operator then moves the scalpel into the position occupied by the needle, sufficiently advancing it into the elbow to penetrate the capsule (Fig. 20.4). At that point, the operator looks at the monitor to see the position of the knife blade within the joint. If the capsule is lax, which is not the case for contractures, fluid insufflation of the joint is used in most cases, immediately before insertion of the scalpel blade. This is done to facilitate penetration of the capsule by the scalpel. In the case of the osteocapsular arthroplasty, the scalpel blade is directed proximally to release the anterolateral capsule and scar tissue off the lateral supracondylar ridge. It is then returned to its original position and rotated 180° so that the blade can be used to release the lateral capsule down to the level of the lateral collateral ligament. The ligament, however, is not released.

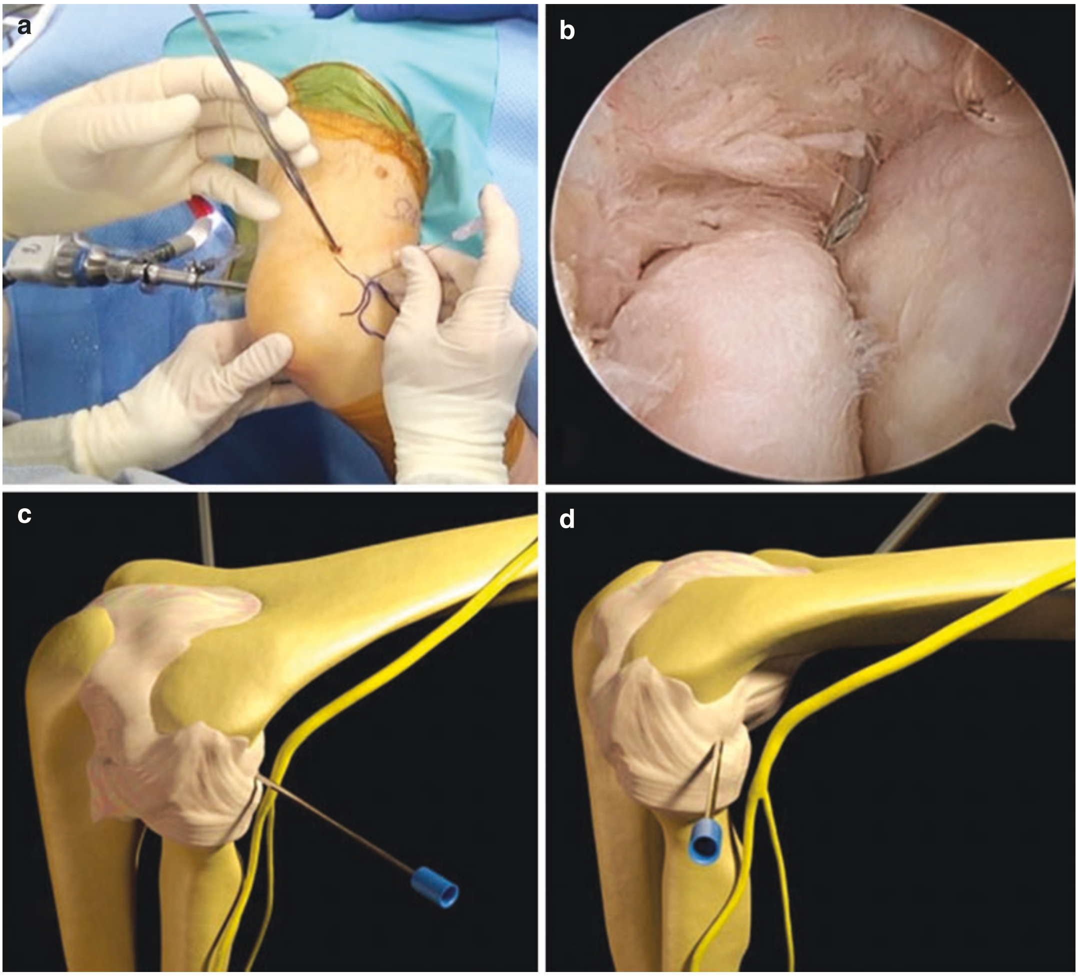

Fig. 20.3 (**a**) Intraoperative photograph of insertion of spinal needle into the anterolateral portal oriented such that the needle lies directly anterior to the radiocapitellar articulation and points toward the arthroscope. The arthroscope is placed in the anteromedial portal, and the retractor is placed in the proximal anterolateral portal. (**b**) Arthroscopic view of needle positioning. (**c**) Animation of needle positioning relative to the radiocapitellar articulation. (**d**) Lateral animation view showing needle position relative to the radial nerve. Used with permission of LBOFIXR. All rights reserved

20.8 Tips, Pearls, and Lessons Learned

We have had the opportunity to learn from our own experience and from surgeons who have communicated (either personally or by publication) their experience with surgical nerve injuries during arthroscopic contracture release. The procedural and technical factors that may have contributed to the safety of this procedure are summarized in a list of our "Top Ten Tips" [12] as follows.

20.8.1 Stay Below Your Curve: Always Keep a Margin of Safety

Arthroscopic contracture release of the elbow is not without the risk of nerve injury even in the hands of expert surgeons. Surgeons must anticipate and try to prevent accidents that can happen due to unpredictable circumstances related to the patient, anatomy, procedure, instruments, or surgical team. We believe it is important to keep a margin of safety by staying below one's learning curve.

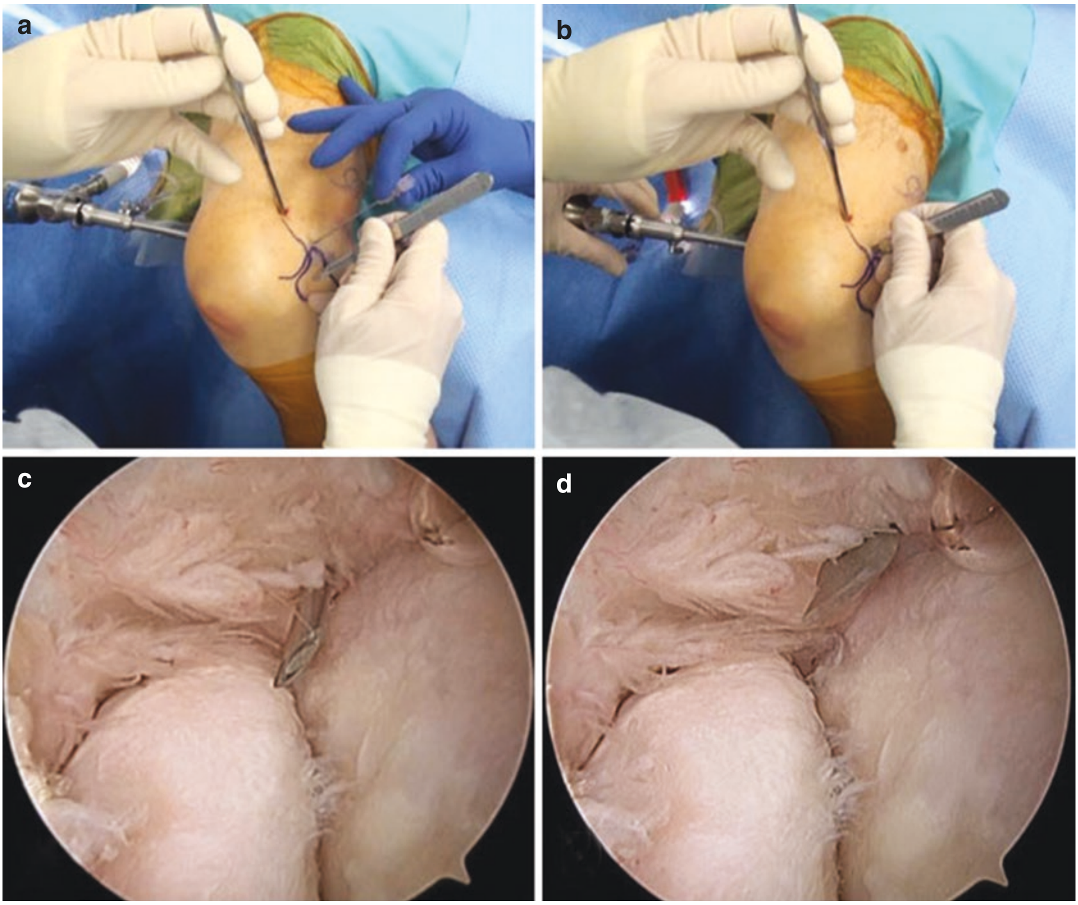

Fig. 20.4 (**a**) The scalpel is positioned adjacent and parallel to the needle. (**b**) The needle is withdrawn and replaced by the scalpel in precisely the same position and orientation in 3-D space. Arthroscopic views show the needle (**c**) being replaced by the scalpel blade (**d**) inside the joint. The scalpel should be positioned parallel to the needle, with the blade rotated into the sagittal plane and the sharp edge facing proximally. Used with permission of LBOFIXR.

20.8.2 Know Where the Nerves Are

The surgeon should know the three-dimensional locations and paths of the nerves with respect to other structures in the elbow, as seen from an intra-articular perspective. Landmarks for localizing the nerves at the joint line are remarkably consistent, especially for the radial nerve. Sometimes knowing where a nerve is will involve exploring it either open or arthroscopically. If there is a possibility that a nerve has been displaced, it should be imaged preoperatively. Since CT scans are routinely obtained as part of the preoperative evaluation of patient undergoing OCA, the courses and location of the nerve can be traced on serial CT scan images (Fig. 20.1).

20.8.3 Use Retractors

In our experience, the most important technical factor that facilitates performing a capsular release is the use of retractors inside the joint. In this regard, the use of retractors in the authors' experience is also the key determinant that permits more complex procedures to be performed safely, without nerve injury. Retractors, which are routinely used in open surgery, are required for proper visualization and to retract nerves away from motorized and cutting instruments. In addition, by retracting the capsule, pressurized distension is not needed and therefore swelling is less likely to become a serious impediment to progress. Therefore, one must be prepared to use multiple portals for each compartment in the joint (one for the scope, one for the shaver/cutter, one or two for retractors).

20.8.4 Avoid Swelling

Swelling increases the difficulty and risk, so it must be prevented. Fluid going in must go out. Inflow is manually regulated using a pulsatile lavage system with auditory feedback. Detaching the suction from the shaver allows the fluid to exit freely.

20.8.5 Detach Suction Tubing from Shaver

When working near nerves, it is safer to eliminate suction by detaching the suction tubing from the shaver.

20.8.6 Do not Use a Burr Near the Ulnar Nerve

High-speed burrs create a vortex by the Bernoulli effect of the Venturi principle. This can result in soft tissue being drawn into the burr just as if there was suction attached to it. For this reason, we recommend switching to a cutting shaver blade with a non-serrated cutting edge, rather than a burr, to remove osteophytes medial to the posteromedial corner of the olecranon.

20.8.7 Shorten Your Grip on the Burr for Better Control

The motorized instruments, developed for larger joints, are too long and heavy for elbow arthroscopy. Holding the blade, or the junction of the handle and blade improves precision and control. While working in the anterior compartment, it also helps to have the patient's hand firmly held between the surgeon's body and forearm.

20.8.8 Use a Consistent Step-Wise Strategy

As with other procedures, consistency improves safety.

20.8.9 Have an Experienced Assistant

Arthroscopic release of an elbow contracture requires an assistant who can manage the fluid and retract tissues

20.8.10 Anticipate and Limit Adversity

Adverse conditions increase the risk of error—which, during arthroscopic osteocapsular arthroplasty, translates into an increased risk of injuring a nerve. We believe that the risk of nerve injury during elbow arthroscopy is a relative risk, which is a function of several factors such as adversity and not just the complexity of the case. A factor unique to every surgeon relates to how they think, act, respond, etc., in ways that might influence the risk of nerve injury, especially if /when adverse conditions arise.

20.9 Difficulties Encountered

20.9.1 Proximal Anteromedial Portal (PAMP) with Prior Ulnar Nerve Transposition

Even though some authors have considered previous ulnar nerve transposition to be a contraindication to use of anteromedial portals for elbow arthroscopy [27–29], the PAMP can be established safely without exploring the previously transposed ulnar nerve based on the degree of certainty with which the nerve can be localized in the region of the planned portal [30, 31].

Decision-making and the surgical approach to the PAMP are ultimately based on the findings of the physical examination in the clinic preoperatively and confirmed again intraoperatively. The key determination is the ability to precisely localize the ulnar nerve by palpation in the region of the planned anteromedial portal. The ulnar nerve in the vicinity of the planned portal site is considered to be either definitely palpable (i.e., with certainty) or not.

If the nerve is definitely palpable, the PAMP is established antegrade with the following technique. If the nerve is mobile, it is rolled back and forth several times to confirm the location. Then, with the nerve rolled either anteriorly or posteriorly and held there by a finger, the PAMP is established about a centimeter away from the nerve (Fig. 20.5a, b). A blunt-tip, pointed 4-mm switching stick is then used to penetrate the capsule and enter the joint. The arthroscopic sheath is gently passed down over the switching stick into the joint. If the nerve is not mobile, the PAMP is placed either anterior or posterior to the nerve, whichever offers the greatest clearance from the nerve and best line of approach to the joint (Fig. 20.5c).

If there is any uncertainty at all about the location of the ulnar nerve localization at the planned portal site, a 1–3 cm incision is made and blunt dissection (spreading longitudinally) is performed down to the joint capsule (Fig. 20.6). The nerve is not visualized but can be palpated through the wound to confirm its location anteriorly or posteriorly. A blunt-tip, pointed 4-mm switching stick is then used to penetrate the capsule and enter the joint. The arthroscope sheath is gently passed down over the switching stick into the joint. Because the edge of the sheath can catch the nerve, the sheath is advanced slowly and without force while it is rotated back and forth (around the switching stick).

20.10 Key Procedure Steps

A "safety-driven strategy" [12, 32] is used in a standardized sequence of four steps: (1) get in and establish a view, (2) create a space in which to work, (3) bone removal, and (4) capsulectomy.

20.10.1 Posterior Compartment

Begin work in the posterior compartment with the arthroscope in the posterolateral portal and the working instrument in the posterior portal. Starting posteriorly allows you to address those parts of the elbow that are most challenging if swelling occurs, including the medial and lateral gutters.

Place a retractor in the proximal posterolateral portal when necessary. If a second retractor is needed, place it in the proximal posterior portal. Switch the portals to complete the work posteriorly, and to prepare to enter the lateral gutter. Access the lateral gutter by the mid-lateral ("soft spot") portal.

Three anterior portals are routinely used, and sometimes a fourth. The anterolateral and proximal anteromedial portals are used for the arthroscope and working instrument and the proximal anterolateral portal is used for a retractor. If a second retractor is needed, the anteromedial portal is used for that

20.10.1.1 Step 1: Get in and Establish a View

Visualize identifiable articular structures and confirm their anatomic orientation.

- In some elbows with contracture and arthritis, this is the most difficult and intimidating step. Contracted elbows are tight with minimal or no space between the capsule and the cartilage surface. Enter the joint with a pointed switching stick, which is pointed enough to penetrate dense scar tissue and the capsule but blunt enough that injury to the cartilage would be unlikely.

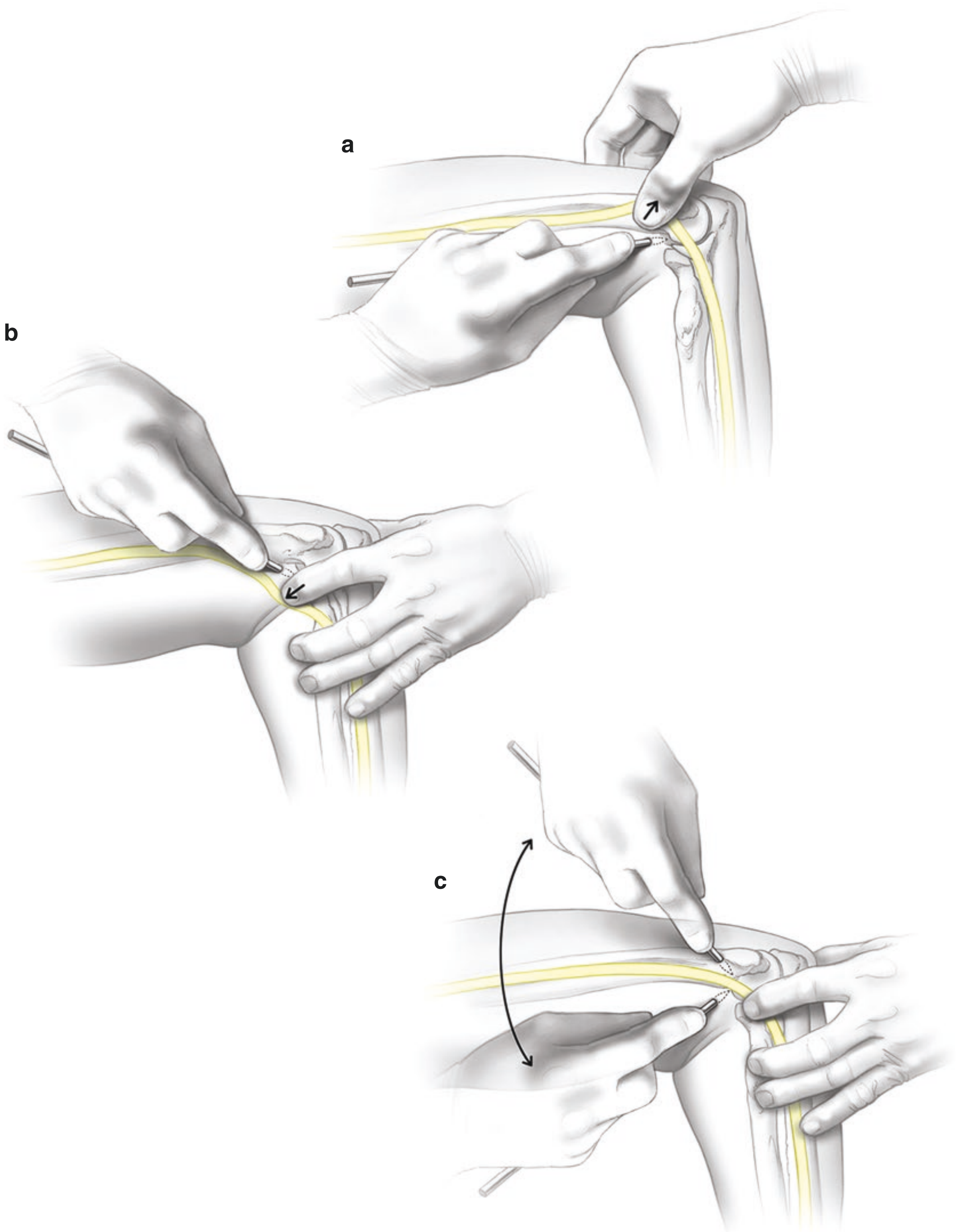

Fig. 20.5 Technique for establishing the proximal anteromedial portal if the ulnar nerve is palpable in the region of the portal. If the nerve is mobile, it is drawn (**a**) posteriorly or (**b**) anteriorly and held there while the portal is established about a centimeter away from the nerve using a pointed switching stick. (**c**) If the nerve is palpable but not mobile, the skin placement of the portal is adjusted anteriorly or posteriorly to permit passing by the nerve on one side or the other, leaving about a centimeter of space between the instrument and the nerve. Used with permission of LBOFIXR.

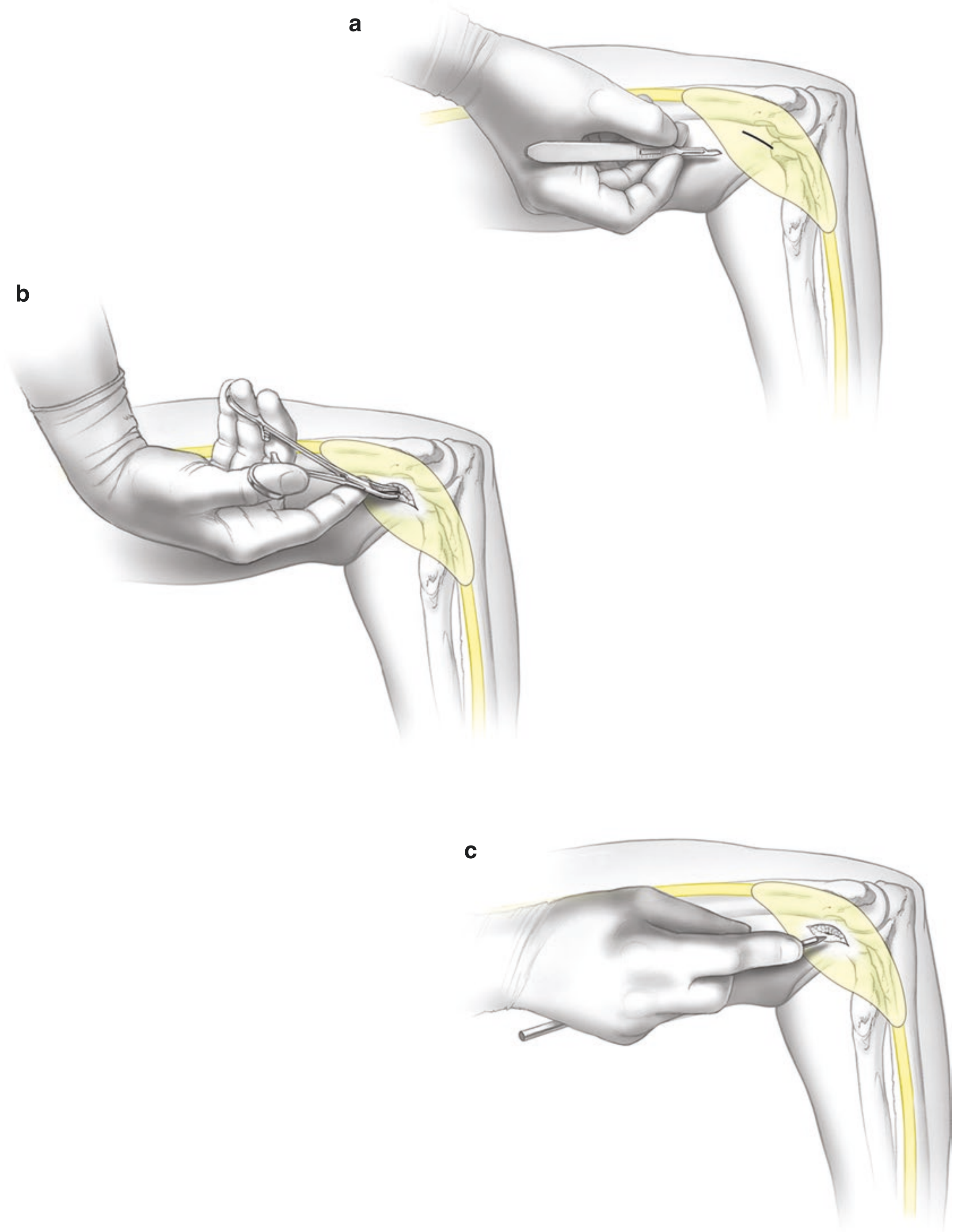

Fig. 20.6 Technique for establishing the proximal anteromedial portal if the ulnar nerve is not palpable in the region of the portal. (**a**) A 1–3-cm skin incision is made in the desired location for the portal. (**b**) A curved hemostat is used to bluntly dissect down past the nerve to the joint capsule, without exposing the nerve. (**c**) A switching stick is passed through the passage created by the hemostat down to, and through, the joint capsule. Used with permission of LBOFIXR.

- Once the switching stick is in place, insert the sheath into the joint over the switching stick and then insert the arthroscope inside the sheath.
- Insert a 4.5-mm or larger shaver (we use a 4.8-mm Gator blade; CONMED Linvatec, Largo, FL) through the posterior portal into the olecranon fossa. The outflow of the shaver unit is kept open and not connected to suction.
- After triangulating and getting the shaver tip into the arthroscopic view, recognizable articular structures are identified.
- Only when identifiable articular structures are visualized, and their anatomic orientation is confirmed, is Step 2 completed. In other words, you are now unequivocally inside the joint.

20.10.1.2 Step 2: Create a Space in Which to Work

Remove debris and loose bodies, as well as excise the fat pad and perform a synovectomy as necessary, so that you can see clearly.

- This critical step can be time-consuming but is a major factor in making arthroscopic osteocapsular arthroplasty safer and more predictable. Mastery of this step requires most of the skills necessary to perform the rest of the operation.
- The use of a retractor (sometimes more than one) can be quite helpful with exposure, especially at the posterolateral and posteromedial corners, and increase safety when you are working near the nerve posteromedially.
- A radiofrequency device is commonly used and is very helpful at this stage (Fig. 20.7a).
- To avoid heating the fluid, use only brief pulsations with a deliberate pause between pulsations.
- In order to be able to move the instruments freely within the joint, and to greatly increase the field of view, strip the capsule off the humerus proximally and along the medial and lateral supracondylar ridges.

20.10.1.3 Step 3: Bone removal

Remove debris and loose bodies, as well as excise the fat pad and perform a synovectomy as necessary, so that you can see clearly.

- Do this before capsulectomy for optimum visualization to minimize soft-tissue swelling and to avoid dissemination of bone debris into the muscle.
- Osteophytes are universally present in hypertrophic osteoarthritis and are common in post-traumatic arthritis. A retractor is commonly placed through the proximal posterolateral portal to minimize the risk of tissues becoming wrapped up around the burr (Fig. 20.7b). This is especially helpful when working around the ulnar nerve.
- To recreate the olecranon fossa, identify the original floor of the fossa and remove osteophytes from it and from the surrounding margins (Fig. 20.7c). The olecranon is restored to its normal shape by removing osteophytes from the tip and the sides (Fig. 20.7d).
- To prevent wrapping up the soft tissues and injuring the ulnar nerve on the medial corner of the olecranon, use a shaver blade (a 4.8-mm Gator blade) rather than a burr. Use a shaver blade, rather than a burr, in the medial gutter for the same reason.

20.10.1.4 Step 4: Capsulectomy

Release the capsule according to the severity of the flexion loss.

- If the patient lacks flexion, as is usually the case, the posterior capsulectomy includes not only release along the supracondylar ridges but also posteromedial and posterolateral capsular releases.
- The extent of the capsular release in each gutter depends on the severity of the loss of flexion. With severe loss of flexion, continue the release through the posterior bundle of the

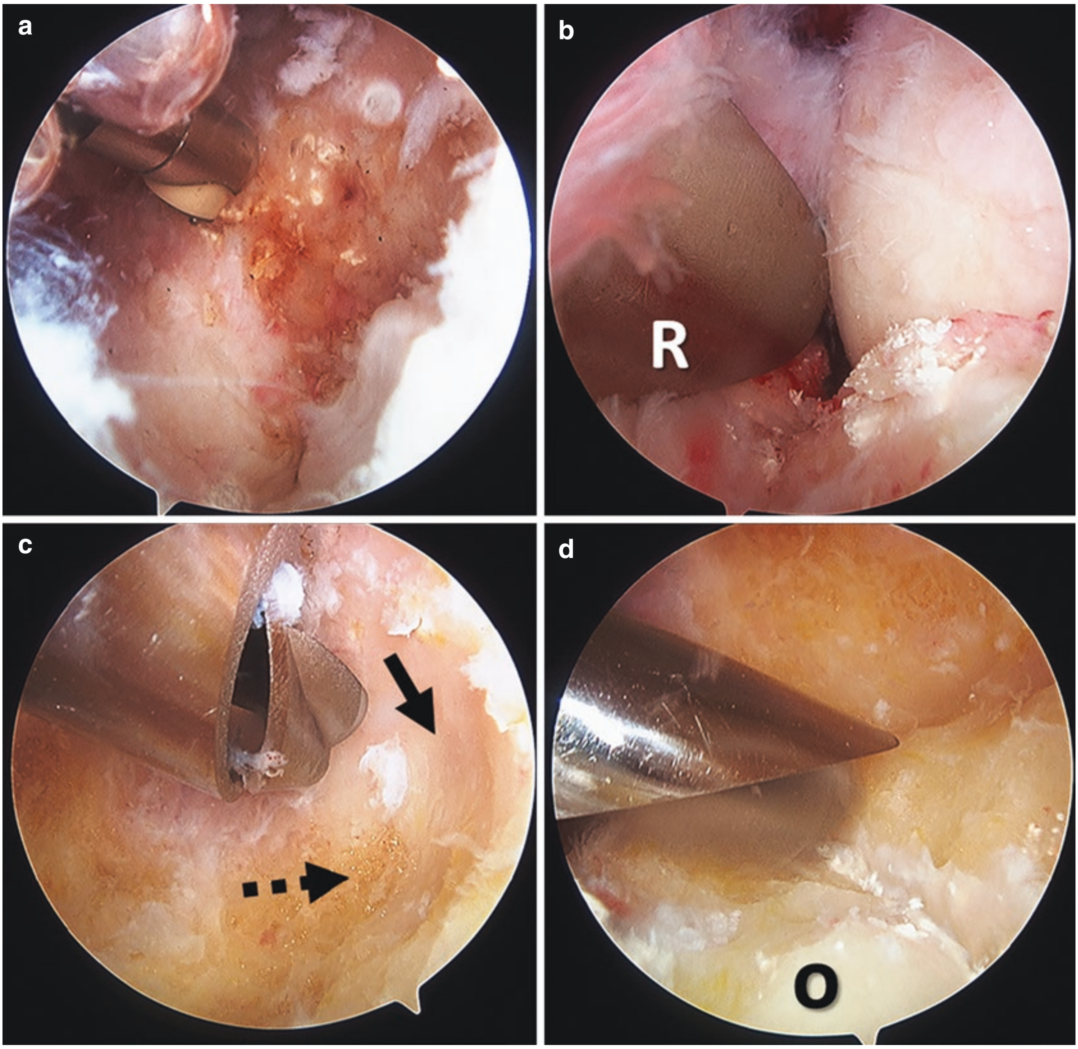

Fig. 20.7 Posterior compartment. Creating a space in which to work in the posterior joint compartment is a crucial step in the osteocapsular arthroplasty of the elbow. It involves synovectomy and removal of debris, scar tissue, and loose bodies. A radiofrequency device is commonly used and is very helpful at this stage (**a**). Adding a retractor (R) through the proximal posterolateral portal increases the space just as retraction does with open surgery (**b**). Bone removal is performed with use of a shaver and a burr (**c**, **d**). The CT scan will demonstrate the amount of osteophytes to be removed (dashed arrow) in order to find the original floor of the olecranon fossa (solid arrow) (**c**). (**d**) Shows the trimming of the olecranon (O). Particular attention should be paid to avoid removing normal olecranon bone, especially in an overhead athlete.

medial collateral ligament on the medial side and to the radial head on the lateral side. In some contractures, the capsule is scarred to the sides of the joint. If this is the case, remove such adhesions.
- If a decompression of the ulnar nerve is performed, the posteromedial capsule release can be performed through that incision.

20.10.2 Medial Gutter

- Perform the work in the medial gutter with the arthroscope in the posterolateral portal and the shaver in the posterior portal. A retractor can be placed through either the proximal posterolateral portal (Fig. 20.7b) or the proximal posterior portal.

- Release the posteromedial aspect of the capsule to restore lost flexion. The capsule can be released through a small incision over the cubital tunnel that permits concurrent ulnar nerve decompression. At the same time, remove the medial osteophytes from the trochlea and olecranon.
- Alternatively, if the posteromedial aspect of the capsule does not need to be released, you can remove the osteophytes arthroscopically if you have the skill to perform the procedure and are fully knowledgeable about the three-dimensional location of the nerve in this area.

20.10.3 Lateral Gutter

- To work in the lateral gutter, begin with the arthroscope in the posterior portal and the shaver in the posterolateral portal. Work around the posterolateral corner is facilitated by the use of a retractor.
- Eventually place the arthroscope in the posterolateral portal and the working instruments in the soft spot portal.
- Remove osteophytes from the posterior aspect of the capitellum and the lateral ridges of the trochlea and olecranon (Fig. 20.8).

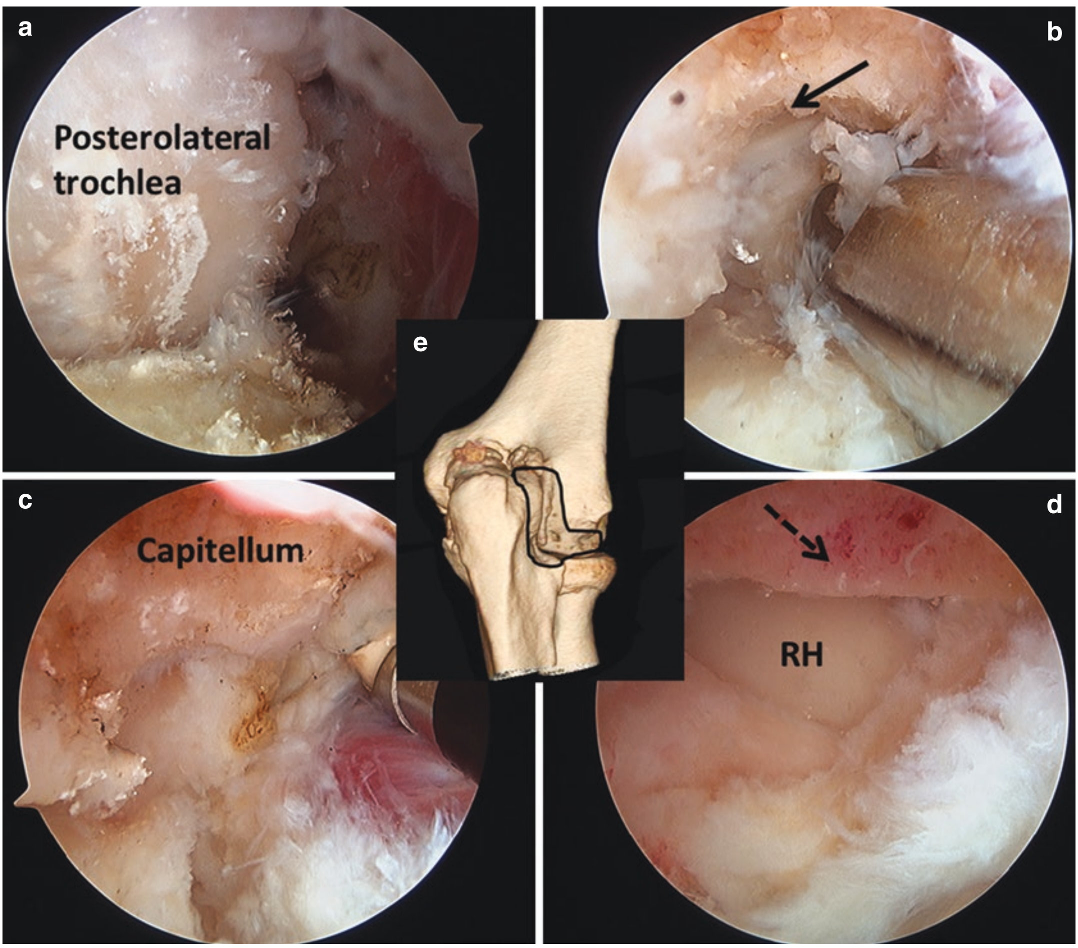

Fig. 20.8 Lateral gutter. Before removing osteophytes, it is necessary to remove soft tissue around the posterolateral corner in order to create a clear space in which to work (**a**). Osteophytes are removed from the posterior part of the capitellum (black arrow, **b**). A radiofrequency device is especially useful in this area (**c**). Once the osteophytes are trimmed from the capitellum (black dashed arrow), the posterior aspect of radial head (RH) is inspected (**d**). The three-dimensional surface rendering CT reconstruction (**e**) is placed here for orientation purposes. Used with permission of Mayo Foundation for Medical Education and Research.

- Carefully inspect the entire lateral compartment for loose bodies, as this is a typical location in which loose bodies may be nestled.

20.10.4 Anterior Compartment

After completing work in the posterior compartment and the medial and lateral gutters, enter the anterior compartment and follow the same four-step sequence.

20.10.4.1 Step 1: Get in and Establish a View

As with the posterior compartment, the first step in the anterior compartment is to visualize the joint structures and to be sure of their anatomic orientation.

- Enter the joint via the proximal anteromedial portal with a pointed switching stick.
- Once the switching stick is in place, insert the arthroscopic sheath into the joint over the switching stick and then insert the arthroscope inside the sheath. Exercise caution to prevent articular cartilage damage.
- Insert a retractor in the proximal anterolateral portal. Then establish the anterolateral portal for the shaver.
- To lessen the risk of subsequent nerve injury, do not proceed further until you have established a view, meaning that identifiable articular structures such as the radial head and capitellum, or coronoid and trochlea, are visualized and their correct anatomic orientation is confirmed.

20.10.4.2 Step 2: Create a Space in Which to Work

The stripping of the capsule is usually extremely effective for improving or creating the space in which to work in the anterior joint compartment

- In contracted elbows, the intracapsular space is contracted, sometimes severely. The safety and efficacy of working with arthroscopic instruments in the front of the elbow require sufficient space in which to work. In elbows with contractures, this space has to be created. This step includes removal of debris, scar tissue, and loose bodies as well as stripping the capsule off the humerus (Fig. 20.9a).
- The capsular attachments along the medial and lateral supracondylar ridges are usually released at this stage so the entire soft tissue mass (capsule, muscle, scar, and neurovascular structures) can be retracted further anteriorly away from the shaver or burr. If the collateral vessels on the medial side are encountered while you are doing this, cauterize them. A retractor is routinely placed in the proximal anterolateral portal, greatly facilitating exposure and execution of surgery in the anterior compartment. Sometimes a second retractor is used, coming in from the anteromedial portal

20.10.4.3 Step 3: Bone Removal

Remove osteophytes and reshape the coronoid and coronoid fossa to their normal shape

- Remove any osteophytes from the coronoid as well as from the coronoid and radial fossae (Fig. 20.9b). Reaching into the coronoid fossa can be difficult. Facilitate this by positioning the arm as explained in the section on patient positioning above.
- To improve control and accuracy during use of the burr, shorten your grip on the device. Instead of holding the handle as you normally would, move your hand partially onto the shaft of the burr itself.
- Use a very slow speed with the burr medially and laterally near the nerve.

20.10.4.4 Step 4: Capsulectomy

Meticulously excise the anterior aspect of the capsule following four consistent steps.

- After bone removal is complete, perform an anterior capsulectomy in a consistent stepwise sequence: (1) detachment, (2) preparation, (3) incision, and (4) excision.
- First, detach the capsule from the humerus proximally and along the medial and lateral

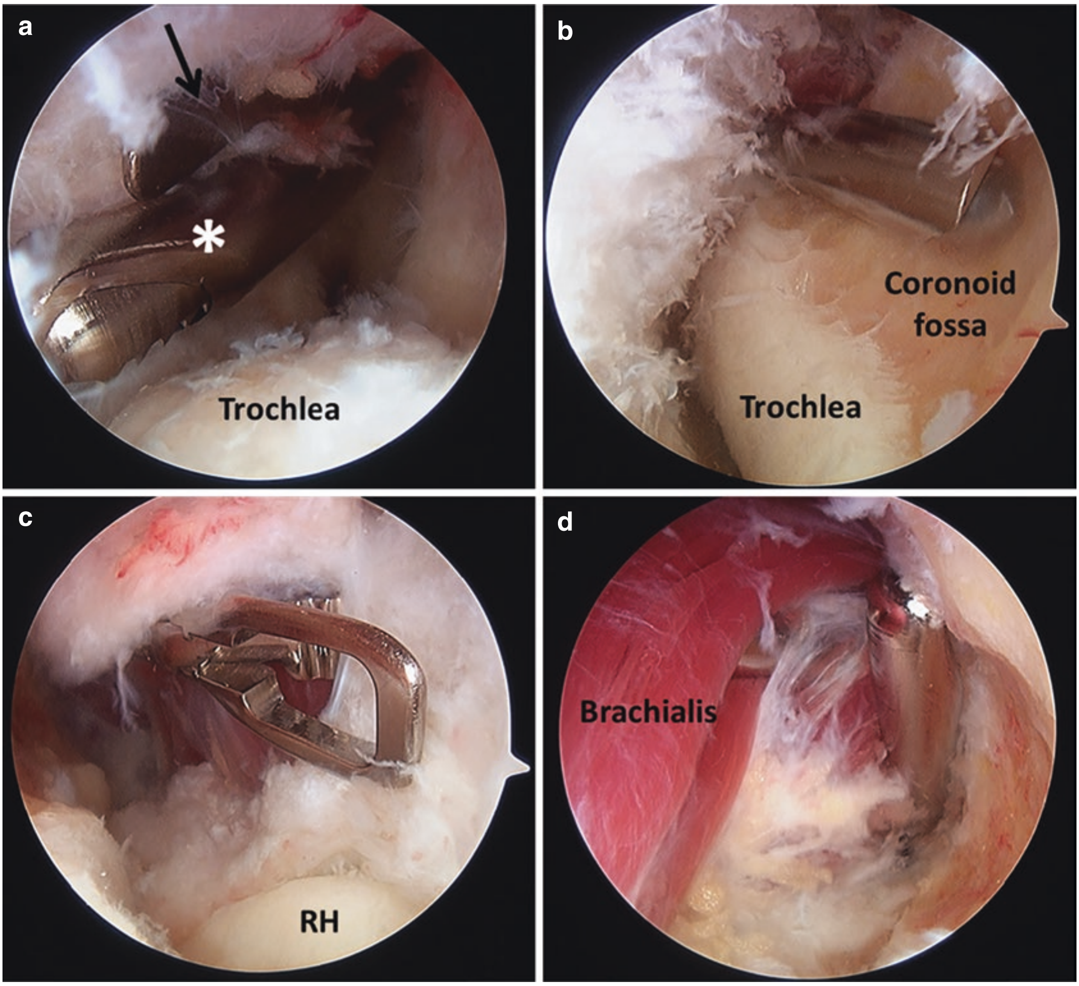

Fig. 20.9 Anterior compartment. The view is established and a working place is created (**a**). This step includes removal of debris, scar tissue, and loose bodies, and stripping the capsule off the humerus. The shaver (white asterisk) and the retractor (black arrow) are placed in the proximal anterolateral portal and in the anterolateral portals. After a safe working place is created, bone removal is begun (**b**). The osteophytes in the radial and coronoid fossae are removed by recontouring the distal part of the humerus. The anterior capsulectomy is best performed by starting with a capsulotomy from medial to lateral (**c**). The remnants of the capsule (**d**) are removed with use of a shaver. *RH* radial head

supracondylar ridges if this was not already done to create a space in which to work during Step 3. Doing this may expose collateral vessels; if so, cauterize them.

- Second, prepare the anterior aspect of the capsule for removal by cleaning it up and defining it as a structure. This includes synovectomy and removal of loose tissue from its surface.
- Third, incise the capsule from medial to lateral with a wide duck-billed punch. Start the capsulotomy (Fig. 20.9c) medially and first extend it down the medial side of the ulnohumeral joint to the common flexor pronator tendon or even to the anterior bundle of the medial collateral ligament. There is normally a continuous layer of muscle anterior to the capsule medially, but laterally there is a triangular region between the brachialis and the extensor carpi radialis longus in which there is no muscle. For this reason, it is easier to avoid

wandering out into the extracapsular tissues medially than laterally. Use a "bite and peel" technique to incise the capsule over to the lateral edge of the brachialis, indicated by a strip of fatty tissue surrounding the radial nerve. The "bite and peel" technique facilitates subsequent removal of the capsule and scar tissue. The capsulotomy is distal, where the interval between brachioradialis and extensor carpi radialis longus is readily identifiable.

- As the fourth and final step, excise the capsule with the shaver (disconnected from suction) to the exposed lateral edge of the brachialis (Fig. 20.9d). After switching portals, divide the remaining lateral capsule with tenotomy scissors and excise it.

20.10.5 Closure

Close the wounds after drains have been placed anteriorly (through the arthroscope sheath into the proximal anterolateral portal) and posteriorly (through the posterolateral portal into the olecranon fossa, exiting proximally through a separate skin puncture).

20.10.6 Postoperative Regimen

Postoperatively, check the nerve function before performing a regional block and commencing continuous passive motion.

- Once normal motor and sensory neurologic function has been confirmed, place an indwelling axillary catheter for a continuous brachial plexus block.
- Continuous passive motion (CPM) is begun through a range of motion equal to that achieved in surgery. Instruct the patient to come out of the machine every hour for 5 min to minimize soft-tissue or nerve problems due to continuous pressure or stretching. On and after the third day, the duration of each period out of the machine is determined by how long the patient can be out of the machine without losing some motion or experiencing difficulty regaining that motion as soon as he/she recommences CPM.
- Remove the indwelling axillary catheter 12 h prior to the anticipated time of discharge from the hospital to permit confirmation of recovery of neurologic function.
- After discharge, each patient continues to use a CPM machine as part of a home therapy program until motion can be maintained without CPM (approximately 4 weeks total).

20.11 Bailout, Rescue, and Salvage

Recurrent stiffness within the first few month is likely due to neurogenic contracture or heterotrophic ossification. Get a CT scan to assess for HO. A history of ulnar neuritis any time postoperatively, and/or posteromedial elbow pain at the end ranges of motion (extension or flexion) is highly suggestive of neurogenic contracture. If so, a two-stage revision—first subcutaneous transposition and second OCA usually 2–4 months later—is performed. Revision osteocapsular arthroplasty for failed or recurred stiff elbow is not a contra-indication. Persistent radiocapitellar pain is treated by radial head excision if it is severe. Whether or not it is best to interpose tissue there, or ever to insert a radial head prosthesis, is not certain. Total elbow arthroplasty is used for persistent painful arthritis especially in low-demand elbows and elderly patients.

20.11.1 Delayed Onset Ulnar Neuritis (DOUN)

DOUN is a neuritis (inflammation) and sometimes neuropathy (loss of nerve function) that may occur after the restoration of elbow motion (7, 8). The incidence of DOUN has been reported to be 11% after arthroscopic contracture release of the elbow. There are three distinct clinical presentation patterns known: rapidly progressive, non-progressive, and slowly progressive. The rapidly progressive pattern (Fig. 20.10), characterized by increasing pain at the cubital tunnel, progressive loss of elbow motion and neuropathy, has been reported to be

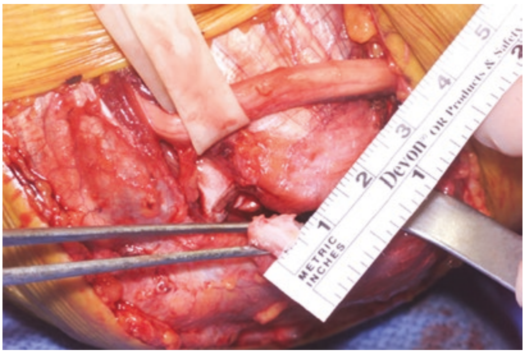

Fig. 20.10 Operative findings in a patient with rapidly progressive delayed-onset ulnar neuritis 8 days after osteocapsular arthroplasty. The posterior bundle of the medial collateral ligament was 6 mm thick, raising the floor of the cubital tunnel and compromising the space within the tunnel. Used with permission of Mayo Foundation for Medical Education and Research.

the most common and required urgent reoperation for nerve management. In cases where ulnar nerve transposition was delayed beyond 2 weeks after surgery, complete recovery of neurological function did not occur. Three factors have been significantly associated with an increased DOUN risk: preoperative HO, preoperative neurological symptoms, and preoperative arc of motion. We recommend limited open ulnar nerve decompression prior to the procedure and keeping a high index of suspicion and avoiding end-range stretching if it causes symptoms of ulnar neuritis or pain near the cubital tunnel.

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Part III

Elbow Arthroscopy

21 Positioning and Portal Placement in Elbow Arthroscopy

Calek Anna-Katharina and Bernhard Jost

Key Points

- Start with simple cases with a normal capsule volume (no contractures)
- Elbow arthroscopies and its steps should always be performed in the same manner.
- The portals should always be placed in 90° flexion of the elbow to reduce the risk of neurovascular damage.

21.1 History and Complications

The first records of elbow arthroscopy date back to 1931. The modern technique, as we know it, was introduced about 50 years later in 1985 [2, 3]. Originally, it was a risky procedure with complication rates up to 20% (infections, contractures, hematoma, and temporary nerve lesions). In the majority of cases this was due to the small size of the elbow capsule and the proximity of neurovascular structures (radial, median, and ulnar nerve). However, major complications—like permanent nerve lesions, mostly related to excessive manipulation—are rare [4].

In the past years, elbow arthroscopy has become popular rapidly with major advances in equipment and precise descriptions of different operative techniques [1]. Nowadays, elbow arthroscopy is widely used and has become an essential part of orthopedic surgery.

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21.2 Indications [2]

Over the last years the spectrum for elbow arthroscopy has expanded to various procedures:

- diagnostic (e.g. biopsies, posterolateral plica)
- removal of loose bodies (e.g. osteochondritis dissecans OCD)
- extensor tendon release (e.g. lateral epicondylitis/tennis elbow)
- synovectomy (e.g. infection, rheumatoid arthritis)
- capsular release (e.g. posttraumatic stiffness)
- debridement/excision osteophytes (e.g. osteoarthritis)
- fracture fixation (e.g. radial head)
- radial head resection

Tips and Tricks

For beginners, the best indications in starting with arthroscopies are the first three above-mentioned procedures. The joint capsule has a higher than normal volume, which facilitates access to the joint.

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21.3 Contraindications [5]

This is an approved safe and appropriate procedure with few (relative) contraindications, except in cases of:

- ankylosis (prevents adequate entry into and distension of the joint)
- local infection
- anterior ulnar nerve transposition (only placement of the proximal anteromedial portal after open identification of the ulnar nerve)

21.4 Anesthesia

Regarding anesthesia, there are two options, each with several advantages as well as disadvantages:

- general anesthesia
- regional anesthesia (infraclavicular plexus block or infraclavicular plexus catheter)

General anesthesia allows immediate postoperative neurological evaluation. A disadvantage may be limited postoperative pain control which could be compensated by using a catheter. Regional anesthesia offers good postoperative pain control but limits neurological monitoring. Furthermore, the prone or lateral decubitus position is less well tolerated by patients in regional anesthesia.

21.5 Patient positioning

There are mainly three patient positionings in use:

21.5.1 Lateral Decubitus (Authors' Preference)

The arm is supported by a padded arm holder with the forearm hanging free at 90° of elbow flexion. The opposite arm should be taken care of by putting it away from the operative field with the shoulder in 90° of abduction and full external rotation with the elbow flexed 90° (Figs. 21.1 and 21.2).

The benefit of this position is good access to the anterior as well as to the posterior compartment. The neurovascular structures can separate from the joint capsule. Furthermore, it allows conversion to open surgical procedure, e.g. for ulnar nerve release.

This position also provides advantages for the anesthetist because of superior access to airways. Moreover, it is better tolerated by the patient than the prone position.

Fig. 21.1 Patient positioning

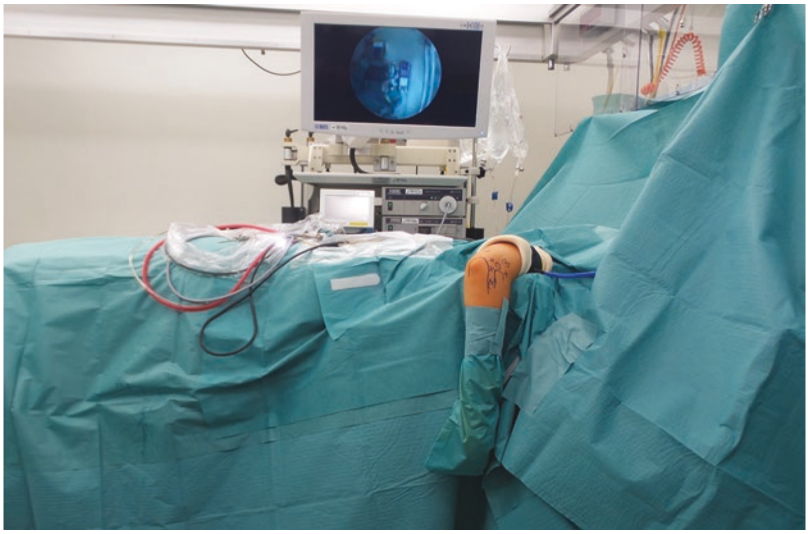

Fig. 21.2 Patient positioning sterile

21.5.2 Supine Position

The patient's arm is supported up over the chest with the shoulder in 90° of abduction and the elbow flexed 90°.

This enables general access to the patient, orientation more common for the surgeon, and facilitates easy conversion to an open procedure.

The disadvantages are diminished stability of the arm, aggravated manipulation, and rather poor access to the posterior compartment.

21.5.3 Prone Position

The patient's arm is stabilized by an arm holder with the forearm hanging down. The shoulder is abducted 90°, the elbow flexed 90°.

The benefits of this position are that neurovascular structures can separate from the joint anteriorly, there are improved access and good visualization of the posterior compartment. Furthermore, it allows conversion to an open surgical procedure.

Drawbacks of this position are poor airway access, no anterior open access, and general anesthesia is required since regional anesthesia is not well tolerated.

21.6 Instruments

The following instruments are used for every elbow arthroscopy:

- Tourniquet ~250 mmHg, which is placed sterile proximal to the elbow. Although a tourniquet is not mandatory, it gives additional space around the elbow by elevating the elbow away from the padded bolster.
- 4.0 mm arthroscope 30°
- Standard arthroscopy pump (with the tourniquet usually at 40 mmHg of water pressure is sufficient)
- Hemostat (Péan)
- Cannula and trocar
- 4.0–4.5 mm shaver/burr
- Grasping forceps
- Electro debrider (only for capsular releases if necessary)
- Switching sticks for changing portals

21.7 Portals [4, 6]

Five standard portals (two anteriors and three posteriors) are usually used, allowing access to almost all elbow arthroscopies. There are two additional portals (one anterior and one posterior) which can be used in certain situations.

Tips and Tricks
For safety reasons, elbow arthroscopies should always be performed in the same manner. The steps should be followed in the same sequence, regardless of diagnosis.

13 Sequential Steps for Portal Placement
Step 1: "Surgery" already starts at the outpatient clinic at the time of consultation. The ulnar nerve has to be identified in the ulnar sulcus. If the nerve does not run all along in the sulcus, is dislocated or transposed anteriorly, the indication for elbow arthroscopy should be questioned (relative contraindication). A proximal anteromedial portal should only be performed openly and preferably elbow arthroscopy should be avoided altogether.

Step 2: The authors' preference is to start in the anterior compartment and if necessary, switch to the posterior compartment. This can also be done vice versa, according to the surgeon's preference.

Tips and Tricks
It does not matter whether the elbow arthroscopy is started in the anterior or posterior compartment, but it should always be performed the same way.

Step 3: Before starting the operation, the contours of the following anatomical landmarks should be marked (Fig. 21.3):

- medial epicondyle with medial septum
- ulnar nerve in the sulcus
- olecranon
- lateral epicondyle
- radial head (and neck)

Step 4: First, identify the so-called soft spot, within the triangle of the lateral epicondyle, radial head, and olecranon (Fig. 21.3). With the elbow flexed, a needle and standard 20 ml syringe with 10–20 ml saline solution are used to insufflate the joint from the posterolateral soft spot in order to extend the capsule and increase the distance between the neurovascular structures and the joint. The needle is left in place.

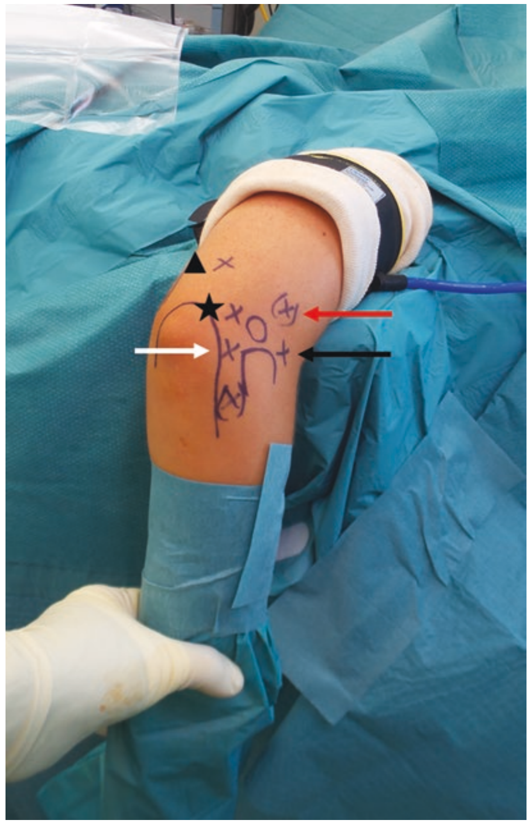

Fig. 21.3 Posterolateral view with lateral and posterior portals, including additional portals in parentheses. Black arrow—standard anterolateral portal. Red arrow—proximal anterolateral portal. Asterix—proximal posterolateral portal. Triangle—straight posterior portal. White arrow—distal posterolateral (soft spot) portal

Tips and Tricks
All portals should be placed with the elbow in 90° flexion to avoid injuries to neurovascular structures.

21.7.1 Anterior Elbow Arthroscopy

Step 5: First standard portal = proximal anteromedial portal (Fig. 21.4).

Fig. 21.4 Medial view, medial portal, medial landmarks. Black arrow—proximal anteromedial portal

This portal lies approximately 2 cm proximal to the medial epicondyle and 1–2 cm anterior to the medial intermuscular septum. After skin incision, the septum is palpated with a hemostat (Péan) from posterior to anterior and back to posterior. With the septum verified, the hemostat is brought from posterior to anterior and pushed forward to the bone/humerus. This is repeated with a blunt trocar in the arthroscopic cannula system. The trocar is brought laterally to the anterior surface of the humerus toward the radial head until the joint capsule is penetrated. The penetration can usually be felt like "falling into the joint" after overcoming the resistance of the capsule. That is the first sign of being in the correct intraarticular position which can be assumed when the trocar is removed from the cannula and the insufflated saline solution leaks out. By the time fluid outflow has stopped, saline solution should be insufflated once again. The needle still stuck in the soft spot is used for this purpose. When the liquid starts pouring from the cannula again, intraarticular position can be assured definitively (Fig. 21.5). Then the arthroscope is inserted, and the intraarticular position can be verified visually. The soft spot needle is then removed.

As mentioned in Step 1, this portal is relatively contraindicated if the ulnar nerve does not run in the sulcus or if previous operations (e.g. subcutaneous anterior transposition of the ulnar nerve) have taken place. In this case the arthroscope should be inserted laterally; it would be even safer to avoid an arthroscopy at all and switch to an open procedure.

Step 6: Second standard portal = anterolateral portal (Fig. 21.3).

Fig. 21.5 Outflowing water

This portal lies anterior to the radial head, 1 cm distal and 3 cm anterior to the lateral epicondyle. The portal is placed under arthroscopic visualization. A needle is inserted in front of the radial head in the direction of the medial epicondyle. Afterwards, the skin and the capsule are incised in the same direction. In the next step the required instruments are inserted. If the anterolateral portal is placed too laterally or too posteriorly, the maneuverability of the arthroscope can be compromised.

Tips and Tricks
After completion of the arthroscopy, the water should not be drained off with a shaver. This diminishes the risk of uncontrolled, excessive debridement, which could lead to damage of neurovascular structures.

Step 7: Additional anterior portal = proximal anterolateral portal (Fig. 21.3).

Sometimes an additional portal for retractors is required to improve visibility.

This portal is placed 1–2 cm anterior to the lateral epicondyle, in the same way as described above. It can also be advantageous for debridement in a tennis elbow with better access to the lateral epicondyle. However, this additional anterior portal is rarely used.

Tips and Tricks
The lateral portals are in close proximity to the radial nerve. If the recommended distances and technical steps are followed, the nerve should be secure.

Step 8: By switching the arthroscope from medial to lateral, the whole anterior joint can be visualized and addressed. Changing portals with the arthroscope should always be done with the help of switching sticks (Fig. 21.6).

Fig. 21.6 Switching sticks and distal ulnar portal (black arrow)

21.7.2 Posterior Elbow Arthroscopy

Tips and Tricks
Posterior portals medial to the midline are contraindicated. Otherwise, ulnar nerve lesions may occur.

Step 9: Third standard portal = proximal posterolateral portal (Fig. 21.3).

This portal is set at about the level of the olecranon tip in the lateral recess, lateral to the triceps tendon (paratricipital). It allows evaluation of the lateral recess, the olecranon fossa, the olecranon tip, and the medial recess, from lateral to medial. This is the portal to start using the arthroscope.

Step 10: Fourth standard portal = straight posterior portal (Fig. 21.3).

This portal lies about 3 cm proximal to the olecranon tip and runs through the midline of the triceps tendon/muscle. It visualizes posteromedial and posterolateral joint parts (recess), as well as the olecranon fossa and the olecranon tip. This is the portal to start using the shaver.

Tips and Tricks

Both portals (proximal posterolateral and straight posterior) are placed simultaneously. The skin is incised together with the muscle and/or the capsule, so that the bone can be entered directly. This maneuver is repeated by blunt dissection with the Péan. In the posterolateral portal, the trocar with a cannula is then inserted. The trocar should be removed with special care so that direct contact with the distal humerus is not lost. The shaver is placed directly on the bone through the straight posterior portal.

Step 11: The first goal should be to establish a view. This might not be easy due to interposition of parts of the capsule; the shaver must therefore be immediately brought into contact with the camera, under almost visualization. In the next step, as much capsule as necessary should be removed in front of the camera to permit inspection.

Step 12: Fifth standard portal = distal posterolateral (soft spot) portal (Fig. 21.3).

The third posterior portal is used to evaluate the radiohumeral joint and the posterior proximal radioulnar joint. The portal is within the soft spot. As usual, a needle is inserted under arthroscopic visualization. It should be placed in the lateral inferior recess.

Step 13: Additional posterior portal = distal ulnar portal (Fig. 21.6).

Arthroscopic surgery has become the standard procedure to treat capitellar OCD [7]. Access to the capitellum has to be ensured to debride these lesions. The standard portals will not enable exact access, so another portal, the distal ulnar portal, is needed. It is placed 3–4 cm distal to the edge of the ulna. After skin incision the trocar is advanced under the anconeus, along the lateral edge of the ulna and directed diagonally toward the radiocapitellar joint, passing behind the radial head into the joint. By flexing the elbow progressively to 90° or more, direct visualization and access to the capitellum is obtained, permitting all sorts of therapeutic measures, e.g., microfracturing.

Multiple Choice Questions

1. Which nerves are most endangered during elbow arthroscopy?
   - Ulnar nerve (x)*
   - Radial nerve (x)
   - Median nerve (x)
   - Nervus cutaneus antebrachii lateralis
2. What are the risks associated with the use of suction during arthroscopy?
   - Poor visibility
   - Lack of fluid in the joint
   - Damage of neurovascular structures (x)
   - Postoperatively more pain due to increased mechanical manipulation
3. What is a disadvantage of positioning in lateral decubitus?
   - Bad access to the posterior compartment
   - Less tolerated by patients with regional anesthesia (x)
   - The conversion to an open approach is difficult
   - The airways are difficult to reach due to the patient's head positioning

*(x) right answer

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22 Basic Procedures in Elbow Arthroscopy

Przemyslaw Lubiatowski, Jakub Stefaniak, and Joanna Wałecka

22.1 Tips and Tricks

Elbow arthroscopy is considered to be a demanding procedure, but with right preparation, good knowledge of anatomy, and planning one can make it much simpler. Most important issue is to perform it safely and of course effectively. We are suggesting some tips and tricks that might help you avoid troubles through each step of elbow arthroscopy.

- "Pre-flight" preparation: Knowledge of anatomy is essential that includes nerves (radial, ulnar, median) and vessels, but also ligaments. We strongly recommend to practice portals and entry into the joint in cadaver lab. Open dissection of the elbow really let us understand the course of vital structures and their relation to instruments. It is also helpful to have the possibility to travel and see other surgeons operating. Alternatively, you may learn from our panoramic videos with elbow arthroscopy techniques enjoying virtual trip into our operating theater (https://www.youtube.com/watch?v=VVzLC6HNqro&t=11s).
- Start with simple procedures: Simple does not mean unnecessary or the ones that can be done without caution or precision. Simple mean that they are short, stay out of nerves, mostly inside the capsule, and just one thing to do. Good examples of pathologies that can be addressed easily are loose bodies, elbow plica, synovitis, or tennis elbow. With easy procedures you do not need to worry about time of ischemia or swelling. You do not need to perform meticulous dissections or resections.
- "On the start line": Get the imaging of the patient on the screen if you need to perform procedures on bones (like osteophyte removal). Especially 3D reconstruction may give you better orientation in space and help you assist in reshaping boney anatomy. Position your patient properly (see previous chapter). Place appropriate tourniquet. You need to have access to all parts of the elbow. Have all instruments in the operating theater that includes: shaver system (with soft blades and burrs), switching stick, graspers, punches, and electrothermal system.
- "Time to start": portals need to be carefully planned (see previous chapter). Most of the time they are predictable and almost every time the same. Entry into the joint has to be effective yet safe. To get most of the anatomical orientation, palpate the landmarks and

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mark them with sterile pen. Inflate the joint with saline. Capsular expansion makes it easier to enter the joint and pierce the tissue, but most of all pushes the nerve and vessels away from the entry point. Pay attention to 3 major nerves [1].

- Ulnar nerve needs special attention, not only because of safety issues, but also risk of compression/tension neuropathy. Check for preexisting nerve relate symptoms before surgery. If nerve decompression is indicated, do that before arthroscopy in "dry" conditions. You can do that with mini-open approach or endoscopically (see other chapter). Consider doing that as preventive procedure when you perform arthrolysis especially for extension contracture, even if patient has a normal nerve function [2].
- Ulnar nerve is normally hidden behind medial epicondyle and is completely safe when you operate in anterior compartment, unless was transposed in previous surgery (check history) [3]. In such case it may be necessary to make small opening and visualize the nerve and be sure to pass by the nerve with scope of shaver or use small and smooth cannula. Another possibility is ulnar nerve instability. Palpate the nerve in the grove and check for any snapping against medial epicondyle on flexion and extension. Ulnar nerve may be in danger posteriorly. Make sure to use posterior and postero-lateral portals, rather than going postero-medially (Fig. 22.1).

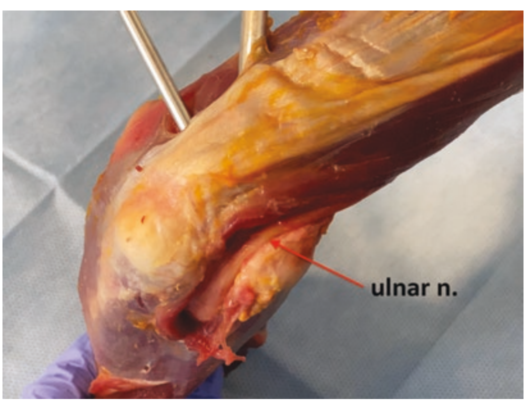

Fig. 22.1 Postero-lateral portals are safe for ulnar nerve

- When working around medial gutter, try to stay inside the capsule. Turn off any suction when making debridement and do not face shaver mouth towards capsule. If you need to release posterior band of ulnar collateral ligament, stay on the bone.
- Radial nerve may be in danger when performing antero-lateral portals and during procedures around antero-lateral capsule. When entering from lateral side, make sure patient's elbow is flexed to 90° and forearm pronated. It will move the nerve around 11 mm away from the articular surface. Point the trocar obliquely towards articular surface (rather than parallel) when entering the joint (Fig. 22.2).
- Once you stay within capsule nerve is completely safe. If you need perform synovectomy at antero-lateral capsule, turn off any suction from the shaver, and avoid turning shaver mouth directly toward capsule (Fig. 22.3). For

Fig. 22.2 Entry through mid-lateral portal. Elbow flexed to 90° and forearm pronated, trocar with sheath pointing obliquely towards articular surface

Fig. 22.3 Radial nerve courses close to the capsule. Once shaving the antero-lateral capsule avoid facing shaver anteriorly and pushing over the capsule

capsular release, make it by detaching capsule from the bone.

- Median nerve is rarely in danger. In normal anatomy it is protected by brachialis muscle (Fig. 22.4).
- However, in posttraumatic cases (prior dislocation) or heterotopic ossification you need to make thorough evaluation before surgery. Check for any symptoms from cubital fossa. Watch closely computed tomography scans for possibly of nerve entrapment. Another imaging modality that we find very useful to assess the course of the nerve is ultrasonography. Otherwise, nerve is safe when you work inside the joint. Make the same precautions as mentioned for radial or ulnar nerves when debriding inflamed synovial sheath. If you need to remove fibrotic capsule, you may release it from the humeral attachment and peel it manually with grasper from overlying muscles.

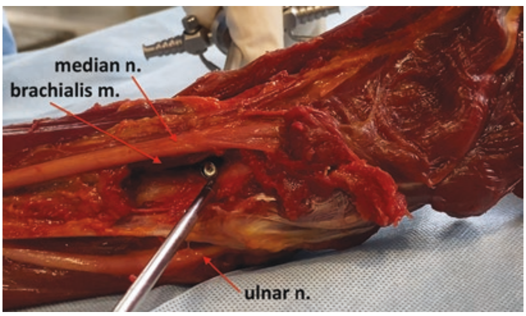

Fig. 22.4 Median nerve is rarely in danger. In normal anatomy it is protected by brachialis muscle

- Visibility: It is mandatory to start your procedure by establishing the view and maintain the visibility. Simply follow O'Driscoll's stepwise approach [4]. Do not increase the pressure on the pump and do not use lavage to expand tissues and increase visibility. That is a major risk of immediate swelling of elbow and forearm, compression of vital structures, and deterioration of visibility. Instead, use elevators or simply blunt switching stick (Fig. 22.5).
- Always perform intracapsular procedures first (synovectomy, loose body removal, osteophytes) and leave capsular release at the end. This will help you maintain fluid inside the capsule, increase visibility, and avoid early edema.
- Postoperatively: You would like to avoid swelling, capsular scarring, hematoma, and heterotopic ossification. Make sure that patient is painless after procedure during early postoperative period. Pain may stimulate fibrosis [5]. Use of preoperative brachial plexus block will provide good control immediately after arthroscopy. In some cases (immediate rehabilitation after arthroscopic arthrolysis) you

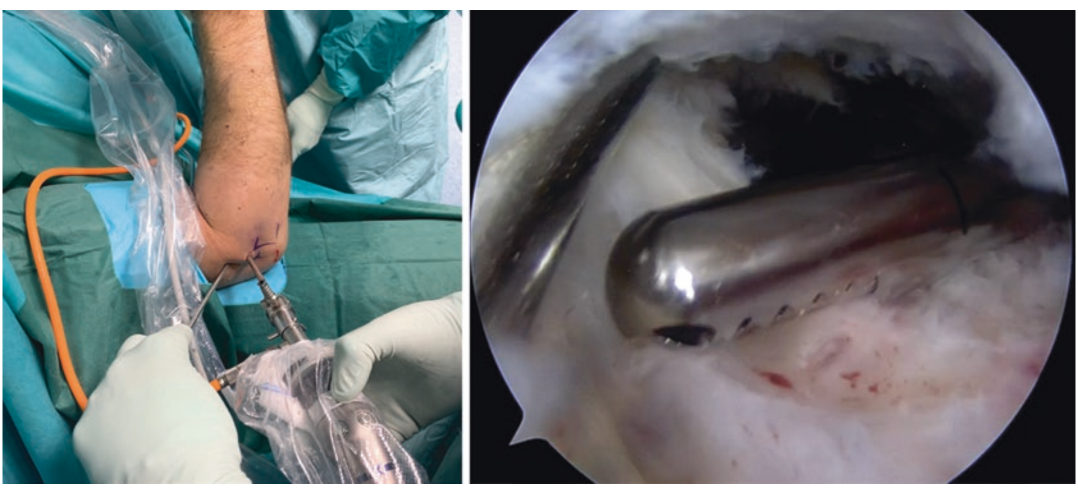

Fig. 22.5 Use of elevators increased visibility without need for excessive pump pressure

may consider using continuous brachial plexus anesthesia. To avoid swelling and hematoma we use compressive dressing and elevate the upper limb for the first 12 h after arthroscopy. Use of perioperative tranexamic acid is another prevention measure to decrease the risk of bleeding [6, 7]. Heterotopic ossification has been reported after elbow surgery [lit]. Both pathophysiology and prevention measures are not very clear. There is common some evidence of effectiveness and common practice to NSAIDs (indomethacin, celecoxib) for 10–14 days [8–10].

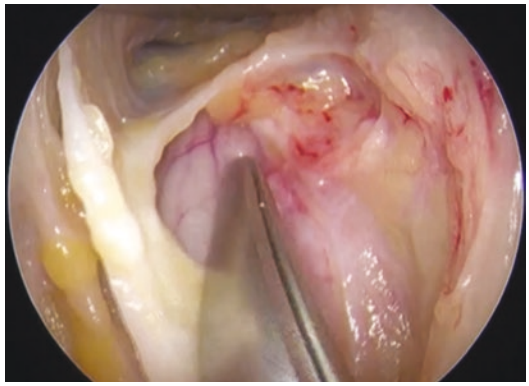

Fig. 22.6 Endoscopic ulnar nerve decompression

22.2 Arthroscopic Synovectomy

The aim of synovectomy is to relieve the pain and possibly prevent degenerative changes and destruction of the joint in patients with uncontrolled rheumatoid arthritis. Since major improvements in pharmacological therapy have been achieved in recent years, the number of patients with such indications dropped. Nevertheless, synovectomy in more resistant cases is still a viable option with proven effectiveness in relieving pain and improved range of motion. It is mostly indicated for patients at the early stages of the disease (Mayo stage I–IIIA) before advanced collapse occurs. Basic preparation includes thorough examination. Elbow specific history is mostly related to pain at rest and at activity, limitations of motion, and ulnar nerve related problems. General aspects include appropriate but unsuccessful rheumatologic treatment, no prior surgeries of the elbow, general health, other joint involvement. Specific physical findings may involve: swelling (mostly around postero-lateral aspect), painful limitation of range of motion, radial head related symptoms, ulnar nerve related signs, and in more advanced cases instability. Imaging always starts with plain X-rays, which are necessary to stage arthritis in the elbow. Magnetic resonance will show synovitis (extent and location) as well as joint surface involvement.

Arthroscopic synovectomy is performed in aforementioned setup and approach. If ulnar nerve needs to be decompressed, the procedure is done before arthroscopy with mini-open and endoscopic approach (dry) (Fig. 22.6).

Basic instruments apart from arthroscope include shaver, switching rod, graspers, and in some cases ablation device. We use 3.5 or 4.5 mm straight, side cutting toothed shaver tip. First anterior compartment is addressed with 3 portals for scope, shaver (or instruments), and rod (for elevation of tissues). Shaver and scope are in opposite portals. Once synovectomy has been done with one setting, then scope and shaver are swabbed to the opposite site. Typically, synovectomy means removal of just synovial membrane. External part of capsule is usually preserved. In most of the cases capsular release is not performed, but if needed that part is performed at the end debridement in particular compartment. Use aforementioned precautions to avoid nerve injury. That includes also median nerve, since brachialis muscle may be very thin in rheumatoid patients.

All other compartments need to be addressed. Addressing olecranon fossa is relatively easy. Once debriding the medial gutter stay within medial capsule. Most distal part may not be easily accessible for complete synovectomy. It helps when you flex and extend the elbow through the procedure and place the shaver in more proximal postero-lateral or posterior portal. Finally lateral gutter is debrided. Typically “soft spot” portal is used for shaver entry and tissue removal. After thorough synovectomy is performed check for any unstable cartilage flaps or marginal spurs and remove them as well.

Radial head resection is performed in cases of symptomatic radio-capitellar joint involvement. With the burr resection starts anteriorly and may be completed posteriorly from lateral gutter and soft sport portal.

Postoperative treatment is typical (see earlier) with immediate range of motion exercises following procedure.

Results of arthroscopic synovectomy show significant decrease of pain, improvement in perceived function, and range of motion [11, 12] in early phases of arthritis. Since not every part and capsular recess can be addressed some authors consider it subtotal as opposed to the open. Although clinical results may be comparable or slightly better in arthroscopic approaches [13] there may be a slightly greater risk of recurrence [14]. Recurrence may occur in about 25% of cases and repeated synovectomy may need 7–20% of patients.

22.3 Arthroscopic Treatment of the Tennis Elbow

Tennis elbow is one of the most common reasons for the pain in musculoskeletal system. It has been commonly attributed to angiofibroblastic hyperplasia and tendinosis ECRB-EDC induced by repetitive activities and overuse. Patients usually have typical positive signs for the tennis elbow including tenderness of the lateral epicondyle and positive resisted finger (EDC) and wrist extension (ECRB).

Differential diagnosis should exclude other reasons for lateral elbow pain:

- radio-capitellar joint arthritis (pain on pro/supination, on axial loading, X-ray changes)
- synovial plica (painful spot usually at posterolateral aspect of the elbow, snapping, no pain on resisted wrist of finger extension)
- posterior interosseous nerve entrapment (pain at the nerve crossing supinator muscle).

Imaging includes X-ray (to exclude arthritic changes) and ultrasound scan (showing tendon degeneration, enthesophytes).

Mainstay of the treatment is non-operative approach. However in around 7–10% of patients have persistent pain that limits significantly daily activities. That group of patients may require surgical treatment. Arthroscopic approach is minimally invasive and relatively simple alternative to classic Nirschl procedure [15]. As described earlier Kuklo [16] and Smith [17] rely on detachment and debridement of extensor carpi radialis brevis origin from lateral epicondyle.

22.4 Arthroscopic Treatment

Patient is lying supine with the arm on the narrow support. This position allows full access to medial, lateral, and posterior aspect of the elbow (Fig. 22.7a).

Before the procedure started, the clinical landmarks are identified and outline with the marker pen: radial head, lateral epicondyle, and olecranon tip (Fig. 22.7b). Joint space is injected with 10 ml of saline to extend the capsule (Fig. 22.7c).

The scope is introduced to the joint through mid-lateral portal with elbow positioned in 90° flexion and full pronation. After thorough evaluation of the joint, scope is moved to the medial side of the joint.

After removing the camera, trocar is pushed medially, and skin is incised over the trocar tip (Fig. 22.8a).

After that scope is easily passed from inside-out through medial portal without risk of ulnar nerve injury (Fig. 22.8b). Using switching stick, the scope sheath is transferred from lateral to medial portal (Fig. 22.8c).

Following the removal of the switching stick, shaver is introduced into the tip of the arthroscopic sheath. Both parts are gently disconnected inside the joint and camera is safely introduced into arthroscopic sheath.

The capsular folds reflect the attachment of extensor origin over the lateral epicondyle [17] (Fig. 22.9).

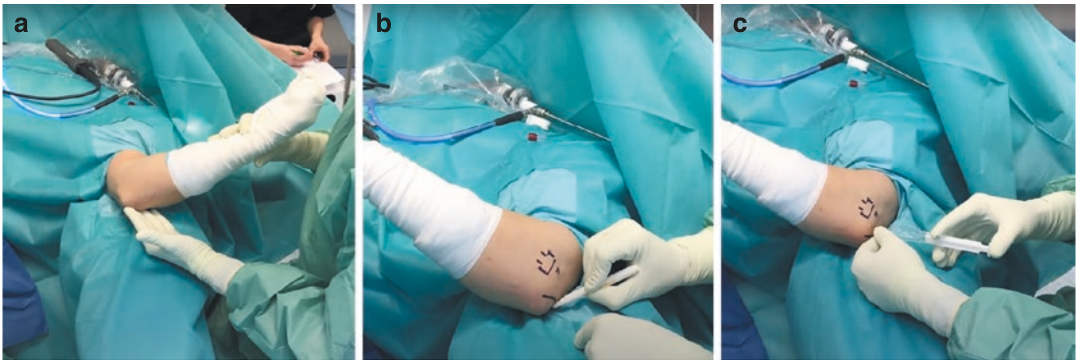

Fig. 22.7 Arthroscopic treatment of tennis elbow: (**a**) arm position, (**b**) landmarks, and (**c**) saline injection

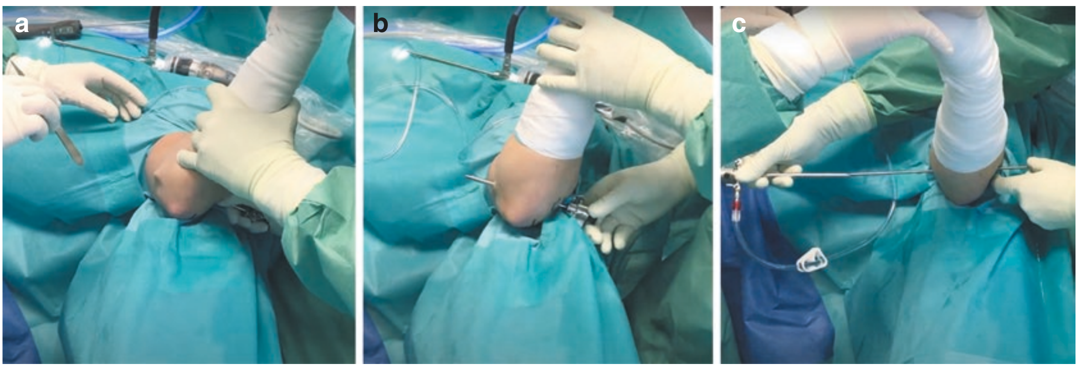

Fig. 22.8 Arthroscopic treatment of tennis elbow: (**a**) trocar is pushed medially, (**b**) after skin incision, the trocar is easily passed from inside-out, (**c**) using switching stick, the scope is transferred to medial portal

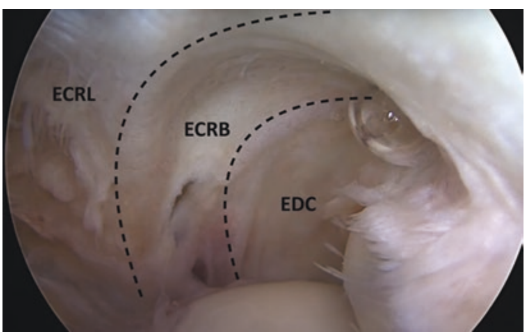

Fig. 22.9 Capsular folds reflecting the attachment of extensor origin (*ECRL* extensor carpi radialis longus, *ECRB* extensor carpi radialis brevis, *EDC* extensor digitorum communis)

Part of lateral capsule is removed with the shaver to expose ECRB and EDC origin (Fig. 22.10a). Then the origin of both tendons is detached from the epicondyle using soft tissue shaver and lateral epicondyle debridement is performed (Fig. 22.10b). Care is taken not to damage radial collateral ligament (RCL) and radial nerve.

Finally, skin is closed, and soft compressing dressing is performed.

You may access our instructional video at https://www.youtube.com/watch?v=aBuDZHt6MZk.

Overall results showed that arthroscopic treatment is reliable method, giving pain relief and letting patient get back to work and sports [18, 19]. Recent systematic reviews and meta-analyses comparing arthroscopic technique to open or percutaneous release showed comparable results in terms of postoperative pain, functional and subjective scores. Yet, some reports showed superiority of arthroscopic and percutaneous approach over open in pain perception and DASH scores and slightly lower risk of complications [20–22].

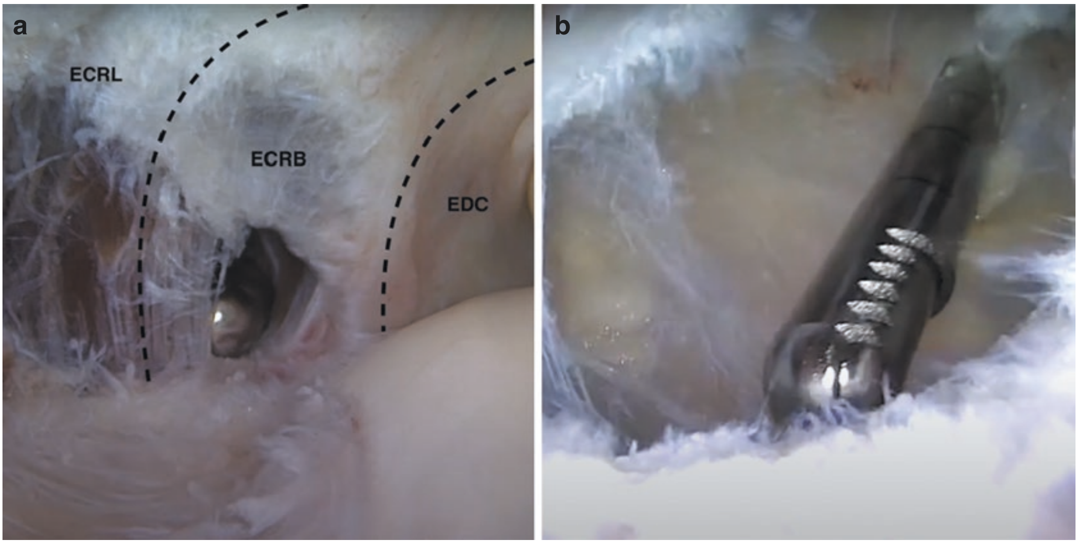

Fig. 22.10 Arthroscopic treatment of tennis elbow: (**a**) exposure of ECRB and EDC origin and (**b**) lateral epicondyle debridement

22.5 Arthroscopic Removal of Loose Bodies

Intraarticular loose bodies commonly lead to patients complaining about locking elbow or temporary or persistent limitation range of movement. They may occur as solitary pathology or be part of degenerative elbow changes. Specific form of multiple bodies occurs in synovial chondromatosis—uncommon condition characterized by cartilaginous metaplasia of the synovial membrane [23]. They are round or oval, may be fatty, marrow-like structures.

Loose bodies come in different sizes, numbers, locations. They may either be completely free and mobile or attached to bone or soft tissue (semi-loose).

Clinical suspicion needs to be confirmed by imaging. Osseous loose bodies can be appreciated on plain X-rays (Fig. 22.11).

However small ones and cartilaginous may be early missed [24]. Both MRI and ultrasound scan can reliably show both calcified and non-calcified loose bodies (Figs. 22.12 and 22.13) [25, 26].

Fig. 22.11 Antero-posterior X-ray view of the elbow. Red arrow points loose body in olecranon fossa

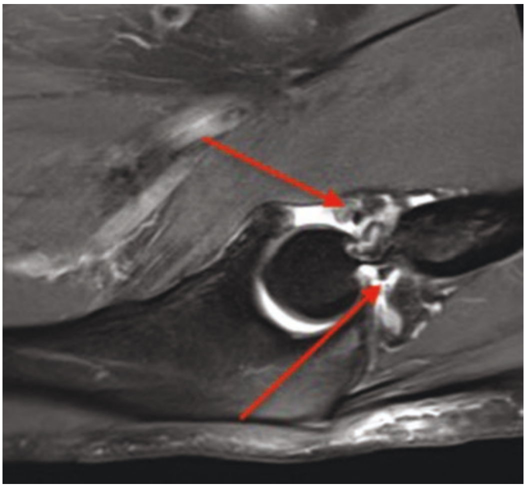

Fig. 22.12 Magnetic resonance imaging showing loose bodies in olecranon and coronoid fossae (arrows)

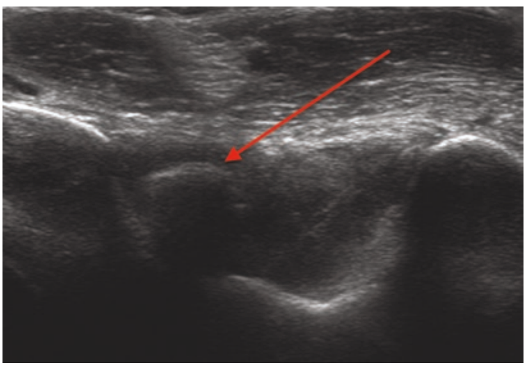

Fig. 22.13 Ultrasonographic of single loose body in olecranon fossa (arrow)

Ultrasound can be performed dynamically, which allows to observe the possible movement of intraarticular loose bodies.

We typically expect from the imaging to show the number of loose bodies, their size, location, and mobility. In cases of advanced degenerative changes computed tomography will not only show the bodies but also help plan reshaping of osteophytes around humeral fossae, olecranon, or coronoid (Fig. 22.14).

Fig. 22.14 Computed tomography with 3D reconstruction of arthritic elbow. Multiple loose bodies (arrows)

22.6 Removal

This is probably one of the best arthroscopic techniques to start therapeutic elbow arthroscopy. It is easy in most of the cases, completely intracapsular, and quick. Most of all it provides immediate relief of symptoms. However sometimes may be tricky to find small hidden and mobile loose body or to remove a large one (>2 cm) (Figs. 22.15 and 22.16).

From technical point of view it takes three stages: finding loose body, grasping, and extracting [27].

Loose body can be hard, floating away, or bulky which makes it difficult to grip with grasper. A variety of arthroscopic graspers are available on the market (toothed, cupped, rongeurs). A small Kocher grasper may be helpful for this purpose. Applying external pressure with the fingers may help. The use of switching stick or retractor may be helpful with exposure to the view. In case of multiple small loose bodies (chondromatosis) using cannula with suction

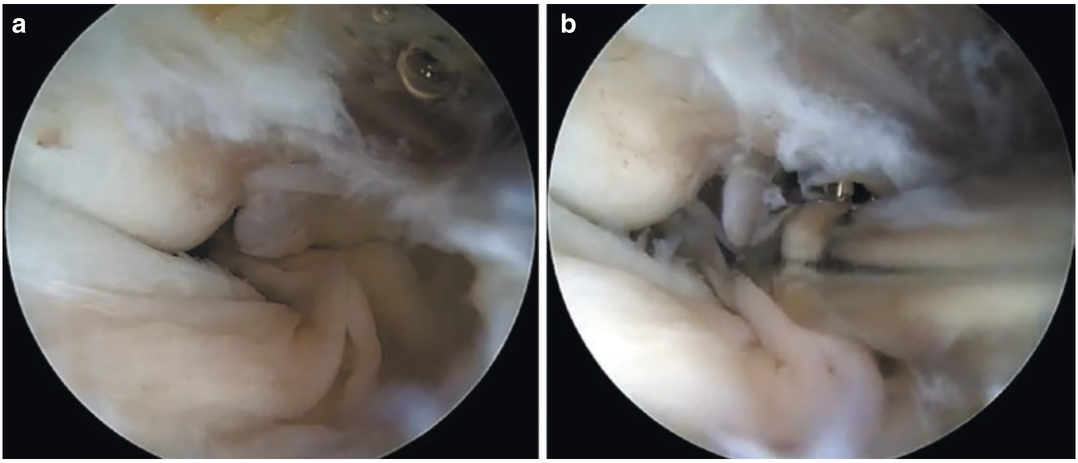

Fig. 22.15 Small loose body hidden in the lateral gutter (**a**) and removed with grasper (**b**)

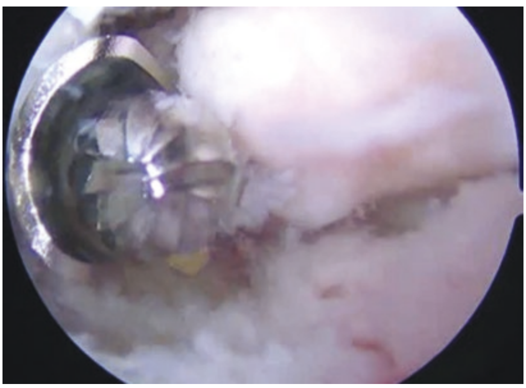

Fig. 22.16 Large osseous loose body in anterior compartment morselized with arthroscopic burr

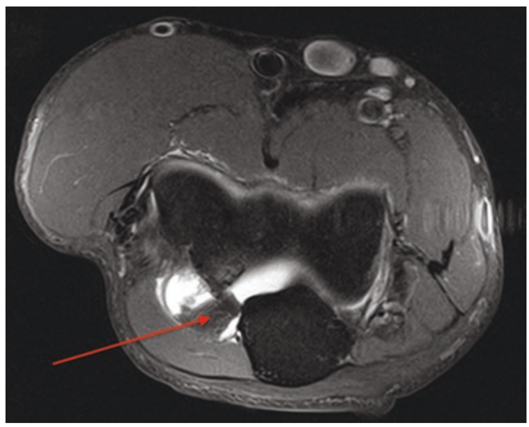

Fig. 22.17 Magnetic resonance imaging showing large synovial plica (arrow)

may be helpful. Another option is to use the shaver.

To pull out large loose body sometimes it is necessary to increase skin and joint capsule incision—enlarge the portal. Another option if the free body is still too large, is to ground it by rongeur or motorized burr (Fig. 22.16).

22.7 Arthroscopic Removal of Synovial Plica

Synovial plica of the elbow is normal anatomic finding, surrounding, and filling the space of radio-capitellar joint [28]. However, in some rare cases, a plica may lead to a painful elbow [29]. Mostly diagnosed as lateral elbow pain accompanied by local tenderness, pain at terminal extension, and/or painful snapping [30]. Usually we need imaging (MRI, ultrasound scan) to support our diagnosis (Fig. 22.17) [31].

In our experience ultrasound scan not only identifies the fold but also allows for dynamic evaluation and is able to demonstrate impingement of plica mostly between radial head and posterior part of capitellum and olecranon. Major problem is to differentiate normal plica from pathologic one. The latter is usually larger, thicker, and inflamed, often impinging against bony margins. Overgrown and inflamed postero-lateral plica is sometimes associated with elbow degenerative arthritis [32].

Arthroscopic removal of synovial plica is also considered as easy and quick procedure. It is indicated for painful plica syndrome that has been resistant to conservative treatment. Procedure is commonly part of arthroscopic treatment of degenerative elbow.

Symptomatic plica is often located in postero-lateral part of radio-capitellar joint. Arthroscopic procedure always starts with evaluation, inspecting both anterior and posterior compartment, finally approaching into lateral gutter. We need to pay attention to location, size, morphology (thickening, inflammation). Important part is to observe the fold during flexion-extension with pro- and supination, checking for snapping and impingement.

Typical elbow arthroscopy setup is used (as described earlier). After thorough inspection of anterior and posterior compartment, scope is moved via postero-lateral portal towards lateral gutter (Fig. 22.18).

Soft spot portal is created to insert the shaver. Arthroscopic hook may be helpful to expose the fold and bring it towards the working space (Fig. 22.19).

Overgrown plica is then removed with shaver (Fig. 22.20). Care needs to be taken not to damage lateral ulnar collateral ligament.

Arthroscopic removal of synovial plica is effective and safe technique. Good and excellent results have been expected in over 81% of cases. Complications are rare.

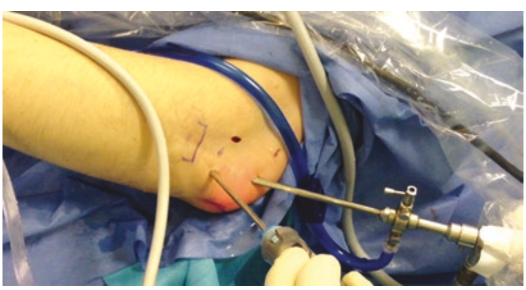

Fig. 22.18 Arthroscopic portals for removal of synovial plica

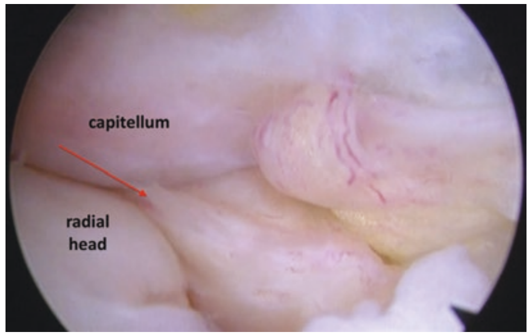

Fig. 22.19 Arthroscopic picture of enlarged synovial plica (also seen on MR Fig. 22.17)

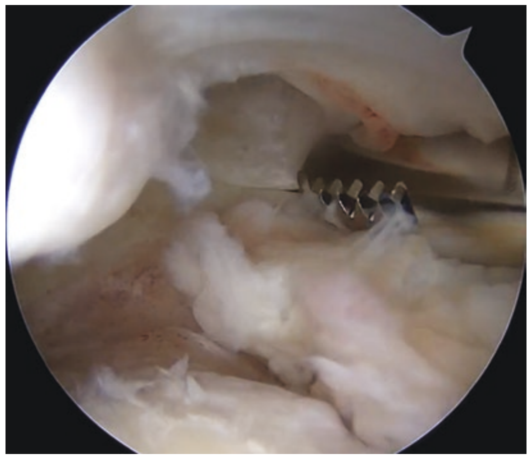

Fig. 22.20 Arthroscopic removal of synovial plica with shaver

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Arthroscopic Management of Elbow Instability

23

Roger van Riet

23.1 Description

Elbow instability can be acute or chronic. When surgery is indicated, the choice can be made to perform an arthroscopic procedure [1–4]. This allows for a complete inspection of the joint with minimal added morbidity to the injured elbow.

23.2 Key Principles

Diagnostic arthroscopy, washout of hemarthrosis, and inspection of the articulating surfaces and stabilizing structures. Osteochondral fragments can be removed, and some fractures can be fixed arthroscopically. Potential to fix or imbricate the lateral collateral ligament complex.

23.3 Expectations

An arthroscopic stabilization should result in a stable elbow while avoiding the increased morbidity of an open procedure. Concomitant procedures can be performed. Complications such as nerve injury are possible. There is a learning curve for elbow arthroscopy and these procedures should preferably be performed by a surgeon experienced in elbow arthroscopy.

23.4 Indications

- Acute instability.
- Selected intra-articular fractures.
- Loose bodies.
- Osteochondral lesions.
- Diagnosis and treatment of chronic lateral instability.
- Diagnosis of medial instability.
- Synovectomy.
- Removal of osteophytes.

23.5 Contra-Indications

- Absolute contra-indications.
  - General contra-indications to elbow arthroscopy apply.
  - Open (fracture) dislocation.
  - Neurological injury requiring surgical evaluation.
- Relative: Inexperienced surgeon.

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23.6 Special Considerations

The surgeon should be proficient in elbow arthroscopy. Conversion to an open procedure is possible if stabilization cannot be performed safely using an arthroscopic technique.

Acute elbow dislocations are reduced, and stability is assessed. Post-reduction computed tomography (CT) is indicated if radiographs are unclear or if a fracture is present. Arthroscopy is indicated in simple dislocations, osteochondral fragments, and some associated fractures, depending on the skill level of the surgeon and fixation technique necessary. There is increased risk of iatrogenic ulnar nerve damage with arthroscopic stabilization of medial sided elbow instability and an open exploration of the ulnar nerve is needed to decrease the risk.

23.7 Special Instructions, Positioning, and Anesthesia

- General anesthesia.
- Assess range of motion and elbow stability.
- Tourniquet.
- Lateral decubitus, arm over a support.
- Avoid compression on the antecubital area.
- Surgical skin preparation and draping.
- Palpation of the ulnar nerve and marking of the anatomy.

23.8 Tips, Pearls, and Lessons Learned

23.8.1 Hemarthrosis

In acute cases the view is obscured due to hemarthrosis. Before entering the joint with the scope, it is useful to perform a washout with the needle and syringe used to insufflate the joint, until the fluid is clear.

23.8.2 Anterior Compartment

Sagging of the annular ligament is a clear sign of lateral collateral ligament (LCL) complex avulsion or insufficiency. In acute cases, loose fragments, radial head, coronoid or other fractures should be identified preoperatively from the CT scan. If present, bony fixation is performed first. Coronoid fractures and some radial head fractures can be addressed with a view from the anteromedial portal and one or more lateral working portals.

23.8.3 Posterior Compartment

The posterolateral portal should be placed at the lateral tip of the olecranon. This will not only allow the scope to enter and evaluate the posterior compartment and MCL but will make it easier to move the scope into the radial gutter to view the posterolateral elbow and LCL complex.

Loose fragments are often found in the olecranon fossa. The synovial fold in the radial gutter is usually very prominent and needs to be removed in order to get an adequate view of the radiocapitellar joint and lateral side of the ulnohumeral joint space.

23.9 Difficulties Encountered

Palpation of the anatomical landmarks and ulnar nerve is sometimes difficult due to swelling. Hemarthrosis and extensive tearing of the capsule and soft tissues obscure the view in acute cases (Fig. 23.1). Tearing of the anterior capsule may put the radial nerve at risk. The ulnar nerve is vulnerable to iatrogenic injury if there is a tear or avulsion of the medial collateral ligamentous (MCL) complex (Fig. 23.2). Extra care should be taken if a soft tissue shaver is used.

23.10 Key Procedural Steps

The patient is placed in lateral decubitus. An aspiration of the joint is performed through the soft spot and the elbow is rinsed and insufflated. Depending on the preference of the surgeon, the arthroscopy can start in the anterior or the posterior compartment. We prefer to start with an anteromedial portal and inspection of the anterior

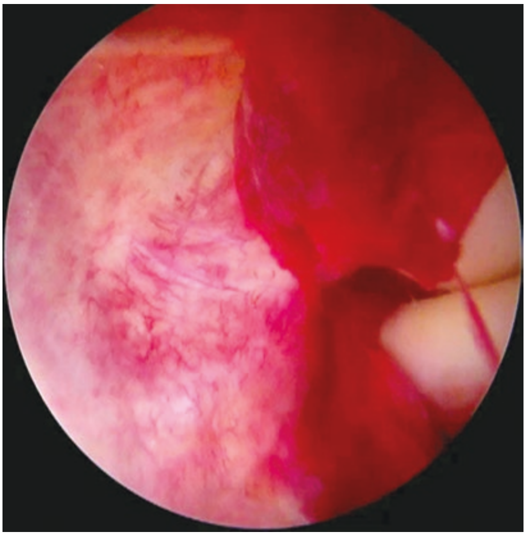

Fig. 23.1 Arthroscopic view of the anterior compartment. Hemarthrosis may obscure the view (courtesy of MoRe Foundation)

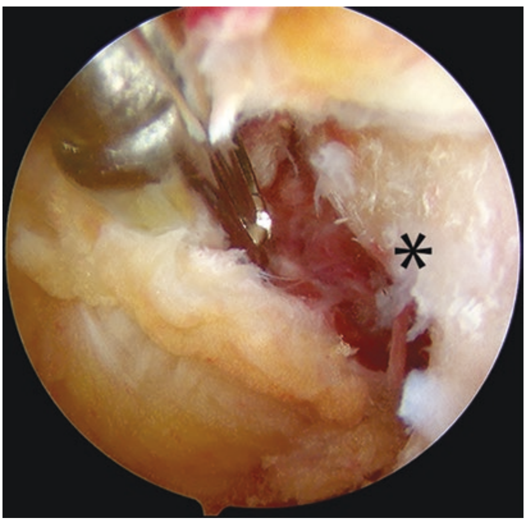

Fig. 23.2 Arthroscopic view of the posteromedial compartment. The Medial Collateral Ligament has been avulsed from the medial epicondyle (courtesy of MoRe Foundation)

compartment. A needle is used to confirm the correct position of the anterolateral portal. The surgeon has to be aware that the anterior capsule may be ruptured, and extra care should be taken when a shaver is used. The anterior compartment is rinsed, and any osteochondral fragments are removed. If indicated, screw fixation of a coronoid fracture can be performed.

A posterolateral portal is made, and the scope is brought into the posterior compartment. The scope is directed to the medial gutter and valgus stress is applied. Opening of the medial joint space implies an MCL avulsion. This can easily be visualized in acute ruptures. A central posterior working portal is made. It is important to palpate and protect the ulnar nerve while creating this portal. Any loose fragments are removed from the gutter and olecranon fossa. The scope is then brought into the lateral gutter and a soft spot portal is made. The synovial fold that is usually present is removed with a shaver and the radiohumeral and ulnohumeral joints are inspected (Fig. 23.3). The avulsed LCL complex is then visualized. The LCL stump is often somewhat retracted distally (Fig. 23.4).

Once all previously described steps have been performed, the LCL complex can be reinserted under direct arthroscopic view. The avulsed ligament is visualized as well as its insertion site. A 14G needle is inserted from outside in through the ligament stump and a no 2 PDS suture is shuttled through the needle. The suture is pulled out through the soft spot portal and the needle is removed. This step is repeated with a second suture. The ligament is reinserted with the use of a bone anchor. A needle is used to identify its correct position and a stab incision is made over the

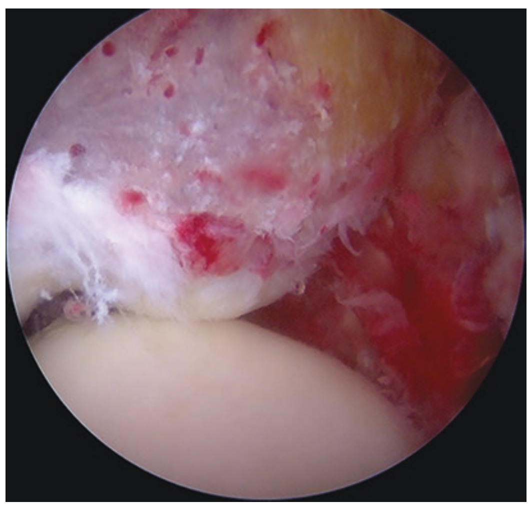

Fig. 23.3 Arthroscopic view of the posterolateral compartment in a dislocated elbow. Note the large cartilage defect at the back of the capitellum (courtesy of MoRe Foundation)

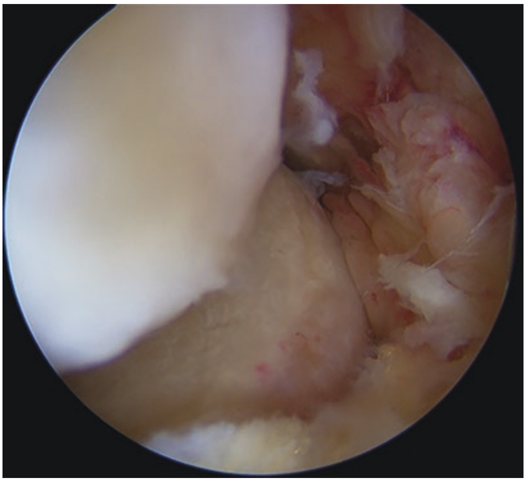

Fig. 23.4 Arthroscopic view of the posterolateral compartment of the elbow. The lateral collateral ligament has been avulsed and the stump has displaced distally (courtesy of MoRe Foundation)

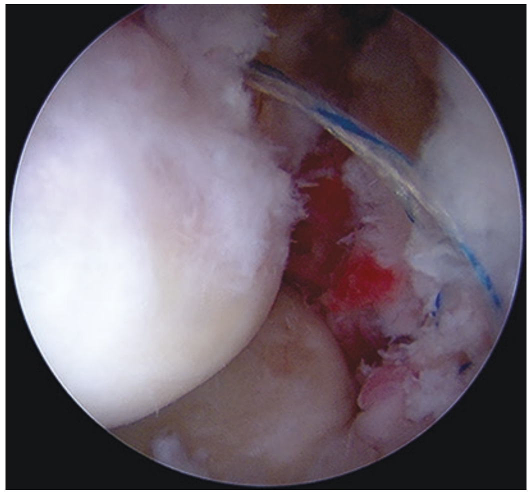

Fig. 23.5 A bone anchor has been placed in the lateral epicondyle. Sutures are brought through the lateral collateral ligament stump. Tightening these sutures will stabilize the elbow (courtesy of MoRe Foundation)

lateral epicondyle. Depending on the anchor it may need to be predrilled and the anchor is inserted. All sutures are pulled out of the soft spot portal and attached to the PDS. These are now pulled back out of their original puncture holes. In this way the sutures from the anchor are pulled through the ligament and the ligament can now be fixed (Fig. 23.5).

This same procedure can be performed on the medial side, but we would recommend visualizing and protecting the ulnar nerve through a small open incision and blunt dissection.

23.11 Bailout, Rescue, and Salvage Procedures

If an arthroscopic repair is not possible, the surgeon can decide to make a standard lateral or medial incision and approach and the fixation of fractures or ligamentous repair can be done as an open procedure.

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24 Endoscopic Cubital Tunnel Release

Stephanie A. Russo, John D. Lubahn, and Reimer Hoffmann

24.1 Introduction

Potential sites of ulnar nerve compression around the elbow from proximal to distal include: the arcade of Struthers (fascial band between the medial head of the triceps and the medial intermuscular septum), the arcuate ligament or "Osborne's ligament" (superficial border of the cubital tunnel), the flexor carpi ulnaris (FCU) fascia, and deep flexor pronator aponeurosis of the forearm [1, 2]. Open in situ and endoscopic decompression techniques are the most common procedures currently performed with some surgeons still using anterior transposition or medial epicondylectomy as their primary treatment of ulnar nerve compression at the elbow.

Advantages of endoscopic ulnar nerve decompression include a small incision and better visualization. A recent study demonstrated that a 2 cm incision and endoscopic technique provided mean proximal and distal fields of view of 8.1 cm and 8.3 cm, respectively [3]. This was significantly greater than the visualization with the same incision and traditional open technique [3]. Additional benefits of an endoscopic technique may include decreased postoperative pain, earlier return to work, and reduced paresthesia around the incision [2]. Endoscopic release of the cubital tunnel allows for decompression of the ulnar nerve proximal and distal enough to address all of the above potential sites of compression.

24.2 Indications

After failure of conservative management of cubital tunnel syndrome, release of the ulnar nerve at the elbow is indicated. Most patients who are candidates for in situ decompression may be considered for endoscopic release. With the technique we describe in this chapter (Hoffmann technique) degenerative changes of the ulnohumeral joint with medial osteophyte formation, cubitus valgus, and/or symptomatic subluxation of the ulnar nerve are no contraindication [1]. Posttraumatic scarring and prior ulnar nerve transposition would be a contraindication to an endoscopic approach.

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24.3 Surgical Technique

Endoscopic cubital tunnel release was initially described by Tsai [4] and later modified by others, including Hoffmann and colleagues [1, 5, 6]. The Hoffmann technique described in this chapter may be performed with a regional block or general anesthesia. A tourniquet is placed as proximal as possible on the upper arm. Alternatively, a sterile tourniquet may be preferred. The extremity should be draped in a fashion that allows full passive motion of the arm. The limb is positioned with the shoulder at approximately 90° of abduction, the elbow flexed, and the forearm supinated on a hand table. The surgeon is seated in the axilla with the patient's elbow supported on a stack of folded towels (Fig. 24.1). An Esmarch wrap is used to exsanguinate the arm and minimize the amount of venous engorgement from the tourniquet.

An incision approximately 2–3 cm in length is made just posterior to the medial epicondyle which is the most important landmark in locating the ulnar nerve. The longitudinal vasa nervorum may also help isolate the nerve [1]. Identification of the ulnar nerve may be more challenging in obese patients or patients with an anconeus epitrochlearis muscle. Once the nerve is isolated, the arcuate ligament is divided from proximal to distal under direct vision.

Specially designed soft-tissue (tunneling) forceps are next utilized to create a tent-like subcutaneous workspace superficial to the facia for endoscopic instrumentation. Care is taken to look for and protect posterior branches of the medial cutaneous nerve (Fig. 24.2).

Fig. 24.2 Posterior branches of the medial cutaneous nerve may cross the antebrachial fascia and should be protected throughout the procedure

Fig. 24.1 The surgeon is seated in the axilla with the patient's arm on a hand table. The patient's shoulder is abducted, and the elbow is flexed and supported on a stack of towels. The monitor is positioned near the head of the bed to facilitate visualization during the procedure

An illuminated speculum (blade length 9–11 cm) is then placed into the workspace created superficial to the fascia. The ulnar nerve is released extending distally 4–5 cm from the medial epicondyle by incising muscle fascia, muscle, and the submuscular membrane. A blunt-tipped dissecting scissor is utilized to explore the nerve distally dividing the fascia between the two muscular heads of the FCU. The speculum is then removed and replaced with a 4 mm soft-tissue endoscope (Fig. 24.3). Blunt scissors are utilized to divide the antebrachial fascia up to a distance of 12–14 cm from the medial epicondyle while visualizing the procedure on a monitor (Fig. 24.1). Cutaneous nerve branches crossing the fascia should be mobilized and protected, while the fascia beneath is divided (Fig. 24.2) [5]. Meticulous hemostasis is important and facilitated by the use of long bayonet forceps to coagulate any crossing vessels that require division. The muscle is bluntly spread using the dissector on the tip of the endoscope, thus exposing the submuscular membrane (Fig. 24.4). This membrane is characterized by bands of variable thickness for a distance of 5–9 cm (footnote 5) distal to the medial epicondyle. Dissection is continued until the nerve has

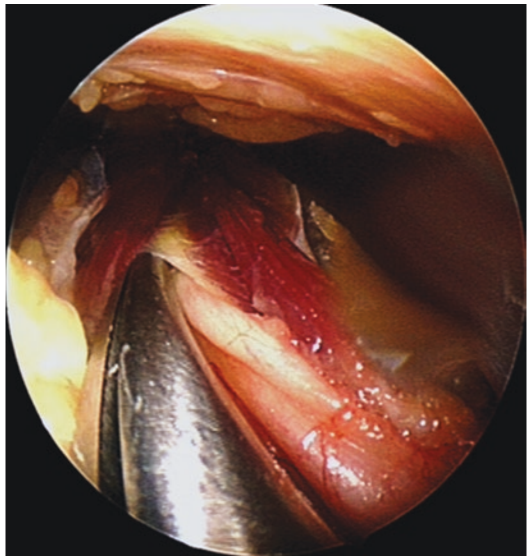

Fig. 24.4 The submuscular fascia overlying the ulnar nerve is divided under direct visualization

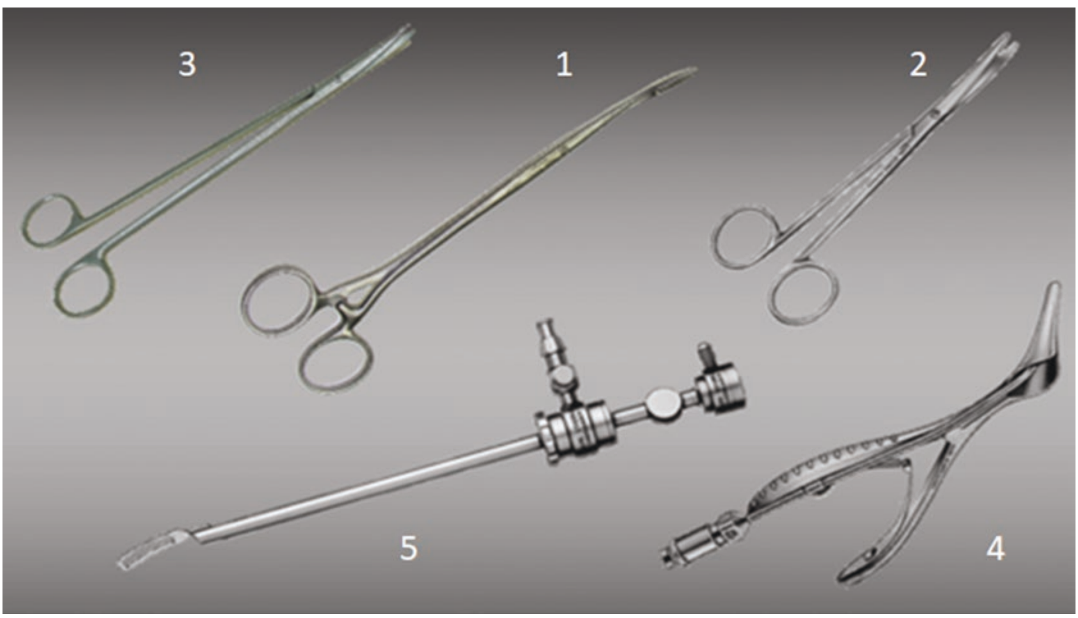

Fig. 24.3 The set of arthroscopic intruments includes (1) blunt-tipped dissecting forceps to create a subcutaneous space, (2) 18 cm and (3) 26 cm blunt-tipped dissecting scissors, (4) lighted speculum for soft-tissue retraction, and (5) a blunt soft-tissue endoscope

been decompressed 10 to 15 cm distal to the midpoint of the retrocondylar groove.

The same surgical technique is utilized for the proximal dissection although it is rare to find significant sites of proximal compression. A proximal subcutaneous workspace is created, an illuminated speculum is introduced, and the brachial fascia is divided 5–6 cm proximal to the midpoint of the retrocondylar groove. The soft-tissue endoscope is used again for the more proximal extent of the dissection up to 14 cm. The aponeurotic edge of the triceps is transected, if present. The intermuscular septum does not require division as it is typically not a source of compression. The arcade of Struthers, a band of fascia between the triceps and the intermuscular septum, is divided, if present and the nerve is carefully explored for any potential sites of compression.

Of note, a "no-touch" technique is utilized throughout the procedure to minimize contact between the surgical instruments and the ulnar nerve. This serves to avoid direct damage to the nerve, as well as to maintain its native vascular supply. Muscular branches of the ulnar nerve can be observed and should be carefully protected during the procedure. Redundant adipose tissue may make the dissection more challenging. In this case, the endoscope may need to be removed and cleaned more frequently to improve visualization.

The wound is then closed, a bulky compression dressing applied, and only then is the tourniquet deflated. In two to three days, the dressing is removed and active range of motion of the elbow is encouraged. Suture removal is performed between 7 and 14 days, according to surgeon preference. The patient is encouraged to use the arm almost normally and sports activities may be gradually increased over the following four to six weeks.

24.4 Outcomes

In a series of 76 nerves in 75 patients treated with the above-described technique of endoscopic cubital tunnel release (Hoffmann technique), 96% of patients had improvement in their sensory symptoms. There was a significant increase in grip strength after surgery compared to preoperative measurements. All patients had full elbow range of motion within one week of surgery. The modified Bishop Rating System demonstrated excellent results in 60.5% of patients and good results in 33% of patients. Postoperative electrodiagnostic studies were performed in 80% of patients, and all of them demonstrated improvement. There were no recurrences within the follow-up period (mean follow-up of 11 months). Complications included four superficial hematomas that resolved without any intervention and one case of complex regional pain syndrome. Additionally, nine patients reported reduced sensation in the medial antebrachial cutaneous nerve distribution. One patient continued to have dysesthesia in this distribution, but no pain. The remaining eight patients recovered full sensation within three months. Ninety-eight percent of patients returned to their prior occupations or activities [5].

Another series of 36 patients that utilized a similar endoscopic technique demonstrated excellent outcomes in 58% of patients and good outcomes in 33% of patients according to the modified Wilson and Krout rating scale [7]. One patient developed a hematoma that did not require intervention, and no cutaneous nerve injuries were noted [7]. All patients reported satisfaction with the procedure and returned to activities [7].

Watts and Bain performed a prospective, nonrandomized trial comparing open and endoscopic decompression of the ulnar nerve at the elbow [8]. Fifteen patients were treated with open in situ decompression, and nineteen patients were treated with endoscopic ulnar nerve decompression. One patient was converted from endoscopic to open decompression due to substantial perineural adhesions, and one patient underwent open decompression following the endoscopic procedure due to worsening symptoms that were attributed to hematoma formation. The overall incidence of postoperative complications was significantly higher in the open in situ decompression group. One year postoperatively, elbow range of motion, grip and pinch strength, Semmes–Weinstein monofilament test, and patient-reported outcomes were assessed. There were no significant differences between groups for the objective outcome measures or patient-reported satisfaction [8].

A recent systematic review of endoscopic versus open in situ decompression of the cubital tunnel suggested improved outcomes with endoscopic decompression [9]. Ten studies were included in the analysis of outcomes and complications. There were 331 patients with endoscopic release and 150 with open release. Excellent or good results based on the Bishop scale were reported in 92.0% of patients in the endoscopic group and 82.7% of the open group. The analysis demonstrated significantly reduced odds of complications in the endoscopic group compared to the open group. The authors concluded that endoscopic in situ decompression is as safe or safer than open decompression and should continue to be utilized [9].

In summary, good to excellent results can be anticipated in the vast majority of patients indicated for endoscopic ulnar nerve decompression at the elbow. The endoscopic approach is safe and allows excellent proximal and distal visualization with minimal surgical site morbidity. While further randomized-controlled trials may improve our understanding of endoscopic versus open in situ decompression techniques, the endoscopic technique offers surgeons a reliable method for ulnar nerve decompression at the elbow.

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Part IV

Sports Conditions of the Elbow

25 Reconstruction of the Elbow Lateral Ulnar Collateral Ligament (LUCL)

Ronda Esper and Joaquin Sanchez-Sotelo

25.1 Indications for Reconstruction of the Elbow LUCL

LUCL reconstruction may be indicated in a number of conditions where LUCL insufficiency contributes to symptomatic instability by itself or in combination with other conditions. These include:

- Traumatic injuries.
  - Simple dislocations with persistent PLRI.
  - Persistent instability after complex elbow fracture-dislocations.
- Iatrogenic injuries.
  - Prior surgical exposures that compromised the LUCL.
  - Ligament attrition and wear secondary to administration of multiple corticosteroid injections for ECRB tendinopathy.
- Progressive LULC stretching secondary to.
  - LUCL degeneration in the setting of ECRB tendinopathy.
  - Chronic varus overload (i.e., upper extremity weightbearing in paraplegics).
  - Congenital or posttraumatic cubitus varus (tardy PLRI).

25.2 Graft Selection

Traditionally, ligament reconstruction at the elbow joint has been performed using tendon autograft. LUCL reconstruction was initially described with the use of palmaris tendon autograft. Disadvantages of using the palmaris tendon include that this tendon is not present in every individual, the morbidity of the harvest, and the potential for harvest-related complications. Other authors have reported the use of a strip of the triceps as well as gracilis or semitendinosus autograft. At our Institution, we have performed the majority of LUCL reconstructions using tendon allograft, most commonly plantaris, peroneus longus, or split semitendinosus allografts.

25.3 Surgical Technique

Various configurations of graft passage and bone fixation techniques have been described. Currently, the majority of the LUCL reconstructions at our institution are performed using a docking technique with fixation using nonabsorbable suture through bone tunnels.

25.3.1 Patient Positioning

The patient is placed in the supine position with the arm laid across the body or on an arm board.

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Before beginning, an examination under anesthesia is performed with special attention paid to the posterolateral rotatory drawer test and the lateral pivot-shift test. Our preference is to use a nonsterile tourniquet that can be placed high on the arm out of the surgical field.

25.3.2 Surgical Exposure

A 7-cm incision is made from just proximal to the lateral epicondyle toward the *crista supinatoris* on the ulna. Once through skin and subcutaneous tissue, the interval (Kocher's interval) between the anconeus and the *extensor carpi ulnaris* is identified (Fig. 25.1). The fascia is sharply incised, and blunt dissection is carried out down to the capsule. It is important that the lateral capsule be identified and protected throughout the case because the ligament will ultimately be reconstructed in an extra-articular position. The capsule is incised in line with the LUCL, just anterior to the posterior margin of the extensor tendon so that there is thick enough tissue to suture during imbrication and closure.

25.3.3 Bone Preparation

Attention is turned to the supinator crest, and subperiosteal dissection is performed just posterior and proximal to its apex. The ulnar tunnel is created by converging the bases of two 3.2-mm-diameter drill sockets (Fig. 25.2a). The first begins immediately posterior to the supinator crest and the second is located proximal and posterior to a bony bridge of at least 1.25 cm between the holes. Alternatively, the ulnar tunnel may be created using a 4.0-mm burr. Once both sockets are drilled, their bases can be connected and cleared of bone debris using a Bankart awl (Kirwan, Marshfield, MA) with a similar radius of curvature as the curved needle of the passing suture. Alternatively, an angled curette may be used. A looped suture is passed through the tunnel using a curved needle. It is tagged and set aside for later graft passage.

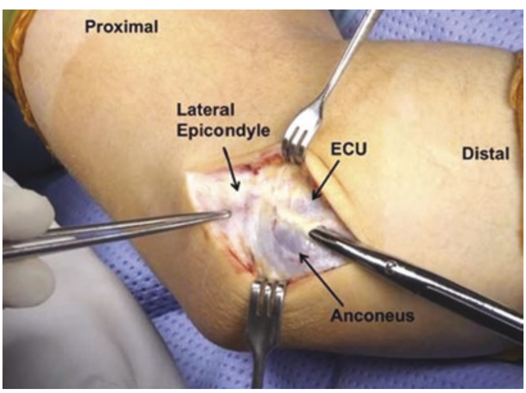

Fig. 25.1 The lateral side of the elbow is approached via lateral skin incision and Kocher's interval is developed between the *extensor carpi ulnaris* (ECU) and anconeus

Once the ulnar tunnel is created, attention is turned to creating the humeral socket. An appropriately positioned humeral attachment site should provide an isometric reconstruction that maintains the same tension throughout the flexion–extension arc. This point is typically at the geometric center of a circle superimposed on the capitellar articular margin (Fig. 25.2b). The isometry of this point can be confirmed by pulling the free ends of the passing suture from the ulnar tunnel to this location using a hemostat once a small starting indentation has been created (Fig. 25.2c). The suture should demonstrate even tension and isometry as the elbow is flexed and extended. With a 3.2-mm drill or 4.0 mm burr, the humeral socket is drilled toward, but not through, the posterior cortex to a depth of 15 mm. The center of this socket is placed approximately 1 mm proximal and 1 mm posterior to the previously identified isometric point. The center of the socket is moved just proximal and posterior because once tensioned, the graft will drape along the anteroinferior rim of the socket, which brings it back to the isometric point. A second socket is drilled toward, but not through, the anterior cortex. Alternatively, a single large socket may be used.

Next, a 2.0-mm drill is used to create 2 holes proximally on either side of the supracondylar ridge, one posteriorly and the other anteriorly. These holes should be at least 10 mm apart to provide a strong bony bridge over which sutures can be tied at the end of the case. A looped pass-

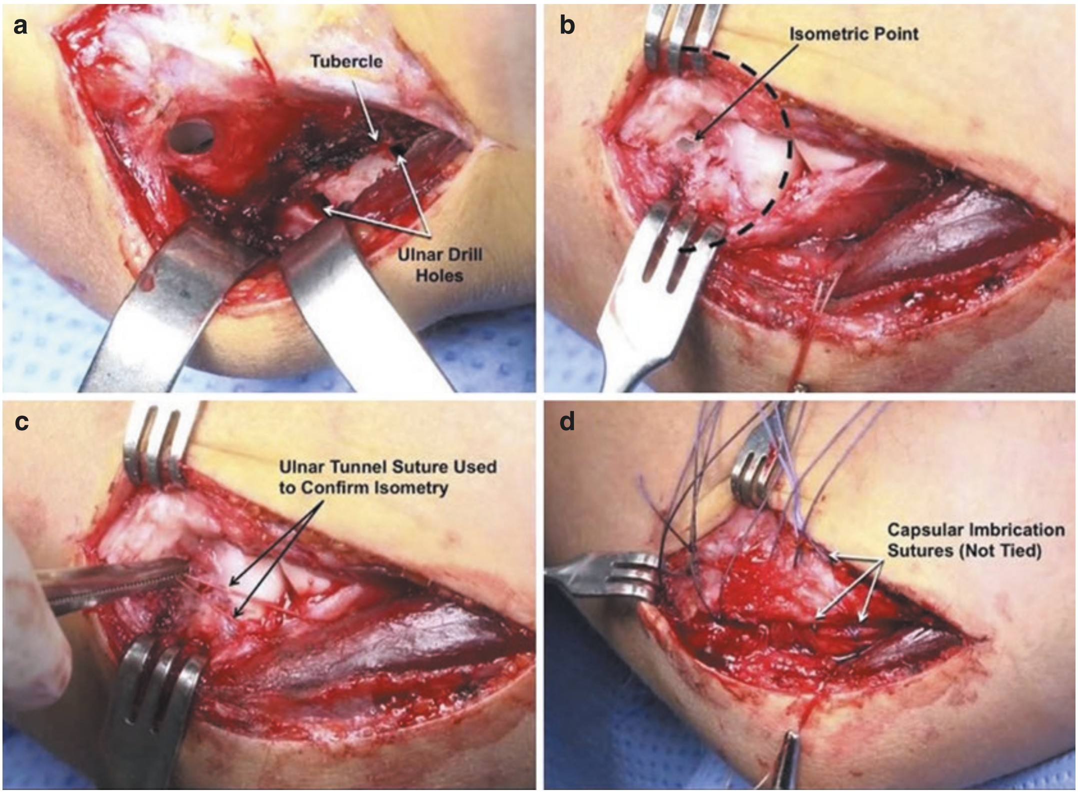

Fig. 25.2 The tubercle on the supinator crest is identified. A 3.2-mm drill or a 4.0 mm burr is used to create a cortical hole adjacent to the tubercle, and another approximately 1.25 mm proximal to the first. (**a**) A Bankart awl or angled curette is used to create a tunnel joining the 2 holes. (**b**) To locate the isometric humeral attachment, the center of the capitellum is identified as the center of a circle superimposed over the articular margin of the capitellum. (**c**) Isometricity is confirmed by holding the tensioned looped passing suture from the ulna on the presumed isometric point, whereas the elbow is taken through an arc of flexion and extension. (**d**) After the humeral socket is created, capsular repair sutures are placed before graft passage. These are tagged, set aside, and subsequently used to imbricate the capsule beneath the graft

ing suture is passed through each tunnel and tagged for later graft passage.

25.3.4 Graft Preparation

If semitendinosus or peroneus longus allograft tendons are used, they are split to reduce bulk. Allograft plantaris and autograft palmaris do not need to be split. In one end of the graft, a running locked suture (No. 2-0 Fiberwire; Arthrex, Naples, FL) is placed and the remaining end is initially left free. Before graft passage, imbricating "vest-over-pants" capsular sutures are placed so that the capsulotomy can be closed at a later stage (Fig. 25.2d). These are tagged but not tied until the graft has been passed.

25.3.5 Graft Passage and Fixation

Using the passing suture, the graft is passed through the ulnar tunnel from proximal to distal (Fig. 25.3a). The sutured end is then docked into the posterior humeral socket using the posterior passing suture that was previously placed. The free end is laid across the aperture of the humeral socket and tensioned, whereas the elbow is flexed and extended. The tendon is marked a few millimeters proximal to the aperture, and a second

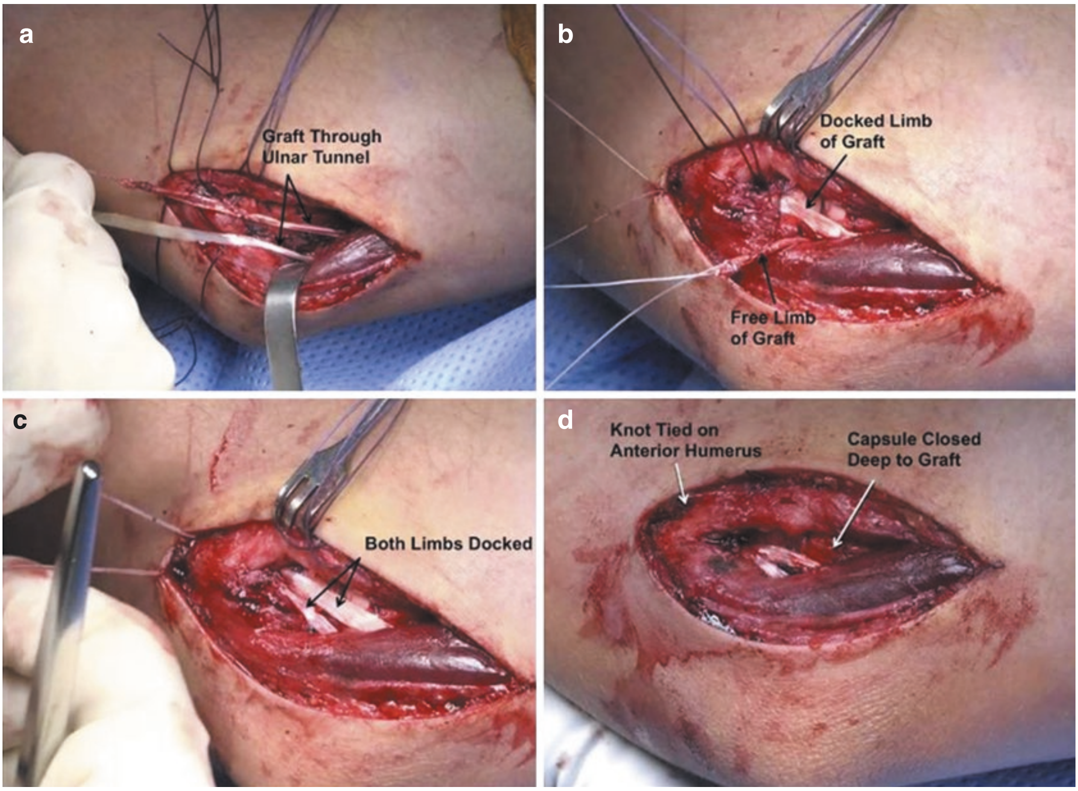

Fig. 25.3 (**a**) Using the previously placed shuttling suture in this right elbow, the graft is first passed through the ulnar tunnel. The sutured end is docked into the posterior humeral tunnel using the suture previously placed through that tunnel. The graft is tensioned and the free limb is pulled across the socket and marked a few millimeters proximal to the aperture. (**b**) This end is sutured and the excess graft is excised. (**c**) Once sutured, this limb is docked into the anterior tunnel using the suture previously placed in that tunnel. The capsulotomy is closed and imbricated. While tension is maintained on the sutures, the graft is tensioned and cycled through multiple flexion–extension cycles. (**d**) The sutures grasping the graft are tied over the lateral supracondylar ridge. It is important that the knot be placed on the anterior aspect of the humerus to reduce irritation

running, locking stitch is applied from this mark traveling 10 mm away from the free end (Fig. 25.3b). The excess graft is excised, and the free end is docked into the socket using the anterior passing suture (Fig. 25.3c). Once again, the graft is tensioned, whereas the elbow is taken through a flexion–extension arc. Before securing the graft, the capsule is closed using the previously placed capsular sutures to ensure that the graft remains extra-articular. The graft is now secured by tying the sutures over the bone bridge. Care is taken to ensure that the knot is placed on the anterior surface of the humerus to avoid irritation under the thin posterior skin (Fig. 25.3d). The wound is then closed in layers.

25.4 Postoperative Rehabilitation

The arm is immobilized in a long-arm cast for 2 weeks. A removable thermoplastic splint is applied for 4 more weeks. It is removed 4 times per day to do overhead range of motion (ROM) exercises in the supine position. Anytime the elbow is moved away from the body, the weight of the forearm is supported by the other hand to prevent inadvertent varus torque during these activities. ROM is progressed as able with a goal of achieving full ROM by three months postoperative. At 3 months, focus is shifted toward strengthening the elbow flexors, extensors, pronators, and supinators. Unrestricted activity and return to sport are generally allowed 6 months after surgery.

25.5 Pearls

- Careful tunnel placement in terms of position and isometry.
- Graft passing and tensioning prior to committing to final graft length.
- Adequate capsule repair to leave graft extra-articular.

25.6 Pitfalls

- Fracture of the ulnar tunnel may compromise graft fixation; this complication can be salvaged with alternative fixation methods, which may range from interference screws to Endobutton fixation across the opposite medial ulnar cortex.
- Fracture or weakening of the humeral tunnels may also occur and can be salvaged in a similar fashion.
- Failure to correct associated pathology (associated symptomatic ECRB tendinopathy, coronoid insufficiency, radial head resection).
- Failure to correct severe varus deformity of the distal humerus in patients with tardy PLRI.
- Failure to protect the reconstruction from excessive gravitational stress.

25.7 Future Directions

Although LUCL reconstruction has been reported to provide satisfactory results in patients with PLRI, a few unknowns remain. The introduction of anchor and tape based “internal stabilizers” has raised the possibility of either restoring adequate stability with a repair without reconstruction; the added value of internal stabilizers at the time of LUCL repair or reconstruction remains a matter of debate. Additionally, although we favor use of allograft reconstruction, the majority of studies to date have reported on the outcomes obtained using autograft; as such, the outcome of allograft-based reconstructions needs to be assessed. Finally, PLRI in the setting of ECRB tendinopathy has emerged as a very common indication for LUCL reconstruction in our practice, but clear guidelines to determine when a patient with tennis elbow also needs an LUCL reconstruction and the relative benefit of repair vs reconstruction in this particular presentation remains largely unknown.

26 Dual Incision Distal Biceps Repair

Thomas B. Lynch, Jonathan D. Barlow, and Robert U. Hartzler

26.1 Description

Distal biceps tendon ruptures most commonly present in middle-aged men who report feeling a pop about the elbow while lifting (eccentric contraction). There have been only rarely reported cases in females [1]. The purpose of this chapter is to provide a useful approach to the management of distal biceps injuries using two-incision techniques.

This chapter will focus on both the traditional (mini) two-incision repair technique and a novel two-incision cortical onlay technique. The author's preference is for a two-incision repair since this seems to facilitate a more anatomic repair, which has been shown to result in better strength and a lower rate of transient neurapraxias of the lateral antebrachial cutaneous nerve [2]. It should be noted that the literature overall shows only minor differences in outcomes between single and two-incision technique in regard to functional outcomes and complications. Minimization of implant costs and the theoretical opportunity for tendon revascularization via bone trough fixation represent additional theoretical advantages of the traditional two-incision technique [3]. The onlay technique with a cortical button has the advantages of faster operative time and ease along with preservation of the cam effect of the radial tuberosity.

26.2 Key Principles

Diagnosis of a complete distal biceps tendon rupture is relatively straightforward and can often be accomplished with a good history and physical exam. Patients will report a pop about the elbow while lifting a heavy object. They often present with a deformity (proximal appearance of distal biceps crease), ecchymosis about the area, and associated pain. The hook test is the most reliable special physical exam test and is performed with the elbow flexed to 90 °, shoulder abducted to 90 °, and the forearm fully supinated. The examiner sweeps from lateral to medial and should be able to easily "hook" the index finger around the distal biceps tendon. The absence of the biceps

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tendon is consistent with a complete distal tendon rupture. Comparison to the contralateral side can be helpful in the diagnosis as the lacertus fibrosus can sometimes be palpated and give a false negative test. In one center, this test has demonstrated a sensitivity and specificity of 100% [4].

The presence of a tendon on hook testing does not rule out a partial tendon avulsion. Patients with a partial biceps tendon tear often have a negative hook test and complain of pain about the cubital fossa made worse with forearm supination and elbow flexion. There is often no history of acute injury. MRI is required in these cases to confirm the diagnosis of partial tendon avulsion. There is ongoing debate if partial tendon tears should be treated with completion of the partial tendon avulsion and repair versus nonoperative management.

The timing of surgical repair of distal biceps tendon ruptures strongly influences the difficulty of repair, the possible extent of dissection required for adequate exposure, and the likelihood of potential complications to surgery. The general rule of thumb is the closer the repair to the date of injury the better the outcomes. Repairs within 2 weeks from the date of injury often require less dissection secondary to easier mobilization of the avulsed tendon stump which has not had time to undergo fibrosis in a retracted position. Rates of superficial nerve palsies and persistent elbow pain are increased in delayed repairs [5]. In cases of subacute or delayed repairs it is advised to have Achilles tendon allograft available to augment the repair if necessary. If an extensive dissection is required to mobilize the tendon or reestablish the tunnel to the radial tuberosity, conversion to a single incision anterior approach is warranted.

26.3 Expectations

Preoperatively patients should be counseled on the risks of infection, nerve injury, failure of fixation, radial tuberosity fracture, heterotopic ossification, and radioulnar synostosis. Generally speaking, postoperative recovery takes 6 months.

Protocols allowing immediate active range of motion following a two-incision repair have been demonstrated to be safe [6]. It is our preference to immobilize the elbow for 1 week in a simple sling. Heterotopic ossification (HO) prophylaxis with 2 weeks of indomethacin and a proton pump inhibitor for gastric protection is reasonable depending on surgeon preference. For the first 6 weeks patients remain non-weightbearing to the affected extremity and are taught active and passive range of motion with flexion, extension, pronation, and supination. At the end of 6 weeks, activities of daily living with a coffee cup weight restriction are begun. At 3 months, strengthening with elastic bands and physical therapy begins. Resumption of full activities including sports and weight lifting resumes at 6 months post-surgery.

26.4 Indications

The choice to perform surgery occurs after the typical risk–benefit discussion between the patient and surgeon. Factors such as hand dominance, profession, potential to participate in strict recovery protocol, and acceptability of cosmetic deformity will all factor into the management decision. The patient can expect to lose roughly half of their supination strength and a third of flexion strength about the elbow if left unrepaired. Repair will regain roughly 80–90% strength in comparison to the contralateral side. The vast majority of middle-aged men elect to undergo surgery; however, nonoperative management has produced acceptable outcomes [7].

26.5 Contraindications

Surgery may be contraindicated secondary to low demand patients who are at high surgical risk. It is important to counsel on the loss of functional strength the patient can expect with nonoperative management.

26.6 Special Considerations

MRI without contrast can be helpful for diagnosis of partial distal biceps disruptions. Advanced imaging also aids in evaluating the degree of tendon retraction in complete tears and rules out a musculo-tendinous rupture. This imaging should be obtained with the arm in flexion abduction and supination (FABS position). This view allows for best visualization if the distal biceps tendon is torn and is the same position for performing the hook test. Obtaining an MRI should not cause a delay in surgical treatment for properly indicated patients if the diagnosis is clear by history and physical examination.

26.7 Special Instructions, Positioning, and Anesthesia

- Supine position
- Hand table
- Sterile tourniquet
- Mini c-arm available (rarely used)
- Achilles tendon allograft available for subacute/delayed repairs
- Commercially available transosseous suture passer or twist of 26-gauge steel surgical wire
- 2 mm drill bit or router burr
- 4 mm round burr
- curved curettes
- #2 non-absorbable suture
- Cortical button (onlay technique)

26.8 Critical Pearls for Success

Early surgery (within 7–10 days) greatly facilitates the operation.

Large Kelly clamps—Key for creating dorsal incision and passing sutures from volar to dorsal incision site.

Bone tunnel distances—Adequate bone tunnel spacing to maximize tendon footprint and reduce risk of fracture.

26.9 Difficulties Encountered

Fibrotic scarring of retracted distal biceps tendon with muscle shortening. This is commonly seen in the delayed repairs and may require the use of Achilles tendon allograft to augment the repair.

26.10 Approach for Two-Incision Repair Techniques

Once the patient is prepped and draped in the supine position the incisions are marked (Fig. 26.1, Video). The anterior incision site (Fig. 26.1a) is a 1–2 cm transverse incision at the most distal elbow crease in the midline. This incision is smaller and more proximal than the one incision technique, as it will be solely used for location, preparation, and passage of the torn tendon to the second incision site. Care is taken to ensure the incision is centered over the arm, as this is key to allow smooth passage of the distal biceps tendon around the radial tuberosity. The posterior incision (Fig. 26.1b) is also marked over the palpable radial tuberosity about halfway between the radius and ulna and centered about 3 cm distal to the radiocapitellar joint.

The anterior incision is made just through the dermis with care not to disrupt the antecubital veins. Metzenbaum scissors and blunt finger dissection are used to open the antebrachial fascia. The ruptured tendon is typically easily visualized superficially or brought out with blunt dissection if retracted. The hematoma is evacuated, and control of the biceps tendon is achieved with an Allis clamp. It is important to adequately mobilize tendon from any adhesions that may have formed and limit tendon mobilization to the radial tuberosity. Elbow flexion aides in achieving more proximal visualization of the tendon.

The tendon is prepared with a transverse cut proximal to the tendinopathic portion in order to create a clean tendon edge (Fig. 26.2a). In the traditional technique, three to four centimeters of the remaining distal biceps tendon should be sutured

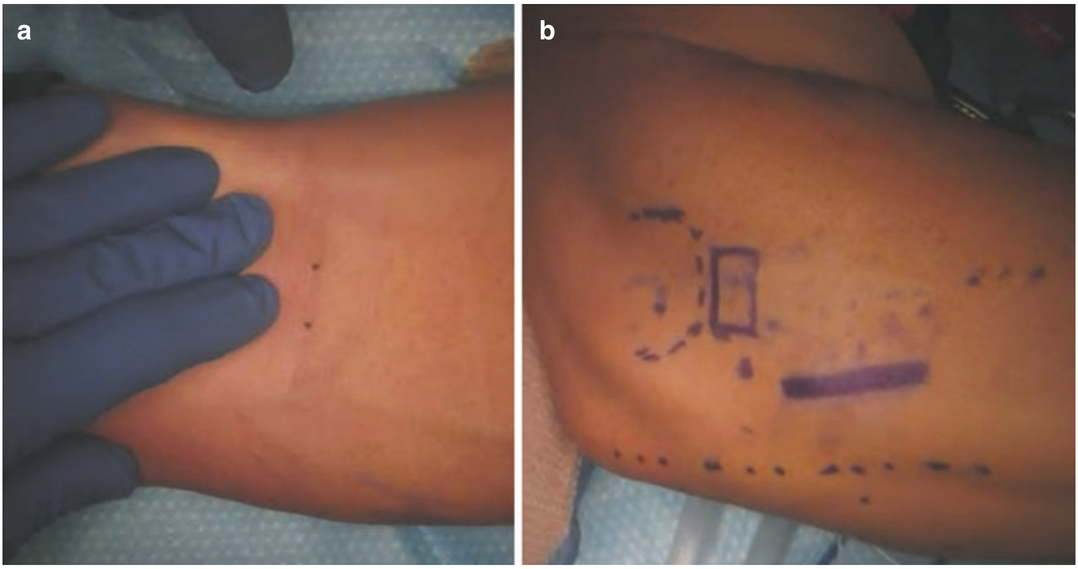

Fig. 26.1 Right elbow with (**a**) anterior and (**b**) posterior incision sites marked

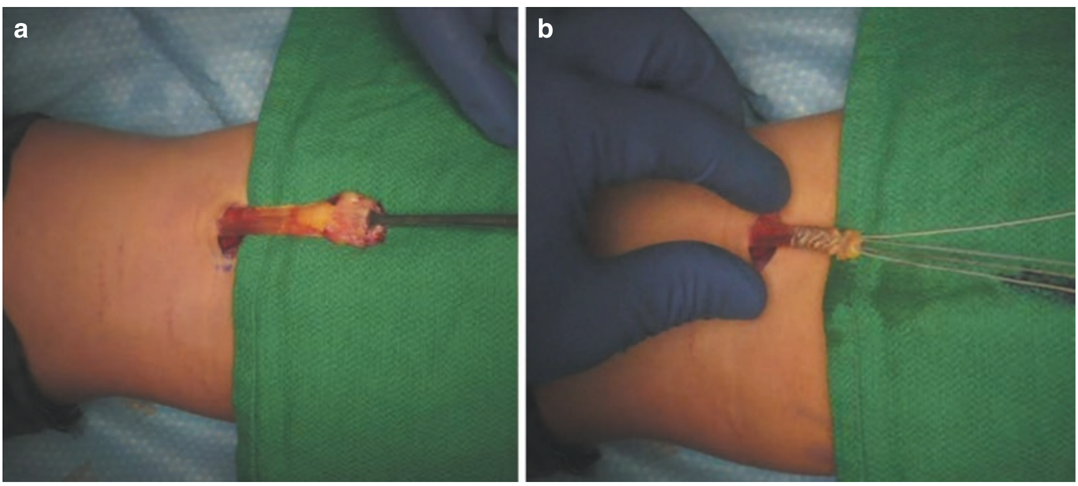

Fig. 26.2 (**a**) Right elbow showing tendinopathic distal biceps and (**b**) prepared distal biceps tendon

(locking whip stitch) using two #2 non-absorbable sutures (Fig. 26.2b) such that 4 tails exit the distal tendon with equal spacing. The sutures should be marked such that the surgeon knows which pair is lateral (long head), as these will be fixed in the more proximal drill holes of the socket (Fig. 26.2b). The surgeon must identify 1) the more central of one of the marked sutures delineating the long head insertion and 2) the more central unmarked sutures delinateing the short head of the biceps as these two sutures will be passed through the central drill hole (Video). The dimensions of the distal tendon are measured.

In the cortical button onlay technique, only one #2 suture is placed as a locking whip stitch. Then a second high-strength suture is placed through the tendon distally with a single pass to be used as a traction and shuttling suture.

Once the tendon has been prepared through the anterior incision, deeper dissection to the radial tuberosity is begun. In a two-incision technique, the lateral antebrachial cutaneous (LABC) nerve is uncommonly visualized laterally as it traverses over the brachioradialis muscle belly. If the nerve is identified, protect it laterally but avoid applying excessive tension. The arm is held in full supination at this time to bring the radial tuberosity into a palpable position. With blunt finger palpation, the tract of the biceps tendon to the radial tuberosity can be reestablished to ensure adequate space to pass the bicep tendon while minimizing risk of disturbance to surrounding soft tissues.

Using a Kelly clamp, concave side facing the radius, the tips of the Kelly are placed on the ulnar most aspect of the radial tuberosity. The arm is then brought into flexion and pronation. Care is taken to keep the Kelly in contact with the radius as it is maneuvered to the dorsal forearm. This prevents ulnar periosteal disruption and risks of heterotopic ossification and radioulnar synostosis. The advanced Kelly elevates subcutaneous tissue on the dorsal forearm, which marks the center point of the dorsal incision. A 3–4 cm longitudinal incision is created over the Kelly, usually at the location marked from the surface anatomy (Fig. 26.1b, Video). Throughout dissection special care is taken to maintain the forearm in a pronated position in order to protect the posterior interosseous nerve (PIN). The fascia overlying the extensor musculature is split longitudinally along its fibers. The extensor digitorum communis (EDC) can be dissected bluntly in a longitudinal fashion. The supinator is next encountered and split in a similar fashion to the EDC. At this point the radial tuberosity bursa is identified. Usually two small Hohmann retractors are placed directly over the bone of the dorsal aspect of the radius (Fig. 26.3). Usually a right angle retractor is sufficient for volar retraction and reduces risk of tension on the PIN. Any tendinopathic remnant and bursal tissue are removed from the radial tuberosity (Fig. 26.3a).

26.11 Traditional Mini-Two-Incision Repair

If the surgeon is unsure of the location of the radial tuberosity, a Kirschner wire can be unicortically placed and the position verified with mini c-arm; however, this is usually unnecessary. Next, a 4 mm round burr is used to create a trough at the radial tuberosity. This trough usually measures 6–10 mm in width by 10–15 mm in length (Fig. 26.3b, Video). A router burr or 2 mm drill is then employed to create three bone tunnels (Fig. 26.3b). Slight supination of the forearm will provide better visualization of the radial (dorsal) side of the trough where bone tunnels will be

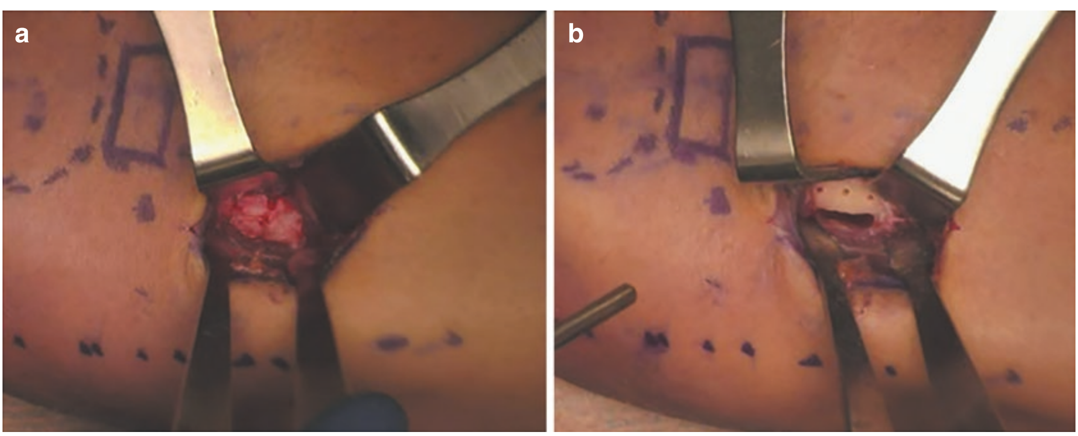

Fig. 26.3 Right elbow with posterior view of the (**a**) prepared radial tuberosity and (**b**) bone trough with bone tunnels

drilled. These tunnels should be at least 5 mm from edge of the trough and at least 7 mm between tunnels. The 7 mm distance approximates the average size of the native distal biceps footprint [8]. Attention should be paid to irrigation and removal of all bony debris during creation of the trough and tunnels.

Next, the tendon must be passed to the posterior incision. A second curved Kelly can be passed from posterior to anterior to facilitate the sutures being passed without twisting to maintain the anatomic orientation of the tendon (Video). Once adequate mobilization of the tendon is observed, the anterior incision can be closed, particularly if the surgeon anticipates that the tendon will need to be fixed in flexion because of tendon loss.

A twist of 26-gauge steel surgical wire can be a very handy tool for shuttling the suture tails from the trough through the bone tunnels (Video). The 2 central sutures are passed through the central tunnel. The medial suture is passed through the distal tunnel, and the lateral suture is passed through the proximal tunnel. Tension is applied to the suture tails and the forearm is pronated and supinated to firmly dock the distal biceps in the bone trough (Fig. 26.4). One of each tail exiting the central bone tunnel is tied to each tail exiting the peripheral tunnels. An arthroscopic knot pusher can be helpful for this. Finally, the incisions are copiously irrigated. The fascia and skin are closed in two layers with absorbable sutures.

26.12 Two-Incision Cortical Button Onlay Technique

Attention is turned to the radial tuberosity through the dorsal incision. The tuberosity is gently decorticated (freshened) with a burr or rasp to promote tendon healing. A drill hole is made on the radial tuberosity at the insertion site of the distal biceps (Fig. 26.5). Aiming the drill to exit more dorsally (raising one's hand toward the ceiling) increases safety margin in bicortical drilling, which has been shown to be safe in one study [9] but was discouraged in another [10]. Unicortical drilling and intramedullary fixation has been described and is an option for repair but is not our preferred technique.

A suture button is placed on the locking sutures of the biceps tendon. We prefer the use of the cortical "onlay" technique, in which the suture button is placed bicortically, and the tendon is pulled to the cortical surface (similar to proximal biceps "onlay" tenodesis). This technique greatly limits the amount of bone disrupted, which reduces the risk of fracture and burden of bone debris on soft tissues. Using an inserter, the suture button is deployed on the far cortex. The distal biceps tendon end is reduced to the bone with a gentle toggle of the two free suture ends threaded through the suture button with care to ensure the suture button lies flat on the far cotex without any slack in the suture. At

Fig. 26.4 Right elbow with posterior view of the docked biceps tendon in trough with sutures tied

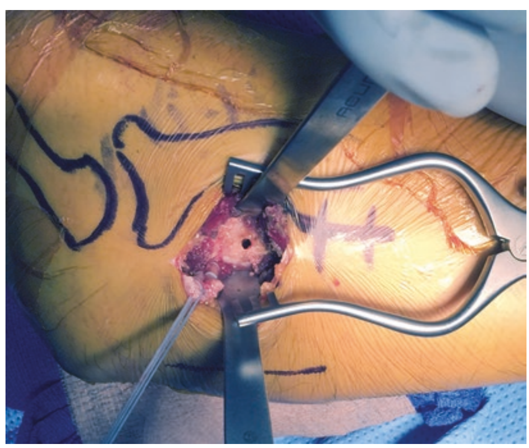

Fig. 26.5 Right elbow with bicortical drill hole for cortical button

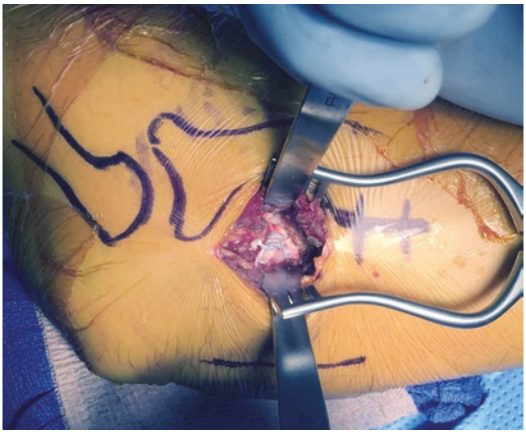

Fig. 26.6 Right elbow with biceps tendon repair using cortical "onlay" technique and cortical button

this point the sutures are tied to complete the repair (Fig. 26.6). The wound is irrigated with care taken to ensure all bone debris is removed from the wound. The fascia and skin are closed in layers.

26.13 Complications

Fixation failure is a rare complication of the two-incision technique. It often results from patient non-compliance or trauma with suture rupture or bicipital tuberosity fracture. Tuberosity fracture is rare unless the surgeon has made too large bone tunnels or put them in too close proximity to the edge of the bone trough (<5 mm).

Heterotopic ossification is a slightly increased risk in the two-incision repair; however, employing the mini two-incision technique with care taken not to disrupt the ulnar periosteum and interosseous membrane greatly reduces this risk. Copious irrigation intraoperatively is thought to provide some prevention benefits. Interestingly, radiographic evidence of heterotopic ossification has not been shown to correlate with loss of forearm rotation [5]. Classically, radioulnar synostosis has been thought to be of higher risk with the two-incision distal biceps repair; however, most recent techniques have found this risk to be exceedingly rare, and it is largely a historical consideration [5].

LABCN Injury is the most common nerve injury encountered and the result of over-retraction. This complication is observed less commonly in the two-incision repair given the decreased anterior dissection required. These nerve palsies are observed and patients can be counseled that they will often resolve within 6 months. PIN Injury is rare in the two-incision repair. The PIN can be protected by pronation during dorsal dissection and refraining from the use of leverage on retractors over the anterior radial neck. These palsies usually resolve within 6 months.

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Single Incision Distal Biceps Repair

27

Claire D. Eliasberg and Samuel A. Taylor

Key Points
- Distal biceps tendon repair is technically easier (fewer adhesions, less tendon retraction) if performed in the acute setting (within approximately 2 weeks from the date of injury).
- When performing dissection, identify and protect lateral antebrachial cutaneous nerve (LABCN) between the biceps and brachioradialis and keep the forearm in full supination to protect the posterior interosseous nerve (PIN) during deep dissection (apply supination at the distal radioulnar joint, not at the hand).
- To avoid mistaking the radial head for the radial tuberosity, use intraoperative fluoroscopy to confirm position prior to fixation.
- Avoid exposure or excessive dissection of the ulna to minimize risk of heterotopic ossification (HO) formation and synostosis.

27.1 Description

A single, anterior incision technique for distal biceps repair is recommended to reduce surgical morbidity, decrease the incidence of heterotopic ossification (HO), and the development of synostosis.

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27.2 Key Principles

Anatomic repair of a distal biceps tendon rupture through a single anterior incision is recommended for active patients with demanding lifestyles. Anatomic repair utilizing careful surgical technique is essential to maximize postoperative strength and to minimize surgical complications.

27.3 Expectations

In the setting of an acute injury, the distal biceps tendon can usually be mobilized and reattached primarily to the radial tuberosity. Chronic and delayed intervention cases may require more extensive release of adhesions and exposure to adequately mobilize the tendon, and in some cases use of an intercalary allograft may be necessary.

27.4 Indications

- Young, healthy, active patients wishing to regain as much strength as possible
- Dominant extremity (relative)
- Right-sided injury as supination strength is more important functionally on the right side (door knobs, screwdriver, opening jars, etc.)

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- Partial tears not responsive to non-operative management (persistent pain and weakness)
- Improved cosmesis (avoid reverse Popeye sign)

27.5 Contraindications

- Poor surgical candidates due to high risk medical co-morbidities, or an inability/unwillingness to comply with postoperative restrictions
- Patient decision following informed consent
- Elderly, low-demand patients (relative)

27.6 Special Considerations

- Fixation methods [1]:
  – Transosseous tunnel
  – Interference screw
  – Suture anchors (one versus two anchors)
  – Cortical button (unicortical versus bicortical)

27.7 Special Instructions, Positioning, and Anesthesia

- Supine position with arm over hand table or arm board
- Fully prep entire arm up to shoulder, use sterile or nonsterile tourniquet placed as far proximally as possible
- May need to retrieve biceps tendon prior to inflating tourniquet if tendon is very retracted (uncommon)
- Preference for neuraxial block and sedation, but general anesthesia may be employed

27.8 Tips, Pearls, and Lessons Learned

- Technically easier procedure (fewer adhesions, less tendon retraction) if performed in the acute setting (e.g., closer to the date of injury, ~2 weeks) [2]
- Use intraoperative fluoroscopy to identify the radial tuberosity and more accurately plan surgical incision
- Surgeon preference is single unicortical button for repair:
  – Allows for tendon preparation prior to deep exposure of the radial tuberosity, thus limiting retraction of the deeper soft tissues
  – Improves suture management
  – After flipping the button intramedullary, pass one of the free limbs through the tendon to augment tendon to bone security
- If using two suture anchors:
  – Place suture anchors ~1 cm apart in a proximal-distal direction to allow adequate bone bridge
  – Use a different color suture from each anchor to help with suture management
  – Use double loaded anchors, but only pass one of the sutures from each anchor into the tendon—after the tendon has been secured, you may remove the second suture from each anchor (allows for a "back-up" suture in case there is an issue such as suture breakage with the other suture)
- Ensure the forearm is in maximum supination when drilling unicortical button hole or pilot holes for anchors:
  – Grab the wrist at the distal radioulnar joint and not the hand to ensure maximum supination of the forearm—this avoids losing some of the supination through the wrist which occurs if you supinate through the hand distally
- Postoperative recommendations:
  – Splint in 90° of flexion immediately postop using bulky dressing and plaster
    Some surgeons prefer to immobilize in supination.
    Authors' preference is wrist free immobilization
  – Distal ROM OK, otherwise maintain splint until follow-up
  – At first follow-up visit (10–14 days), remove sutures and transition to hinged elbow brace locked in 90° of flexion

- Begin progressive, incremental ROM in hinged elbow brace from weeks 2 to 6 post-op, but with no active elbow flexion or supination
- Once full ROM is achieved (goal week 6 postoperatively), may remove hinged brace and start active ROM without brace and then start progressive strengthening
- Return to full activity by ~5–6 months post-op

27.9 Difficulties Encountered

- If tendon is significantly retracted proximally:
  - May need to "milk" the tendon from proximal to distal direction toward the incision
  - Flex elbow in order to draw the incision closer to the retracted tendon (Fig. 27.1a)
  - Release any adhesions surrounding the biceps tendon
  - Release adhesions between the biceps and brachialis muscles
  - May need to extend incision to retrieve distal tendon stump (uncommon)
  - If tendon can still not be adequately mobilized to radial tuberosity, consider tendon allograft.
  - Morrey et al. showed that as long as the tendon can be secured with the elbow in 90° of flexion, the patient will be able to recover their extension [3].
- If exposure is limited by crossing vascular structures (e.g., recurrent radial vessels), take care to tie off and/or cauterize crossing vessels
- Avoid excessive retraction on the lateral antebrachial cutaneous nerve and the superficial radial nerve

27.10 Key Procedural Steps

- Identify and protect lateral antebrachial cutaneous nerve (LABCN) between the biceps and brachioradialis
- Retrieve the biceps tendon proximally (see above), control distal tendon stump using Allis clamp (Fig. 27.1b), and secure the tendon with a whipstitch or Krakow (Figs. 27.1c, d) and pass sutures into unicortical button (Fig. 27.1e)
- Identify interval between brachioradialis and pronator teres (Fig. 27.2a) and trace this down to the radial tuberosity (Fig. 27.2b) (most easily palpated in maximal supination)
- Keep forearm in full supination to protect posterior interosseous nerve (PIN) during dissection (apply supination at distal radioulnar joint, not hand)

27.11 Bailout, Rescue, and Salvage Procedures

- If inadequate native tendon to reach radial tuberosity → use allograft tendon
- Important to recognize patients in which use of an allograft is a possibility—even if the chance is low, it is important to ensure that the consent form includes use of an allograft
  - Chronic tears
  - Presence of residual tendon on the radial tuberosity
- Allograft options: [4–6]
  - Hamstring
  - Fascia lata
  - Achilles
  - Flexor carpi radialis
  - Tibialis anterior

Fig. 27.1 (**a**) Identify and palpate biceps tendon proximally by flexing the elbow in order to draw the incision closer to the retracted tendon. (**b**) Once the distal biceps tendon is identified, utilize an Allis clamp to control distal tendon stump. (**c**) Controlling the distal tendon stump with the Allis clamp, the tendon can be whipstitched. (**d**) Final whipstitch construct. (**e**) Load the sutures into a unicortical suture button

27.12 Pitfalls

- Mistaking radial head for radial tuberosity → use intraoperative fluoroscopy to confirm position prior to fixation (Fig. 27.3a) and to confirm suture button placement (Fig. 27.3b)
- Avoid exposure/dissection of the ulna and clear the surgical site of all bony debris after drilling the radial tuberosity to minimize risk of HO formation and synostosis (Fig. 27.4)
- Careful identification and protection of LABCN, superficial radial nerve, and PIN throughout the procedure to avoid iatrogenic injury [7–11].

Questions

1. The most common complication following single incision distal biceps repair involves injury to which of the following nerves?
   (a) posterior interosseous nerve
   (b) superficial radial nerve
   (c) ulnar nerve
   (d) **lateral antebrachial cutaneous nerve**
   (e) median nerve

   (Cain, Journal of Hand Surgery, 2012) [8]

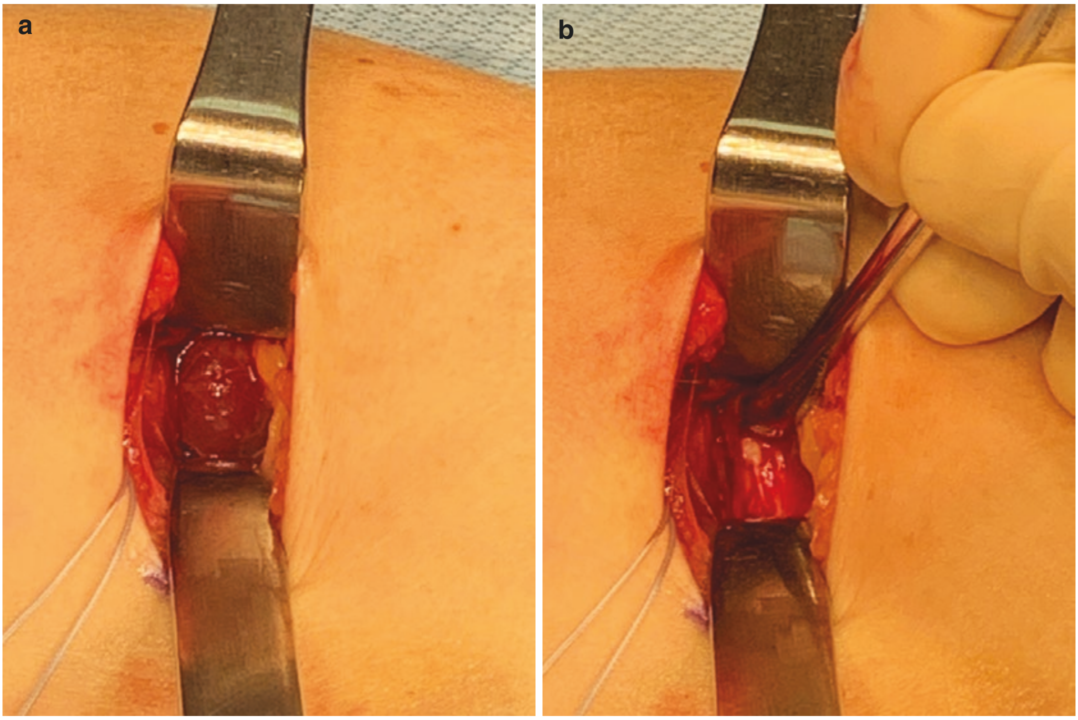

Fig. 27.2 (**a**) Carry out dissection between brachioradialis and pronator teres to radial tuberosity. (**b**) Carry out dissection to radial tuberosity, which can be most easily palpated in maximal supination

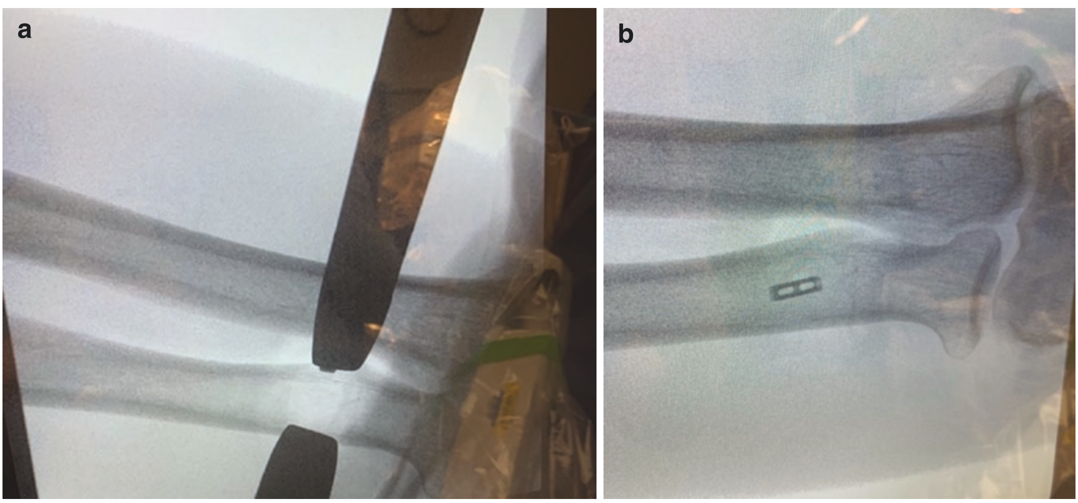

Fig. 27.3 (**a**) Confirm position using fluoroscopy to avoid mistaking the radial head for the radial tuberosity. (**b**) Confirm final placement of suture button using fluoroscopy

Fig. 27.4 Clear the surgical site of all bony debris after drilling to prevent heterotopic ossification

2. Which of the following surgical fixation constructs has demonstrated superior biomechanical properties (i.e., ultimate tensile load and stiffness) in comparative biomechanical studies?
   (a) **cortical button**
   (b) transosseous tunnel
   (c) interference screw
   (d) suture anchors

   (Chavan, AJSM, 2008) [1]

3. What is the greatest loss of strength expected if a patient is treated for a distal biceps tendon rupture non-operatively?
   (a) elbow flexion
   (b) **forearm supination**
   (c) forearm pronation
   (d) wrist flexion
   (e) elbow extension

   (Morrey, JBJS, 1985) [12]

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28 Arthroscopic Osteochondral Grafting for Capitellar Osteochondritis Dissecans (OCD)

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28.1 Description

Autologous osteochondral grafting is a very reliable surgical treatment for capitellar osteochondritis dissecans (OCD) in young overhead-throwing athletes. It provides a high rate of return to overhead-throwing sports [1, 2].

28.2 Principles

An osteochondral defect in the capitellum causes elbow pain during throwing motion. Once an overhead-throwing athlete has capitellar OCD of more than 5 mm in diameter, compressive pressure in the radiocapitellar joint increases during throwing even when the medial collateral ligament is intact [3], resulting in an increase in size of the OCD lesion over time if the athlete keeps playing. Autologous osteochondral grafting decreases compressive pressure in the radiocapitellar joint and enables the athlete to return to overhead-throwing sports without elbow pain.

28.3 Indications

Autologous osteochondral grafting is the most suitable treatment for capitellar OCD lesions classified as International Cartilage Repair Society (ICRS) category III or IV (Fig. 28.1).

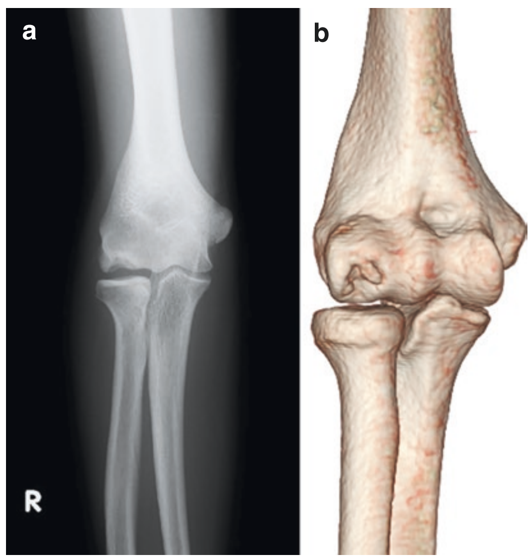

Fig. 28.1 X-ray (**a**) and three-dimensional computed tomography (**b**) findings in capitellar OCD (ICRS IV) before surgery

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28.4 Contraindications

- ICRS I or II OCD lesions
- Presence of the capitellar growth plate
- OCD diameter less than 5 mm
- Sports not involving overhead throwing

28.5 Procedural Steps

28.5.1 Positioning and Preparation

The patient is placed in the supine position with a traction device (Fig. 28.2). The arm is positioned at 90° of shoulder abduction with the forearm suspended from a pulley with 2 kg of weight. During surgery, the OCD can be visualized very well by changing the elbow flexion angle. A tourniquet is not necessary for elbow arthroscopic surgery. A 4.0-mm 30° arthroscope, burrs, shavers, and a radiofrequency device are used.

Fig. 28.2 The patient is placed in the supine position with a traction device. The arm is positioned at 90° of shoulder abduction with the forearm suspended from a pulley with 2 kg of weight

28.5.2 Diagnostic Arthroscopy

The elbow is distended with 10 mL of saline through the direct lateral portal (lateral soft spot, which is located within a triangle formed by the radial head, the lateral epicondyle, and the lateral aspect of the olecranon). First, the arthroscope is inserted through the anteromedial portal; working instruments are manipulated through the anterolateral portal. Diagnostic arthroscopy is performed to determine the presence of loose bodies (Fig. 28.3), osteophytes, and chondral damage. Next, the arthroscope is inserted through the direct lateral portal to visualize the radial head, capitellum, trochlear notch, and trochlear ridge (Fig. 28.4). Care should be taken to avoid damage to the posterior antebrachial cutaneous nerve. If CT or MRI images show any loose bodies or osteophytes on the posterior side of elbow joint, a distal posterolateral portal is created 1 cm proximal and 1 cm lateral to the tip of the olecranon. Loose bodies or osteophytes are then removed through the posterior working portal. An OCD working portal is created 1–2 cm medial or lateral to the direct lateral portal (Fig. 28.4). To make a perpendicular approach to the lesion through the OCD working portal, a spinal needle

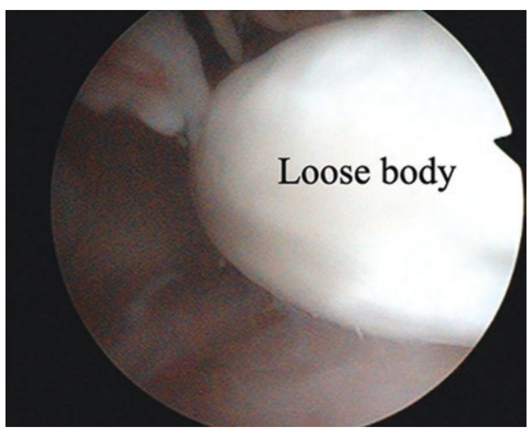

Fig. 28.3 Loose bodies can be found during diagnostic arthroscopy

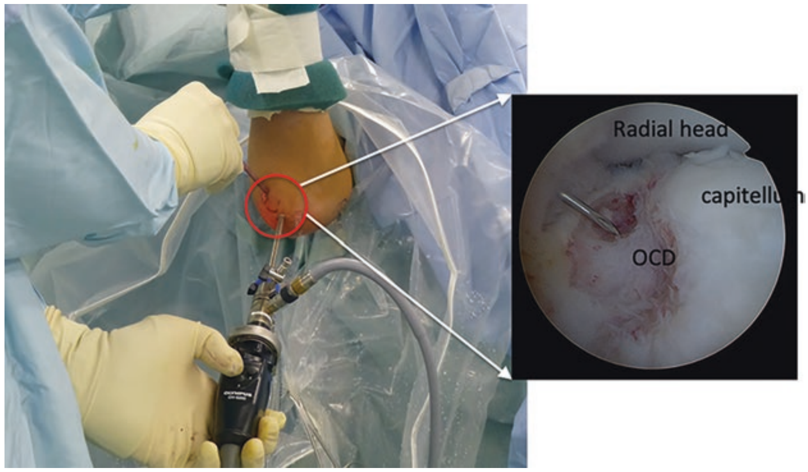

Fig. 28.4 Direct lateral portal used for the scope and the OCD working portal

is introduced through the anconeus muscle at 90° to 100° of elbow flexion before the skin incision is made. The OCD lesion is evaluated and graded by probing. If the lesion is unstable and loose (ICRS III or IV), it is prepared by shaving and removing any loose fragments to establish healthy cartilage borders. In the case of a partially detached fragment, the loose cartilage is debrided, starting at the detached end until stable cartilage border is found.

28.5.3 Osteochondral Grafting: Measuring Defect Size and Creating Recipient Socket

The OATS (Osteochondral Autograft Transfer System, Arthrex, Naples, FL) is used for osteochondral grafting for capitellar OCD. The OCD working portal is widened to insert a cylindrical osteochondral graft 6–10 mm in diameter. After skin incision, the subcutaneous soft tissues are spread bluntly to avoid neurovascular structures. The size of the lesion is measured by using an appropriate Sizer (Arthrex) (Fig. 28.5). The size and number of osteochondral grafts are determined from the size of the lesion. In osteochondral grafting, the entire lesion does not have to be replaced: It is acceptable to retain a 1- to 2-mm-diameter defect after surgery [3]. The recipient harvester is positioned perpendicular to the osteochondral defect and struck with a mallet to create the desired depth of 10 to 15 mm (Fig. 28.6). The recipient harvester can be very easily struck to reach a depth of 10 mm, but after it passes this depth, it sometimes does not penetrate farther into the bone because of the presence of the hard bone of cortex on the contralateral side. In this case, the recipient harvester should not be struck further. The harvester is then rotated to disunite the core from the capitellum.

28.5.4 Osteochondral Grafting: Harvesting the Osteochondral Graft from the Knee

With the patient in the supine position, the arthroscope is introduced into the patellofemoral joint through an anterolateral portal (Fig. 28.7). Cylindrical osteochondral grafts (6–10 mm in diameter and 10–15 mm long) are harvested arthroscopically from the superior lateral edge of the lateral femoral condyle (Fig. 28.7). The donor harvester is positioned perpendicular to the donor surface and struck with the mallet to the same depth as that of the recipient socket; when the recipient socket depth differs between the lateral and medial sides because of surface unevenness, the greater depth is used here. The donor harvester is then rotated to disunite the graft from the femur.

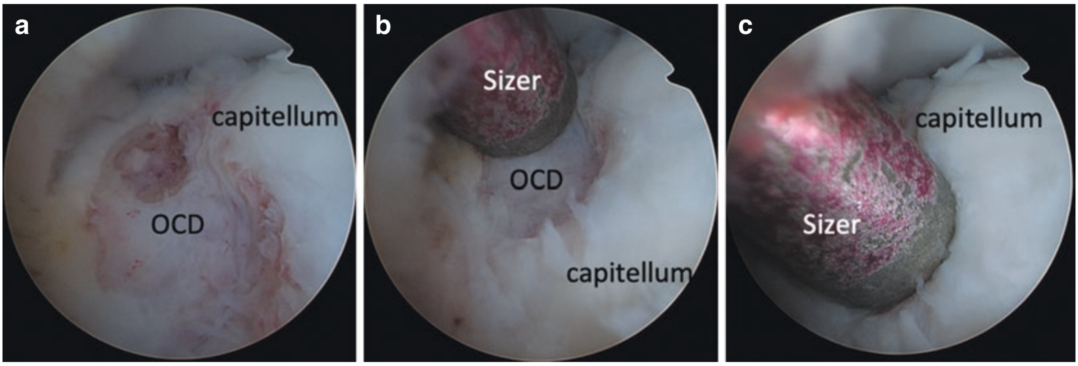

Fig. 28.5 (**a**) Capitellar OCD (ICRS IV), (**b**, **c**) The size of the lesion is measured with an appropriate Sizer (Arthrex)

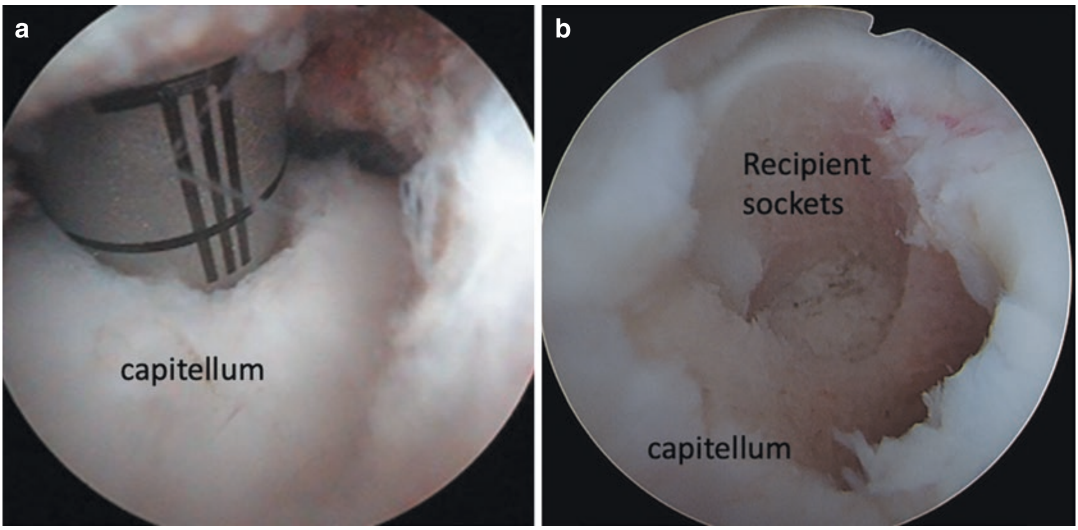

Fig. 28.6 (**a**) The recipient harvester is positioned perpendicular to the osteochondral defect and struck with a mallet to the desired depth of 10 to 15 mm. (**b**) Recipient sockets in the capitellum after two bone cores have been removed

28.5.5 Osteochondral Grafting: Inserting the Harvested Osteochondral Graft into the Capitellum

The recipient socket depth in the capitellum is measured by using an Alignment Rod (Arthrex) (Fig. 28.8a). Also, the length of the osteochondral graft harvested from the femoral condyle is measured. Once the graft has been removed from the femur, its length usually differs from that measured in situ during donor harvesting. When the harvested graft is shorter than the recipient socket depth, a chip taken from the removed recipient bone (Fig. 28.9) is inserted into the recipient socket to make the recipient socket depth the same as the harvested graft length (Fig. 28.8b) before the osteochondral graft is inserted. If the harvested graft is longer than the recipient socket depth, the harvested osteochondral graft should be cut to match the recipient socket depth.

The donor harvester with the harvested osteochondral graft is placed into the recipient socket in the capitellum after the direction of insertion is checked by using Alignment Rod. While the har-

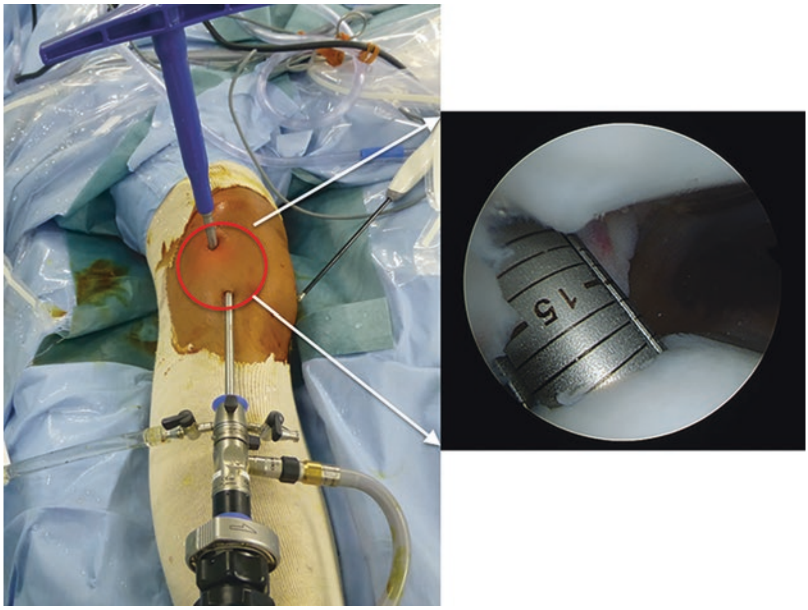

Fig. 28.7 Cylindrical osteochondral grafts are harvested arthroscopically from the superior lateral edge of the lateral femoral condyle

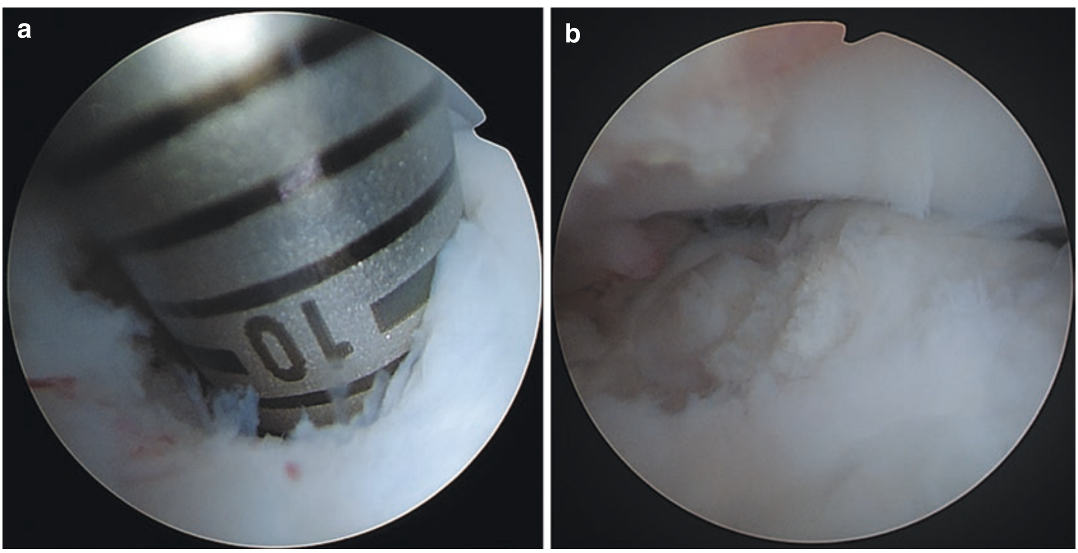

Fig. 28.8 (**a**) The recipient socket depth in the capitellum is measured by using an Alignment Rod (Arthrex). (**b**) Capitellum after insertion of two osteochondral grafts

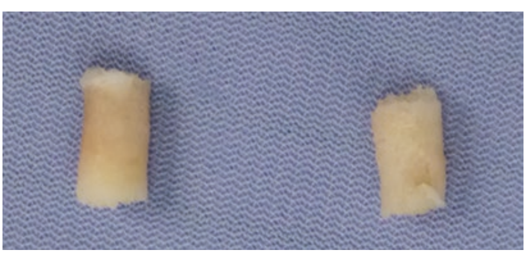

Fig. 28.9 Recipient bone cores from the capitellum

vested osteochondral graft is being pushed out from the donor harvester by rotating the Core Extruder (Arthrex) (located at the back of the harvester), the donor harvester is struck with the mallet. We recommend not pushing the graft out more than 3 mm, because the graft can be broken by the mallet's impact. The direction of strike may be wrong if the graft is not inserted into the recipient socket during impact. If the cartilage of the graft bulges out of the socket, the cartilage is debrided to create a flat surface in the capitellum. If more than 2 mm of the graft is outside the recipient socket, the graft should be taken out and trimmed.

28.6 Handling Difficulties

The most difficult step is insertion of the harvested graft into the recipient socket. First, if the direction of graft insertion differs from the direction of the recipient socket, it will not be possible to insert the graft into the socket. Second, the graft length should match the depth of the recipient socket. One millimeter difference may be acceptable, but 2 mm or more difference will create problems. In particular, a graft that is too long will create an uneven articular surface, and this may in turn cause elbow pain or limited range of motion.

28.7 Bailout and Salvage

When the harvested osteochondral graft cannot be inserted into the recipient socket because the harvester has been struck in the wrong direction, or when part of the graft remains outside the recipient socket in the elbow joint after the donor harvester has been removed, a switch to an open procedure is recommended. If the skin incision at the OCD working portal is extended to 3 cm, the capitellar OCD can be exposed very well.

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29 ORIF Treatment of Olecranon Stress Fracture for Sports Players

Kozo Furushima, Yoshiyasu Itoh, and Yukio Horiuchi

29.1 Description

Olecranon stress fracture (OSF) is a type of posterior elbow injury. Stress fracture occurs when stress is concentrated on bone [1, 2]. Particularly in baseball players, vulgus extension overload (VEO) is mainly responsible for the overload on the olecranon during the follow-through phase because the olecranon and olecranon fossa are under valgus stress during the cocking and acceleration phases and overextension stress during the deceleration phase [3–10], and the olecranon and olecranon fossa impinge.

In adolescence, the olecranon is fragile because of the immature ossification centers and the process of the epiphyseal plate. However, mechanical stress on the elbow joint during the throwing motion is almost the same regardless of age. Therefore, the epiphyseal plate dehiscence of the olecranon is very similar to the mechanism of OSF in adults. Stress fractures are classified into several types according to the age of onset, which is related to skeletal maturation [11].

OSF is a critical injury in athletes, especially baseball players, because they cannot return to throwing without bone union. Many stress fractures are refractory, as is the OSF. Few studies have reported successful surgical treatment of OSF, suggesting that, in many cases, it is difficult to treat. This study reports an effective treatment method for OSF.

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29.2 Key Principles

- Evaluation of the direction of the fracture line and the classification of surgical methods.
- Fixation with bone graft is most appropriate.
- Union around the ulnar articular surface is important.

29.3 Expectation

Return to competitive pitching/throwing at roughly 6 months post-op.

29.4 Indication

- Patients with no tendency of union at approximately 1–2 months after the start of conservative treatment.
- Athletes expecting complete recovery before returning to sport.

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29.5 Contraindication

Athletes who do not want further continuation of their sports career.

29.6 Special Consideration

[Diagnosis and classification].

It is important to note that in baseball players with OSF, the direction of the fracture line differs slightly according to the age of onset. During the growth period, when the bone is still immature, the lateral view of the elbow joint on the unaffected side (the other side) should be used as a reference. In some cases, it is difficult to diagnose fractures only by simple X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) images. Posterior elbow injuries in baseball players require attention because they can be easily overlooked unless careful attention is paid to the presence or absence of stress fractures.

Olecranon stress fractures can be classified into five types [11] (Fig. 29.1). In adolescents with delayed closure of the epiphyseal plate, adolescent-type stress fracture (physeal type) due to a delay in olecranon epiphyseal closure or incomplete epiphyseal closure can be observed when compared with the unaffected side (Fig. 29.2). Fractures in patients with epiphyseal closure can be classified as adult-type stress fractures. The physeal type can be further classified as an adolescent type. The transitional type is classified as the transitional period between the adolescent and adult types. Classical, sclerotic, and distal types are classified as adult types (Fig. 29.2). Thus, OSF types are associated with the age of onset (Fig. 29.3).

The above classification is based on the direction of the fracture line. Characteristically, the fracture line runs toward a wide opening on the ulnar articular surface and originates from the ulnar articular (medial) part (Fig. 29.4).

Classification of olecranon stress fractures (Fig. 29.1)

(a) Physeal type: Delay in closure or incomplete closure is seen along the epiphyseal plate. The frontal view on simple radiography shows widening of the epiphyseal plate and a fracture line running perpendicular to the epiphyseal plate. The lateral view shows a fracture line originating from the articular surface of the olecranon and running in a dorsal-distal direction with the widening

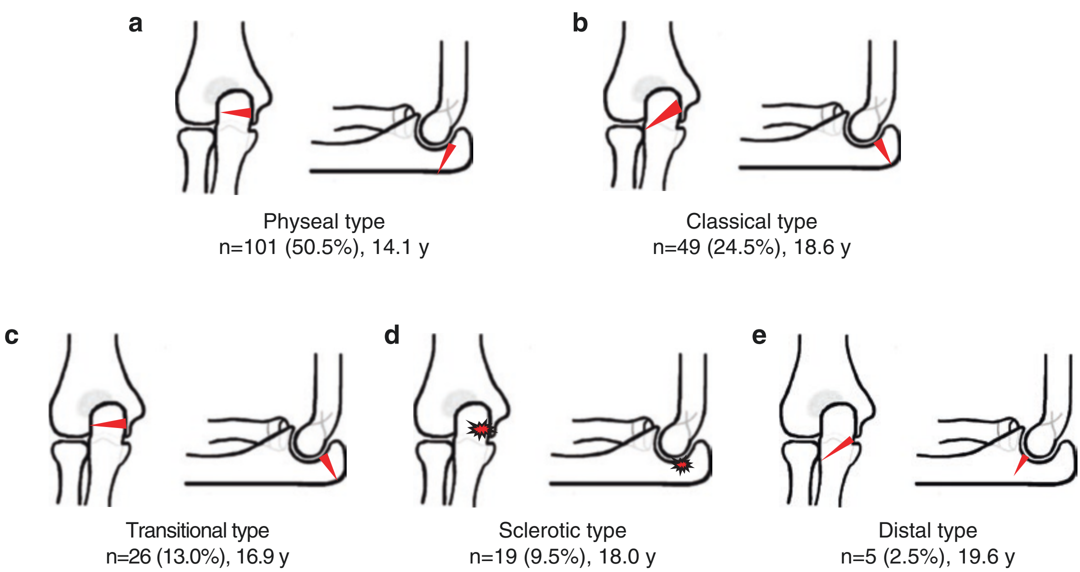


Fig. 29.1 Classification of olecranon stress fractures, incidence, and mean age (n = 200)

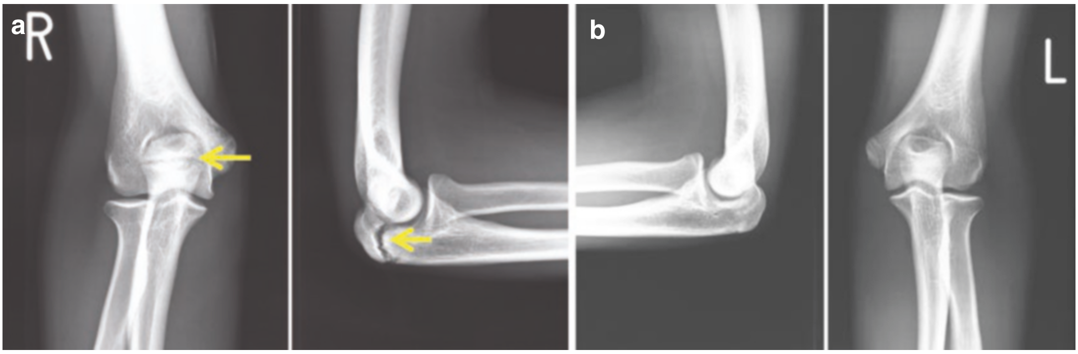


Fig. 29.2 Physeal type. (**a**) Throwing side. (**b**) Non-throwing side. As in the epiphyseal plate, the frontal view in simple X-ray shows a fracture line running perpendicular to the ulnar axis. The lateral view shows a fracture line running from the articular surface of the olecranon in a dorsal-distal direction. The epiphyseal line on the non-throwing side is already closed

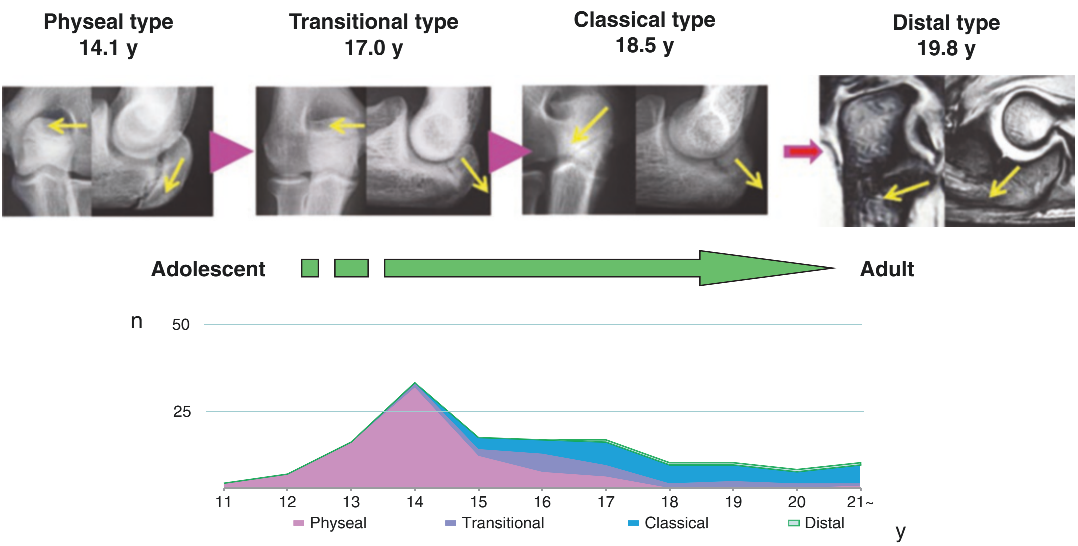


Fig. 29.3 Relationship between the age of onset and disease type. The classification is based on changes in the age of onset before and after epiphyseal closure in adolescence. If the fracture occurs before epiphyseal closure, it is classified as the physeal type. If the fracture occurs after epiphyseal closure, it is classified as the classical type. If the fracture occurs during the transitional period between the physeal type and classic type, it is classified as the transitional type. If the epiphyseal plate on the joint surface of the ulnar olecranon is slightly visible, the site is considered as the origin of the stress fracture and the fracture is classified as the classical type. Conversely, if the epiphyseal plate of the site has been completely closed, it is classified as the distal type. Because the mean age of the distal type group is higher than that of other groups, the epiphyseal plate may not be involved in the development of stress fractures

of the articular surface side (Fig. 29.2), which can be classified into stages I–IV (Fig. 29.5).

(b) Classical type: The most common type is the adult type. The frontal view in a simple radiograph shows a fracture line originating from the olecranon proximal ulnar side and running in the distal-radial direction. The lateral view shows a fracture line originating from the articular surface of the olecranon and running towards the dorsal-proximal direction (Fig. 29.6).

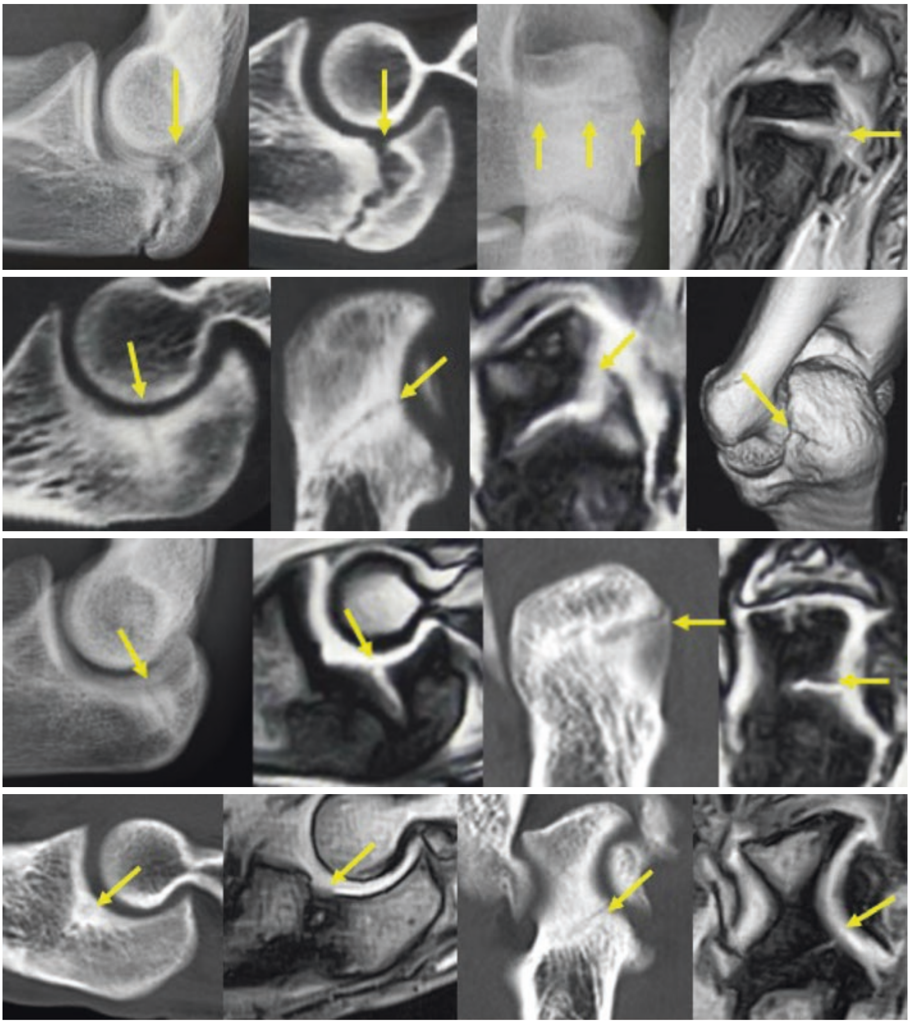
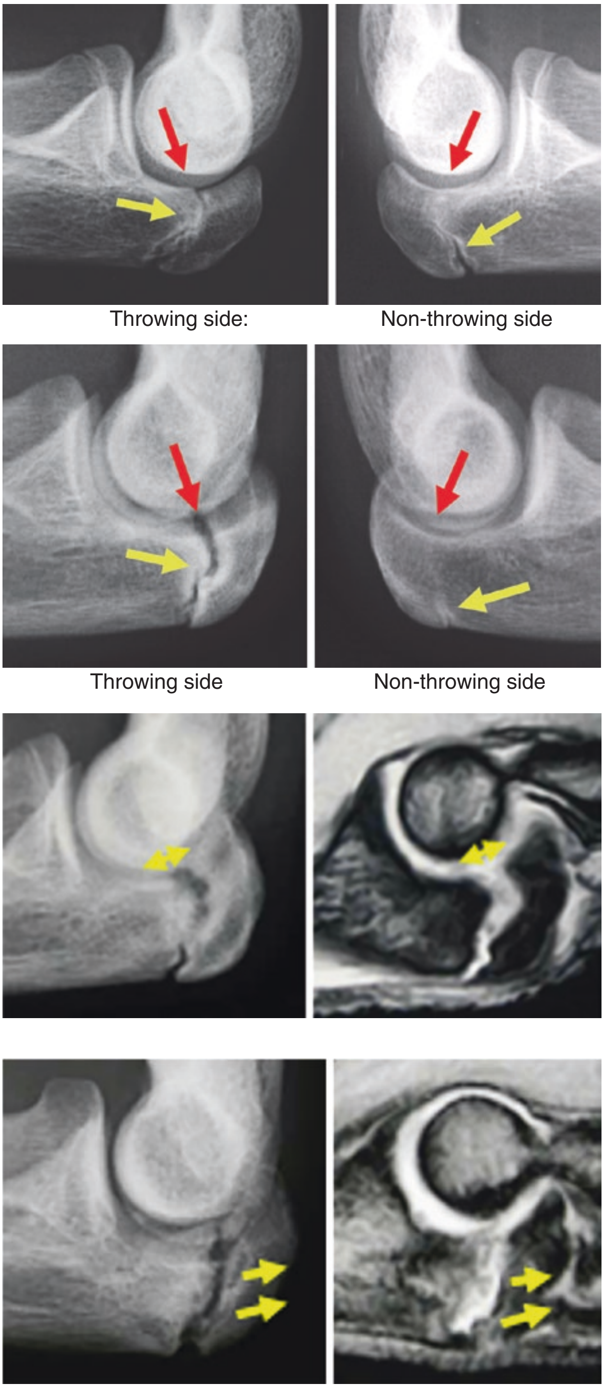


Fig. 29.4 Direction of the fracture line in olecranon stress fracture. A significant widening on the ulnar articular surface is shown. The fracture lines originate from the ulnar (medial) part

(c) Transitional type: As in the physeal type, the frontal view on simple radiography shows a fracture line running perpendicular to the ulnar axis along the epiphyseal plate. As in the classical type, the lateral view shows a fracture line originating from the articular surface side and running towards the dorsal-proximal direction (Fig. 29.7).

(d) Sclerotic type: This corresponds to the period of stress fracture healing. The simple radiograph shows osteosclerosis, although without a clear fracture line. As shown in the figure, MRI can be used when diagnosis by only simple radiography is difficult. Furthermore, MRI shows a wide area with T2 low signal intensity (Fig. 29.8).

(e) Distal type: The frontal view on a simple radiograph shows a fracture line originating from the cortical notch on the trochlear groove distal to the origin of the fracture line of the classical type. The lateral view shows a fracture line running from the articular surface toward the dorsal olecranon. CT and MRI are useful for diagnosis (Fig. 29.9).



Stage I

Throwing side: Delay in the closure

Non-throwing side: Before epiphyseal closure

Stage II

Throwing side: Delay in the closure

Non-throwing side: After epiphyseal closure

Stage III

Delayed closure

Widening on the ulnar articular surface

Stage IV

Delayed closure
Instability due to the extension of the fracture line to the dorsal olecranon

Fig. 29.5 Physeal type: Stage classification

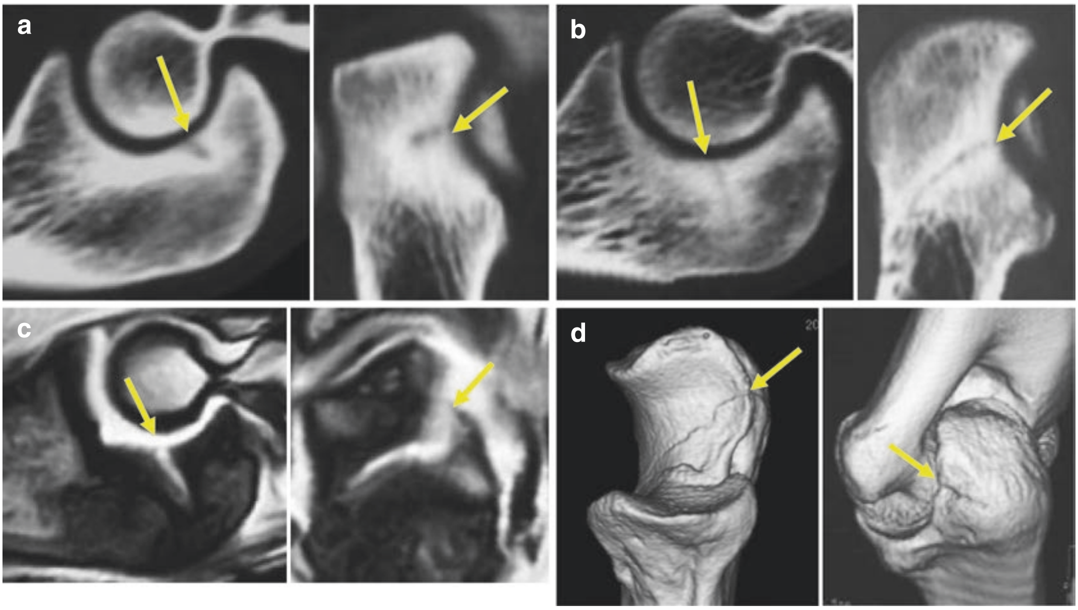


Fig. 29.6 Classical type. (**a**) CT: The fracture line originates from the articular surface and ulnar side. (**b**) CT: The frontal view shows a fracture line originating from the olecranon proximal ulnar side and running towards the distal radial side. The lateral view shows a fracture line originating from the articular surface side and running in the dorsal-proximal direction. (**c**) MRI: The widening of the origin on the articular surface side and the ulnar side. (**d**) 3D-CT: The fracture line originates from the medial olecranon fossa. It is suggested that the articular surface and ulna are under high stress

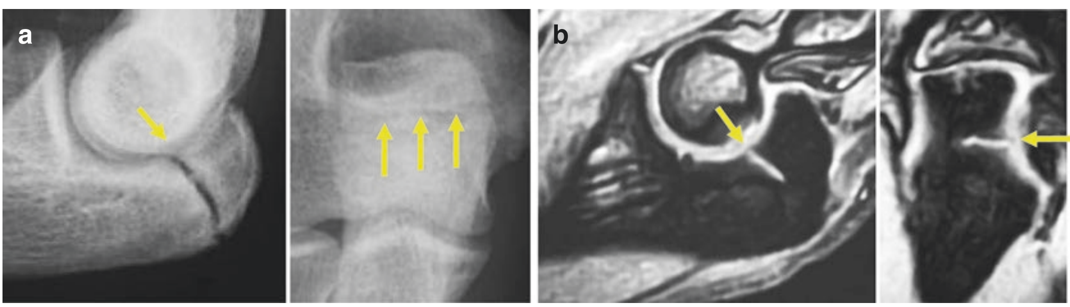


Fig. 29.7 Transitional type. (**a**) X-P, (**b**) MRI. As in the classical type, the lateral view shows a fracture line originating from the articular surface side and running towards the dorsal-proximal direction. As in the physeal type, the frontal view shows a fracture line originating from the ulnar side and running towards the radial direction along the epiphyseal plate. It is suggested that the articular surface and ulna are under high stress

Stage classification in the physeal type (Fig. 29.5) [11].

Detailed analysis of the physeal type shows the range of severity and the staging (I–IV) according to severity. In most cases, the epiphyseal plate on the throwing side closes earlier than that on the non-throwing side. Staging should be performed with this in mind. Stages I and II indicate delayed union. In stage I, the epiphyseal line on the non-throwing side is not closed, whereas in stage II, the line is closed. Stages III and IV represent incomplete unions. Stage III shows the widening of the fracture line only at the articular surface, whereas stage IV shows the widening of the fracture extending to the dorsal side.

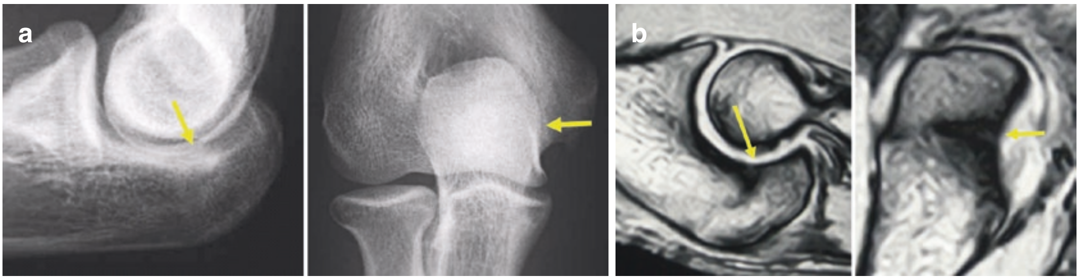


Fig. 29.8 Sclerotic type. (**a**) Simple X-P: The frontal view shows osteosclerosis although the fracture line is not a clear. (**b**) MRI: The articular surface and ulna show low signal intensity on T2 weighted images, indicating a recovery from stress fracture

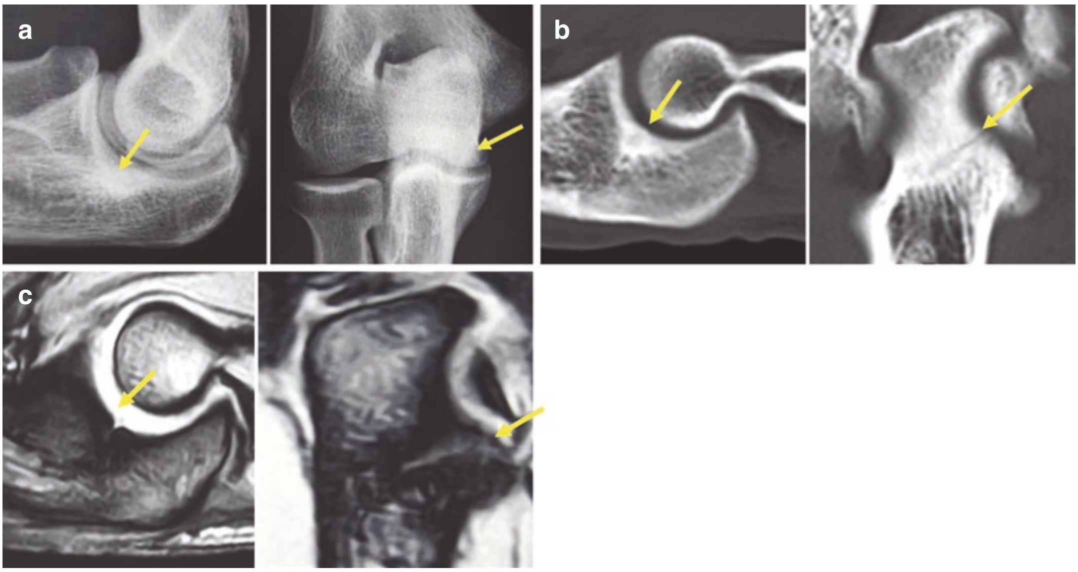


Fig. 29.9 Distal type. (**a**) X-P: The fracture line originates from the olecranon distal ulna side showing the images of osteosclerosis. However, it is difficult to diagnose only by simple X-ray. (**b**) CT, (**c**) MRI: The frontal view shows a fracture line originating from the cortical notch on the trochlear groove and running in the distal-radial direction. The lateral view shows a fracture line originating from the articular surface side and running in the dorsal-distal direction of the olecranon. The fracture line originates from the articular surface and the ulnar side

29.7 Indications for Surgery

In stage I and II physeal types, conservative treatment is generally recommended. Conversely, stages III and IV fractures without a tendency for union following at least 3 months of conservative treatment are indicated for surgery. In many cases, conservative treatment in stage III leads to union. In stage IV, full recovery after conservative treatment is difficult to achieve because of the widening of the epiphyseal line toward the dorsal olecranon. According to Matsuura et al., in patients with osteosclerosis, it is difficult to achieve union with conservative treatment [12].

Even among patients with adult-type OSF, those without a tendency for union after 2–3 months of conservative treatment, with a widening of the fracture line on the articular surface and complications of ulnar collateral ligament (UCL) injuries, are indicated for surgery. Although the incidence of distal type OSF is low, in many cases, the fracture line originates at the cortical notch on the trochlear groove, a mechanically fragile site, which occurs in mostly older adults and highly competitive athletes, and surgical treatment is preferable. Patients with the sclerotic type are not indicated for surgery because they are deemed to be in a period of stress fracture healing.

29.8 Special Instructions, Positioning, and Anesthesia

- Surgery is performed under general anesthesia and fluoroscopy.
- The surgery requires a table compatible with fluoroscopy.
- A non-sterile tourniquet was placed on the upper arm as proximal as possible to the axilla.
- Regarding the upper extremity, the surgery is performed by approaching the ulnar side of the elbow with the shoulder abducted and externally rotated as much as possible to allow maximum elbow flexion and a posterior elbow approach.

29.9 Tips, Pearls, and Lessons Learned

In this surgical method, the site of bone peg insertion is also important. It is essential that the bone pegs are inserted proximal to the ulnar olecranon joint surface and that the peg alignment is perpendicular to the fracture site. For this purpose, in the classical and traditional types, the direction of the fracture line is examined in advance by simple X-ray, CT, and MRI imaging, and the direction of the insertion of the internal fixation materials is drawn in advance. Although it is important to insert the bone pegs below the articular surface, caution is required to avoid penetrating the fracture surface. The guide wires should be inserted in the direction of the bone peg insertion, and accurate positioning should be confirmed by fluoroscopy. A hole (approximately 3.2–4.0 mm) is gradually created in the same direction by using a drill. Bone pegs of the same diameter, harvested from the cortex of the olecranon, should be inserted into the bone hole to cross over the fracture line.

In the classical type, an approach to the ulnar side of the elbow is used. The posterior olecranon approach is used in the physeal and transitional types. In the distal type, a medial or posterior approach is used.

29.10 Difficulties Encountered

29.10.1 An OSF Patient with Incomplete Union

Osteosclerosis was detected at the fracture site of a patient who had an Acutrak screw inserted in another hospital, in which no union was achieved. Because pain during the throwing motion persisted, the patient underwent re-surgery for Acutrak screw removal and bone peg grafting. However, due to severe osteosclerosis at the fracture site, the Acutrak screw could not be removed initially. Finally, after extensive grinding of the surrounding bone, the Acutrak screw was removed. A large bone peg and fresh bone fragments were used for subsequent fixation and grafting of the large bone hole. The patient achieved union approximately 4 months after the grafting.

It should be noted that such surgery is more invasive and involves difficulty in screw removal.

29.10.2 A Patient with Complications of OSF and UCL Injuries

The patient with OSF was a pitcher. Regarding the OSF classification, the patient was classified as the classical type based on the fracture line and had evident pain in the posterior elbow. MRI detected UCL injuries. Although slight instability was observed, the patient had no pain in the UCL. Therefore, bone peg grafting was performed only for OSF. The patient successfully achieved union of the fracture site and was able to return to the sport 6 months after surgery. Three months later, the patient returned to the

Table 29.1 Incidence of UCL injuries and avulsion fracture of the medial epicondyle

Type (*n*)	UCL injuries	Medial epicondyle Avulsion fracture	Total	Incidence (%)
Physeal type ($n = 101$)	44	28	72	71.3
Classical type ($n = 49$)	39		39	79.6
Transitional type ($n = 26$)	17	2	19	73.0
Sclerotic type ($n = 19$)	18		18	94.7
Distal type ($n = 5$)	4		4	80.0
$n = 200$			$n = 152$	76.0

stadium to pitch baseball. However, due to the gradual recurrence of the posterior elbow, he visited our hospital and was diagnosed with refracture at the site of stress fracture union on a simple radiograph. The examination also revealed elbow instability with valgus stress and pain in the UCL. During re-surgery, the patient underwent grafting at the site of refracture and UCL reconstruction. Later, he was able to return to the sport without recurrence. Elbow instability in valgus stresses increases the risk of OSF and, in many cases, complicates OSF (Table 29.1). UCL reconstruction should be considered simultaneously in the presence of UCL instability.

29.11 Key Procedure Steps

The physeal type usually requires inverted bone grafting. The treatment of classical, traditional, and digital types uses internal fixation with bone pegs as the primary treatment. This is because it is difficult for OSF patients to achieve union, and in many cases, fixation with metal devices such as screws does not lead to successful union. Bone pegs are autologous bones that achieve union by avoiding the fracture lines and promoting union around the autologous bone grafting, usually leading to a complete union. Conversely, the use of DTJ screws may increase the risk of mild persistent pain and delay in union, although they provide high stability. Therefore, in our hospital, the use of DTJ screws is limited to patients who provide informed consent to undergo high-risk surgery, expecting an early return to the sport.

We use the following three surgical methods [6]:

1. Inverted bone grafting for the physeal type (Fig. 29.10)
   A skin incision requires a longitudinal incision from the dorsal olecranon. After an incision into the fascia, the periosteum is exfoliated from the ulna using a raspatory. A rectangular piece of bone is harvested from a site at one-third of the mid-olecranon using a chisel or bone saw after locating the epiphyseal plate (the site of dehiscence) with a needle (Fig. 29.10). The fresh bone graft should be deployed proximal to the joint after adequately curetting the site of dehiscence (the harvesting site) on the articular surface (Fig. 29.10c). After curetting, the harvested piece of bone is inverted and grafted (Fig. 29.10d). The bone graft is placed and fixated using tension band wiring and two 1.5-mm Kirschner wires and a˜1-mm mild steel wire (Fig. 29.11).
   - In many cases, the use of inverted bone grafting in the physeal type facilitates union.
   - This is a noninvasive method to promote a successful union.
2. Bone peg grafting for classical (Fig. 29.12) and traditional (Fig. 29.13) types.
   In both types, placement and fixation of the grafts are recommended, one proximal to the ulna and the other proximal to the midpoint of the articular surface.
   Classical type: The site of the bone peg insertion is the ulnar articular surface (Fig. 29.12b). Under fluoroscopic guidance, a 1.2-mm Kirschner wire is inserted from the site of the medial cortical site. A hole (approx-

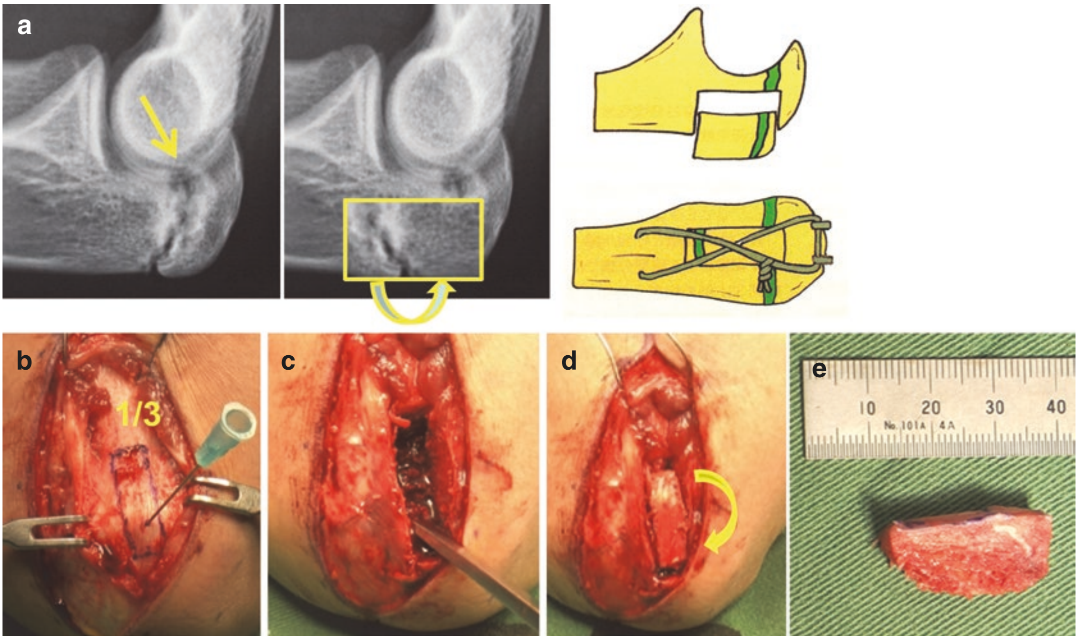


Fig. 29.10 Physeal type: Inverted bone grafting. (**a**) Images of inverted bone grafting. (**b**) The epiphyseal line is located using a needle. (**c**) The site of dehiscence on the articular surface of the harvested site is adequately curetted. (**d**) The harvested piece of bone was inverted and grafted. (**e**) Harvested piece of bone

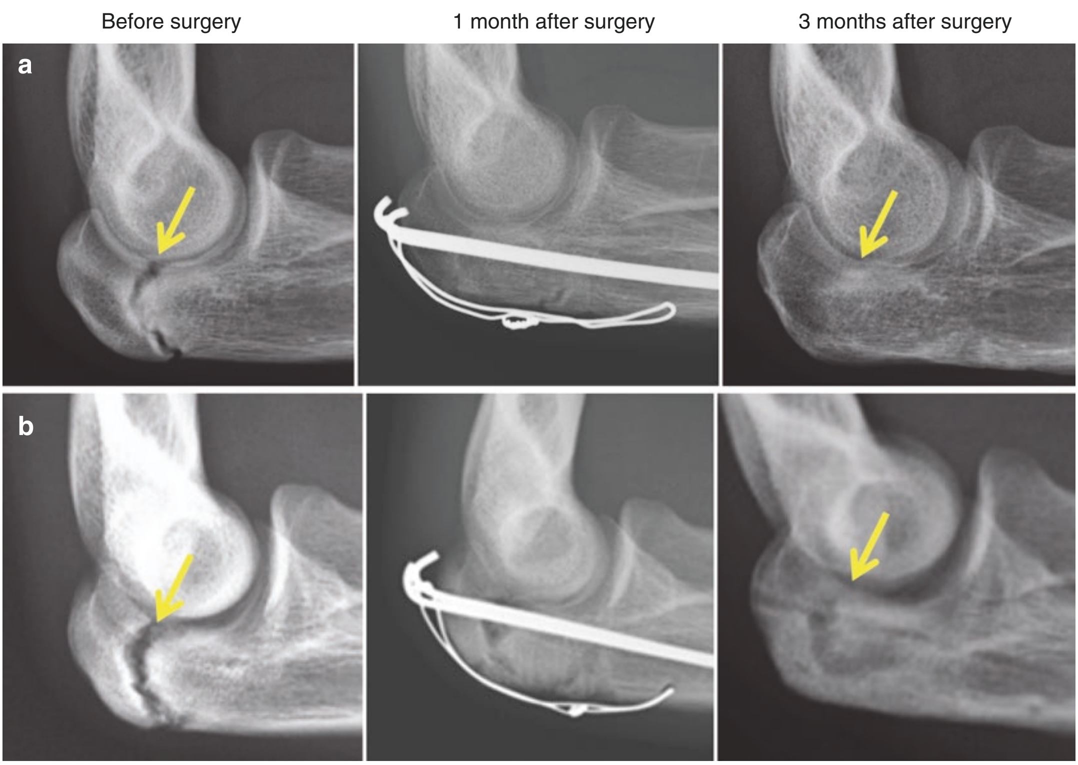


Fig. 29.11 (**a**) Case 1: stage III. (**b**) Case 2: stage IV

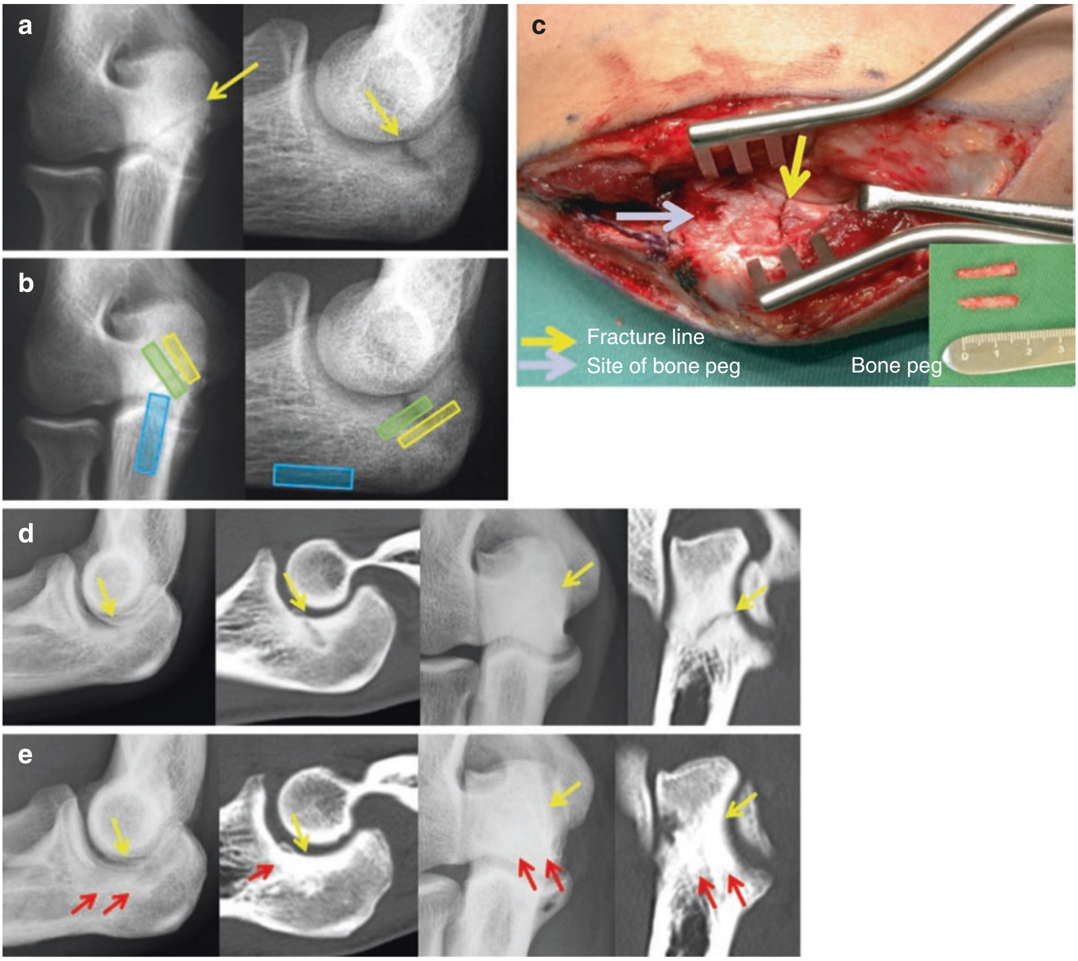


Fig. 29.12 (**a**) Classical type. Preoperative simple X-ray. (**b**) Images of bone peg insertion. (**c**) Two bone pegs are inserted using an approach to the ulnar collateral ligament of the elbow. The diameter of the bone peg is 3.5 mm. (**d**) Preoperative simple X-ray and CT imaging of the classical type. (**e**) Simple X-ray and CT imaging at 5 months after surgery. Union has been achieved around the bone pegs

imately 3.5–4.0 mm) is gradually created in the same direction using a drill. Once the Kirschner wire is inserted into the optimal position, a bone hole is created with the drill so that the wire passes the fracture site. The hole is gradually drilled to a diameter of approximately 3.5–4.0 mm. Harvest two bone pegs (of 3.5, 4.0 mm; length, 20 mm; size, equivalent to that of the drill guide holes) from the olecranon. The two bone pegs of the same diameter should be inserted until they pass the fracture site using an impactor (Fig. 29.12). Confirm the position of the fracture line on the preoperative CT (Fig. 29.12d) and that of the bone union on the postoperative CT (Fig. 29.12e).

Traditional type: In the transitional type (Fig. 29.13a), the bone peg should be inserted from the harvesting site because the fracture line is perpendicular to the ulnar axis. Because the fracture line originates from the ulnar articular surface, one bone peg needs to be inserted into the ulnar and the other into the midpoint. Because the cortical notch of the trochlear groove has a bulge on the ulnar articular surface, the bone peg for the midpoint, compared to the other bone peg, needs to be inserted more proximal to the ulnar

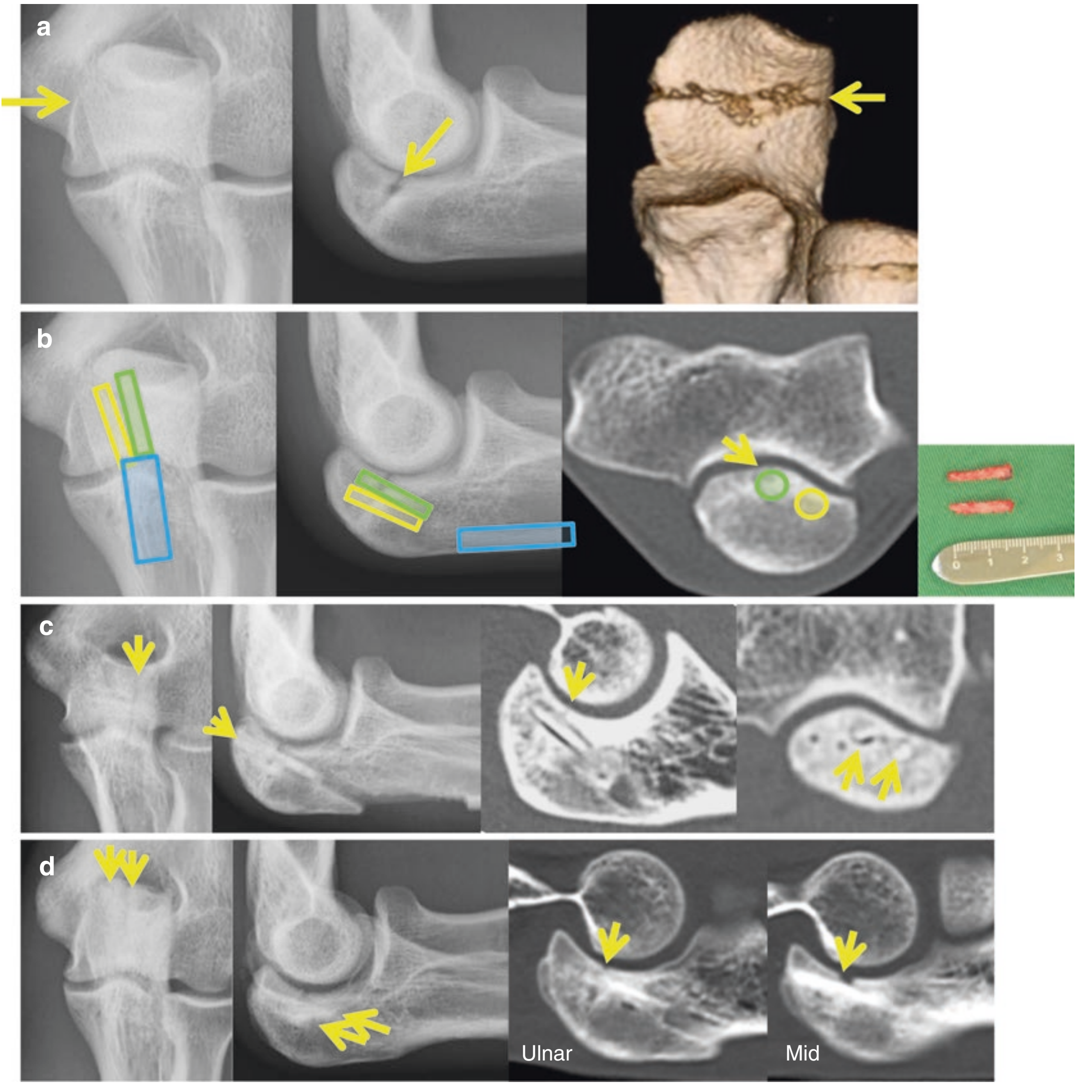


Fig. 29.13 (**a**) Transitional type. Preoperative simple X-ray and CT imaging. (**b**) Images of bone peg insertion. (**c**) Simple X-ray and CT imaging at 1 months after surgery. Two bone pegs are inserted using the dorsal olecranon approach (Ulnar and Mid). The diameter of the bone peg is 3.5 mm. (**d**) Simple X-ray and CT imaging at 5 months after surgery. Union has been achieved around the bone pegs

articular surface, as shown in the lateral view (Fig. 29.13). Postoperative CT shows that the bone peg is placed proximal to the articular surface (Fig. 29.13c). Simple X-ray and CT imaging at 5 months after surgery show union in the region around the bone pegs (Fig. 29.13d).

- Because bone grafting promotes bone union around the site of the graft, we often use the surgical method in which bone pegs with a diameter of 3.5–4.0 mm are harvested from the olecranon.

3. Fixation with the DTJ screw (Fig. 29.14).

   Under fluoroscopy guidance, a 1.2-mm Kirschner wire is inserted and the direction of the screw should be determined. In the classical and traditional types, the direction of the insertion of one or two large DTJ screws should be perpendicular to the fracture line as much as possible with the Kirschner wire as a

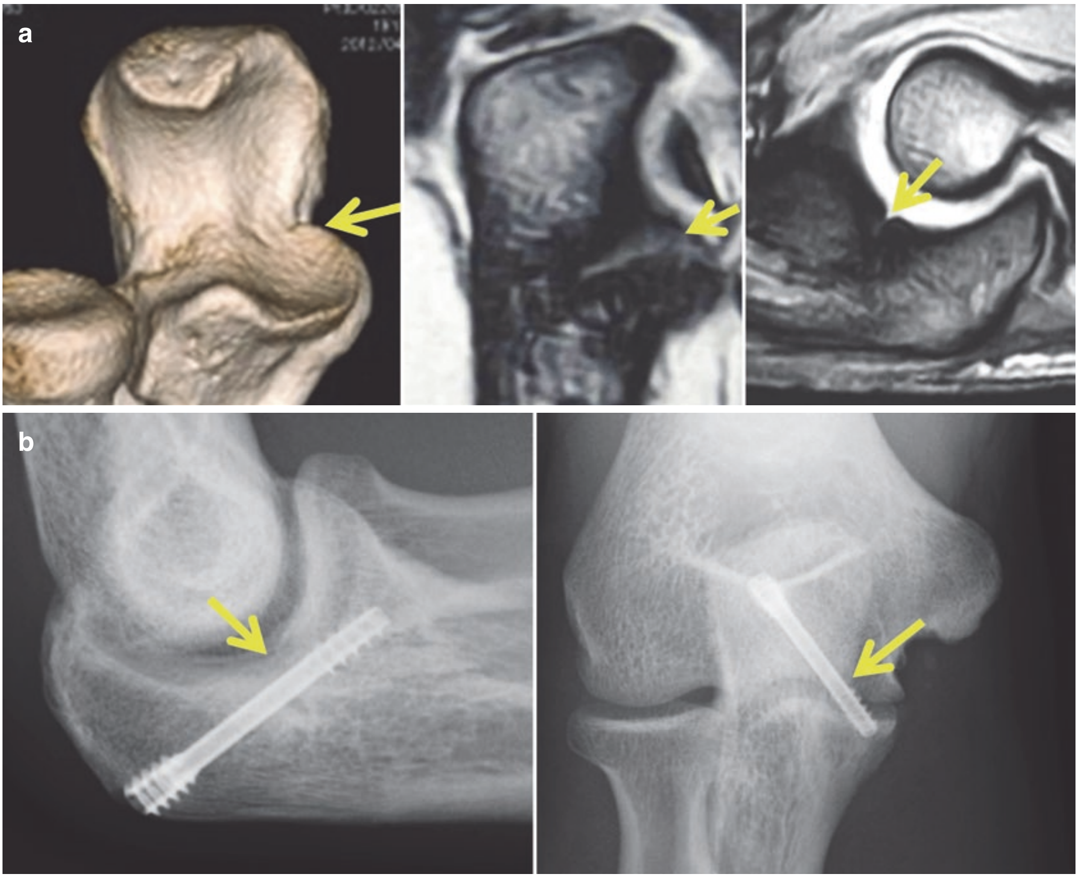


Fig. 29.14 (**a**) Distal type. Preoperative CT and MR imaging. The fracture line originates from the fragile site of the ulnar trochlear groove. (**b**) Direction of bone peg insertion in postoperative simple X-ray

guide. In the distal type, when the DTJ screw is inserted vertically in the direction of the fracture line, the screw should be inserted slightly radial to the dorsal olecranon in the direction of the medial side (sublime tubercle).

- We do not use the Acutrak screws because they are more difficult to remove than DTJ large screws, and it is difficult to perform salvage surgery in cases of incomplete union.
- [Rehabilitation]
- Inverted bone grafting and bone peg grafting require splint fixation for 2 weeks after surgery. The splint is removed 2 weeks after surgery and the active range of motion training is initiated. Inverted bone grafting requires follow-up to monitor the bone union. Because it takes approximately 2–3 months to achieve bone union, patients usually resume pitching practice at 3–4 months after surgery and return to competitive pitching at 5–6 months after surgery. Bone grafting requires simple radiography and CT imaging to evaluate bone union. In many cases, not only the site of bone peg insertion but also the surrounding site achieve union. If bone union is confirmed at approximately 3–4 months after surgery, patients are allowed to resume pitching practice. Patients after fixation with DTJ screws are allowed to resume light pitching practice at approximately 8 weeks after surgery if they have

no pain. However, caution is required because it does not necessarily mean that the patients achieved bone union.

29.12 Bailout, Rescue, and Salvage

- Fixations with metal screws also require caution because, in some cases, patients do not achieve complete union.
- Because it is difficult to remove metal screws due to the hardening of the fracture site caused by osteosclerosis, fixation should be achieved with retained metal screws.
- When seeing patients after fixation with metal screws, check whether there is space for bone pegs next to the screws. When it is not possible to remove the metal screws, insert the bone pegs.

29.13 Pitfalls

- Aim to achieve union of the ulnar articular surface of the olecranon and the articular surface of the mid-trochlea.
- Use thick bone pegs (of about 3.5–4.0 in diameter) as much as possible. The site of the bone peg insertion should be at least 6–7 mm from the fracture site.
- Avoid the articular surface.
- In the case of the complications with UCL injuries, reconstruction may be considered.
- Determine the surgical method based on classification type.

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30 Revision UCL Reconstruction: Humeral Side

Masaki Akeda and Tetsuya Yamazaki

30.1 Expectations

Regardless of the site of ligament injury, temporary repair of the ligament cannot be expected to improve the function of elbow joint, so reconstruction of the UCL with a new graft is selected [1].

30.2 Indications

Medial elbow pain during the throwing motion due to UCL injury which resistant to conservative treatment after primary UCL reconstruction. Significant deterioration of throwing performance associated with UCL dysfunction due to elbow valgus instability.

30.3 Contraindications

Medial elbow pain due to other reasons such as flexor-pronator muscle injury, ulnar nerve problems, and osteoarthritis of the elbow joint.

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30.4 Special Considerations

To grasp the information of the previous surgery it is important to make a strategy of the revision surgery. Several methods exist for the exposure of UCL, graft choosing, graft configuration, and graft fixation in UCL reconstruction (Fig. 30.1) [2–5]. Because some athletes can play sports in different countries, it becomes difficult to correct previous information. Magnetic resonance imaging (MRI) is used to evaluate the grade of UCL injury and other complications such as olecranon stress fracture and flexor-pronator muscle injury (Fig. 30.2). Computed tomography (CT) findings indicate the information regarding the bone tunnel and the bone morphology around the insertion of UCL (Fig. 30.3). Those preoperative assessments should be considered to work out the surgical strategy.

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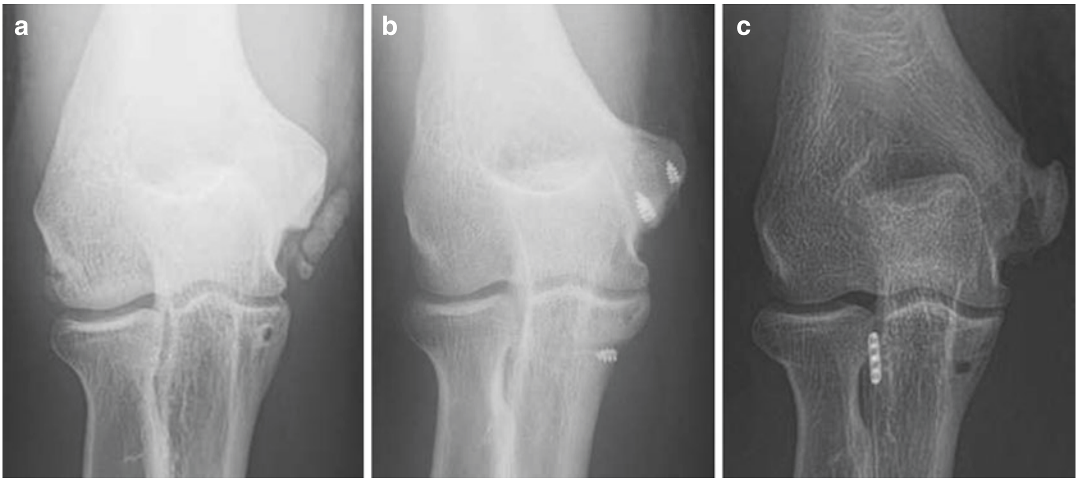

Fig. 30.1 Several methods exist for UCL reconstruction. Dislocation and heterotopic ossification of the bone peg used for humeral side fixation (**a**). Example of using small metal screws for graft fixation on both sides (**b**). Example of the button used on the ulnar side (**c**)

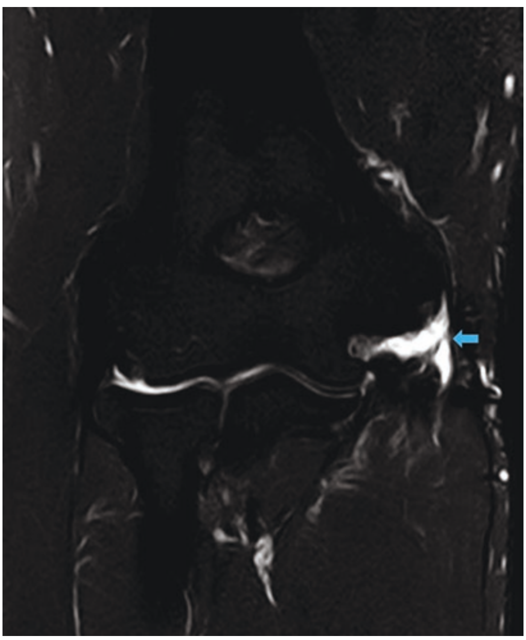

Fig. 30.2 MRI findings indicate UCL reinjury at the humeral side and partial injury of flexor-pronator muscle

30.5 Special Instructions, Positioning, and Anesthesia

- General anesthesia would be recommended because revision surgery would take longer than primary UCL reconstruction.
- Supine position with shoulder 90° abduction in throwing side.
- Palmaris longus of the contralateral side, gracilis muscle, or allograft has been used as the new graft for revision surgery.
- Tendon stripper in case of hamstring muscle graft.

30.6 Tips, Pearls, and Lessons Learned

The use of intraoperative ultrasound and neurostimulator may be useful in identifying ulnar nerve buried in scar tissue. It is also helpful to use

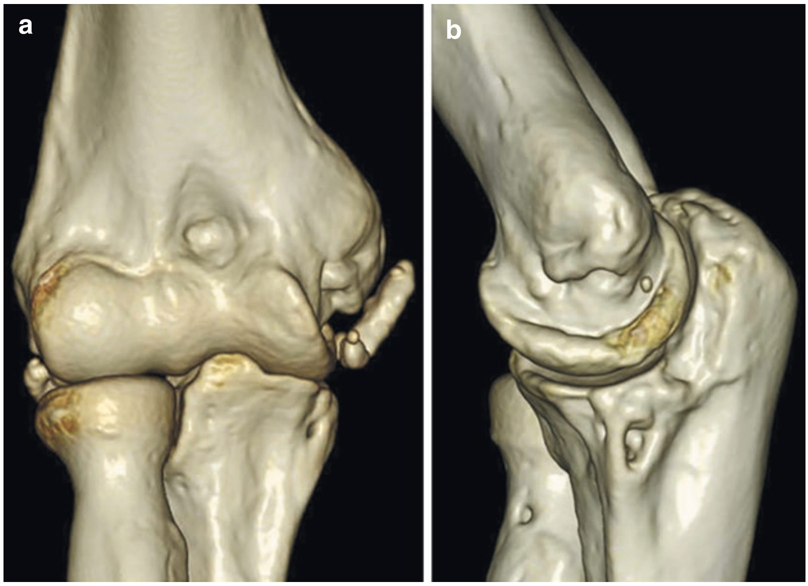

Fig. 30.3 CT findings indicate the information regarding the bone tunnel and the bone morphology around the insertion of UCL. (**a**) Anteroposterior view of the right elbow joint after the primary UCL reconstruction. An abnomal large bony fragment is showed around the insertion of UCL at humeral side. (**b**) Lateral view from the medial side of the right elbow joint after UCL reconstruction. Bony shape and position of the bone tunnel made by previous surgery can be evaluated at both humral and ulnar side

an X-ray fluoroscopy device during the operation to estimate the position of the bone tunnel and the instrument previously used for ligament fixation.

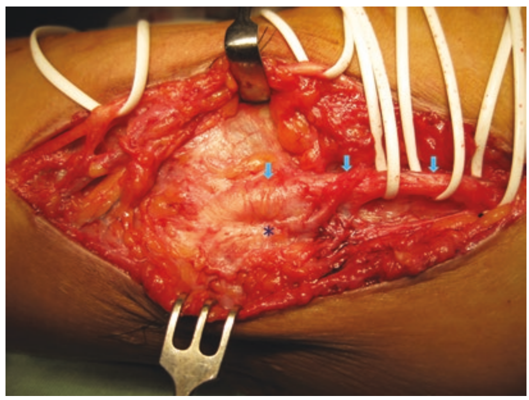

Fig. 30.4 The ulnar nerve (blue arrows) was transferred anteriorly in the primary surgery and buried in the scar tissue. Medial epichondyle(*)

30.7 Difficulties Encountered

Careful attention is required because the ulnar nerve transferred anteriorly in the previous surgery may be buried in the scar tissue before exposing the UCL. Since it may be difficult to determine the optimal bone tunnel position due to tissue scarring, ossicle, bone shape change around the bone tunnel, etc., it is desirable to grasp the condition by preoperative CT examination.

30.8 Key Procedural Steps

Each autograft such as palmaris longus or gracilis muscle would be harvested from the contralateral arm or lower extremities before starting the procedure of elbow. Skin incision is approximately 5 cm from the medial epicondyle of humerus to proximal and distal direction. Previous surgical wound would be used as possible. First of all, ulnar nerve should be identified to avoid damage when the anterior transfer procedure has to be done in the primary surgery. It is expected to take time to identify the ulnar nerve if it is buried in scar tissue (Fig. 30.4). After ulnar nerve is protected safely, previous damaged graft is exposed with muscle splitting approach of flexor-pronator muscle (Fig. 30.5). The graft which was set at previous surgery would be removed with surrounding scar tissue and some other unnecessary tissue such as ossicles around the graft and stitches in primary surgery (Fig. 30.6). Each graft configuration methods can be chosen for revision surgery. To

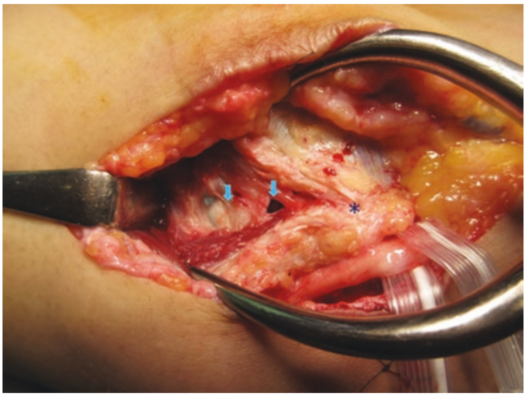

Fig. 30.5 Previous graft was exposed with muscle splitting approach of flexor-pronator muscle and torn at the humeral side

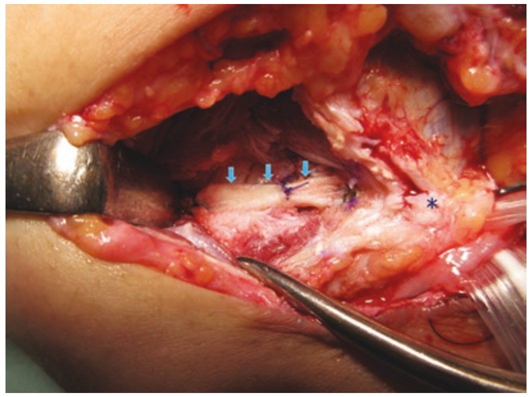

Fig. 30.7 The new graft (blue arrows) has to be positioned by keeping its isometric pattern as possible during a motion of the elbow joint

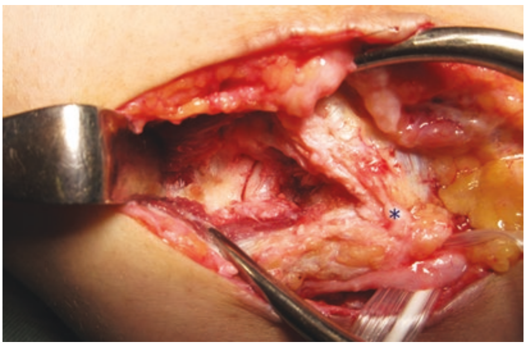

Fig. 30.6 The damaged graft should be removed with surrounding scar tissue and some other unnecessary tissues such as ossicles and stitches used in primary surgery

choose the graft configuration, it will be very important to comprehend the condition of the previous bone tunnels and the bone morphology around bone tunnels using a CT examination at both humeral and ulnar side (Fig. 30.3). If the previous bone tunnel has been closed, the new graft can be set much as primary reconstruction. In case the previous bone tunnel is not available for some reasons such as remaining medical devices for fixation of the graft, the new tunnel has to be made avoiding them. Regarding the choice of the graft fixation method for ulnar side, single socket tunnel will be created at approximately 5–7 mm distal from the medial elbow joint space in case the shape of sublime tubercle of the ulna is flat. Conversely, in case it is sharp, docking technique might be easy for graft fixation at the ulnar side, but it requires attention for bone quality of the sublime tubercle of the ulna. At the humeral side, the bone tunnel should be created at the center of the original insertion of anterior oblique ligament (AOL) of UCL. In any case, the new graft should be positioned by keeping its isometric pattern as possible during a motion of the elbow joint (Fig. 30.7). After setting the new graft, flexor-pronator muscle is sutured as covering it. The ulnar nerve will be positioned as avoiding its overtension and traction during the elbow flexion and extension movement. Confirmation of hemostasis is important to avoid postoperative tissue scarring.

30.9 Bailout, Rescue, and Salvage Procedures

Various surgical techniques (screw fixation, bone tunnel method as docking technique and pull-out fixation method, etc.) should be prepared for cases where bone tunnels cannot be created at appropriate positions, bone destruction around the bone tunnel during graft fixation, or in case the instrument used in the previous surgery cannot be removed.

30.10 Pitfalls

The important thing before surgery is to collect as much information as possible regarding the previous surgery. If the ulnar nerve has been transferred anteriorly in the previous surgery, the nerve may be buried in the scar tissue, so careful attention must be needed when approaching the UCL. Several surgical techniques should be prepared to respond for changing of bone morphology and to avoid interference with instruments used in previous surgery.

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Revision UCL Reconstruction: Ulnar Side

31

Jin-Young Park

31.1 Introduction

Although excellent results can be achieved in up to 90% of primary elbow UCL (ulnar collateral ligament) reconstructions, retears of the ligament have been reported. As the number of primary reconstructions continues to increase, one could expect an increase in the number of revision UCL reconstruction performed. The reported rate of revision UCL reconstruction varies from 1% to 14% [1–4]. They remain a challenging problem.

Given that the patient has already had a prior UCL reconstruction, details regarding surgical technique, graft type, ulnar nerve treatment, and any concomitant procedures are imperative to take into account when considering revision surgery [5]. Furthermore, details of the patient's previous therapy and throwing rehabilitation, following their primary surgery should be discussed as this may represent an area needing adjustment. Lastly, motivation, career goals, level of competition, and anticipated future career length are all important factors to consider, as they will likely influence treatment outcomes and patient expectations. It is important that patients understand UCL revisions are associated with inferior outcomes compared with primary reconstruction and that they may not return to play at the same pre-injury level of competition [6].

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31.2 Indications

Indications of revision UCL reconstruction are similar to primary UCL reconstruction, including pain with valgus stress, positive moving valgus stress test, greater than 1 mm of relative valgus laxity on stress radiographs or ultrasound, and complete tears of the UCL in MRI (Fig. 31.1).

31.3 Contraindications

There are no absolute contraindications of UCL reconstructions reported in the literature, except general contraindications such as infection, nerve injury, flexor-pronator muscle deficiency, and so on. Risk factors leading to revision UCL reconstruction were reported in baseball players (Table 31.1).

31.4 Author Preferred Technique/ Procedure

31.4.1 Preoperative Planning

Given that the patient has already had a prior UCL reconstruction, details regarding surgical technique, graft type, flexor-pronator repair/ debridement, olecranon osteophyte resection, and any concomitant procedures are imperative to know when considering revision surgery.

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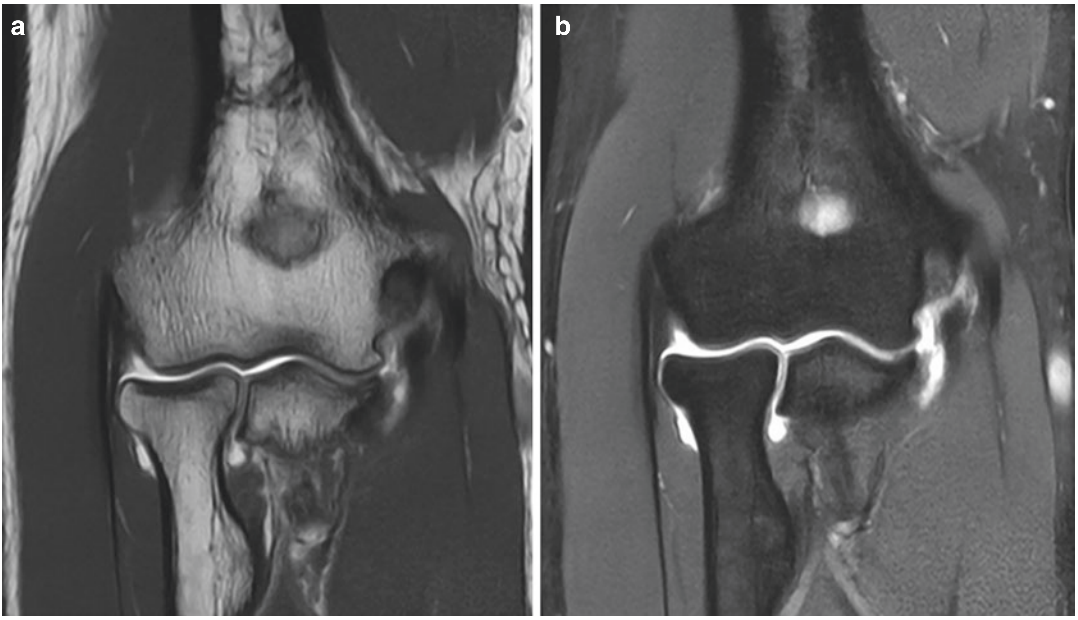

Fig. 31.1 Ruptured reconstructed UCL on the humeral side. (**a**) T1 signal intensity, (**b**) T_1 Fat sat signal intensity

Table 31.1 Risk factors associated with UCL revision [5, 7]

1. Younger age at initial reconstruction
2. Shorter status
3. Increased frequency of fastball use
4. Less experience in major league baseball before initial reconstruction
5. Fewer pitches thrown throughout first year after initial reconstruction
6. Longer time to return to play after initial reconstruction
7. Increased post-reconstruction number of games pitched, compared with pre-reconstruction
8. Decreased post-reconstruction number of innings pitched compared with pre-reconstruction

Information about ulnar nerve decompression and/or transposition associated with the primary procedure is critical, as is the type of transposition. Furthermore, detail of the patient's previous therapy and throwing rehabilitation following their primary surgery should be discussed, as this may represent an area needing adjustment.

The physical examination of the patient with a failed UCL reconstruction is largely consistent with evaluation at the time of index injury. However, key differences include palpation along the length of the UCL to determine the specific location of any tears, such as humeral vs. ulnar-side graft failure, and any gross postoperative changes. The integrity of the UCL graft should be assessed by performing maneuvers that place the elbow under valgus stress: opening of the medial aspect of the joint more than 1 mm is abnormal and may indicate partial or complete graft failure [8, 9].

In order to perform a thorough nerve examination, which includes the Tinel test, and assessment of nerve stability throughout elbow motion, information about the initial procedure is helpful. The flexor/pronator muscle group is a secondary stabilizer to valgus stress at the elbow. Flexor/pronator muscle group strength testing and palpation of its origin on the medial epicondyle should therefore be performed.

Stress radiographs can be used to compare medial joint opening with valgus stress. For this comparison, stress radiographs should be obtained of both elbows. However, recent studies have shown that pitchers with symptomatic UCL injuries have a valgus opening similar to that of asymptomatic pitchers, calling into question the relevance of such stress radiographs [10, 11].

MRI is the ideal image modality to best assess soft tissue structures and status of the UCL graft; however, the appearance of the primary UCL graft through the healing and ligamentization process has not yet been fully characterized. Therefore, the appearance of the graft and overall utility of MRI will vary depending on the amount of time elapsed since the primary surgery. Furthermore, analyzing the integrity of the graft may be difficult in the presence of metal artifacts. In recent years, there is growing support to use ultrasound evaluation of UCL injuries, as it allows for a dynamic assessment of the instability [9, 12, 13] (Fig. 31.2).

Given the variability in surgical techniques, tunnel configurations, and the amount of bone removed at the time of primary UCL reconstruction, a computed tomography (CT) scan with

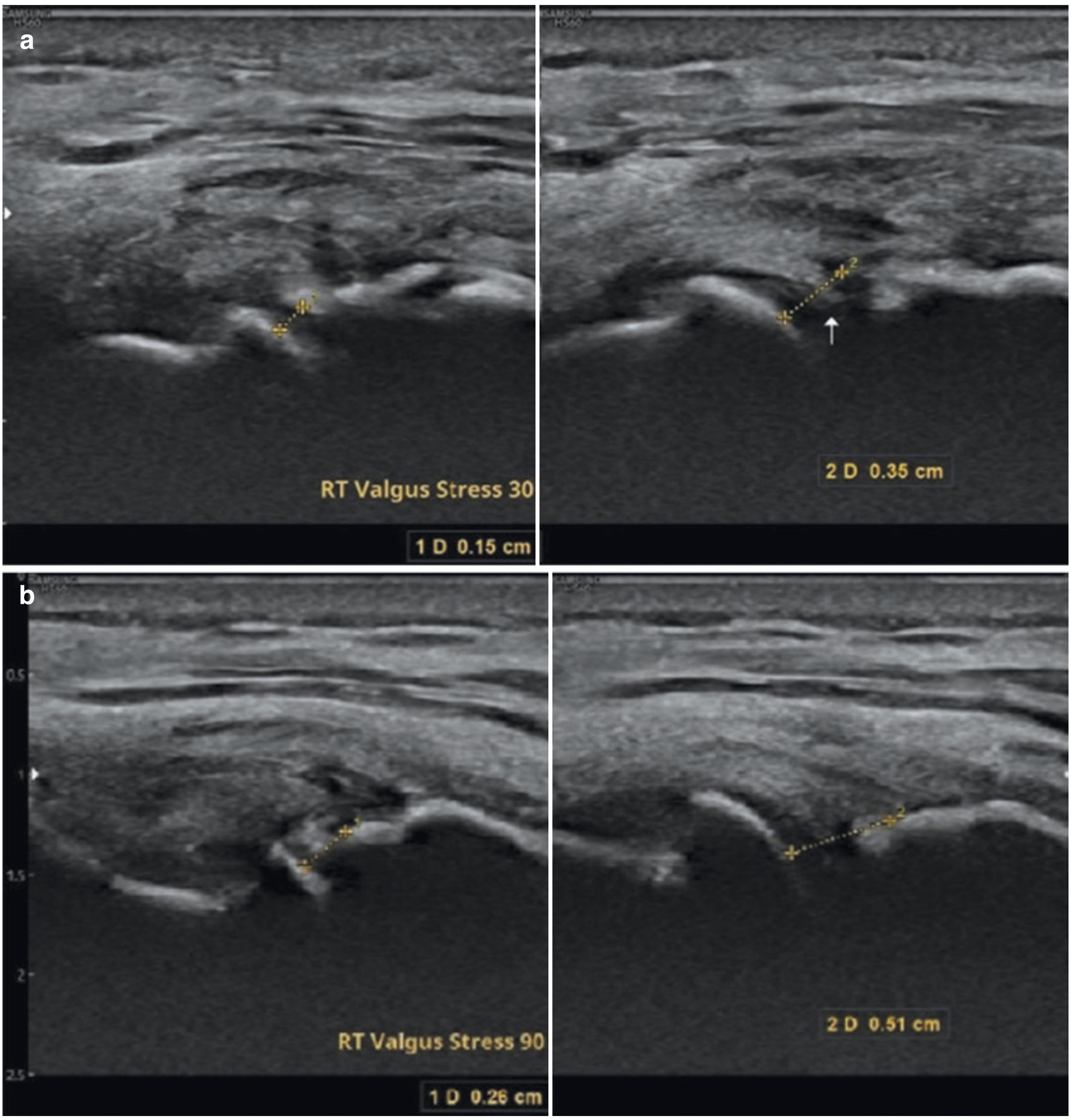

Fig. 31.2 Stress ultrasound. Opening of the medial aspect of the joint more than 1 mm is abnormal and may indicate partial or complete graft failure when compared with contralateral elbow. (**a**) Medial gap formation in valgus stress view in 30° flexion, (**b**) medial gap formation in valgus stress view in 90° flexion

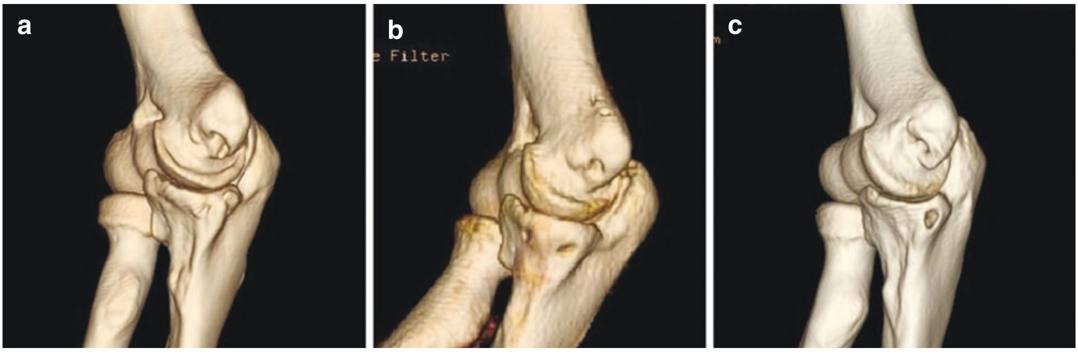

Fig. 31.3 A computed tomography scan will provide the exact location of the prior ulnar and humeral tunnels as well as the bone quality of these tunnels. (**a**) Figure of eight technique, (**b**) Docking technique, (**c**) DANE TJ technique

three-dimensional reconstructions may be needed to further evaluate remaining bone stock and tunnel geometry [14]. The CT scan provides the exact location of the prior ulnar and humeral tunnels, as well as the bone quality of these tunnels [15] (Fig. 31.3).

31.4.1.1 Patient Positioning

The procedure can be performed under regional anesthesia with or without sedation or general anesthesia. The patient is placed supine with the operative arm extended onto an arm table and a (sterile) tourniquet applied to the upper arm. If gracilis tendon autograft is to be used, the ipsilateral or contralateral leg must be prepped with a tourniquet placed proximally on the thigh.

31.4.2 Approach

The previous surgical incision often can be used for the revision procedure. Extra care is required when looking for the medial antebrachial cutaneous and ulnar nerves because scarring from the initial surgery can distort the anatomy and make it difficult to identify the nerves (Fig. 31.4).

31.4.3 Graft Selection

As for the index procedure, different grafts can be used for the revision surgery. Both allografts and autografts have been described. For primary UCL reconstruction, a palmaris autograft often is the graft of choice. In patients in whom this graft was used for the index procedure, some surgeons may now use a gracilis autograft for the revision surgery. Other options include a contralateral palmaris longus autograft, triceps tendon, or an allograft tendon. The gracilis graft has a larger diameter than a palmaris longus tendon, which should provide increased initial strength. The disadvantage of a larger diameter graft is that larger drill holes are required, which could increase the risk of ulnar tunnel or medial epicondyle fracture.

31.4.4 Step-by-Step Description of the Technique

The initial surgical technique, residual anatomy, and the cause of failure dictate the revision surgical technique. Tunnel widening is less common in revision UCL reconstruction than in revision anterior cruciate ligament (ACL) reconstruction, most likely because the tunnels are extra-articular and are not bathed in articular fluid (Fig. 31.5). Therefore, bone grafting and staged procedures are rarely necessary. However, revision UCL reconstruction is a technically demanding procedure as a result of scarring, formation of adhesions, and distorted anatomy.

When UCL reconstruction failure appears to be caused by mid-substance graft laxity or a tear, the same surgical technique used for the primary procedure may be used, assuming good tunnel position and bone stock are present. However, the

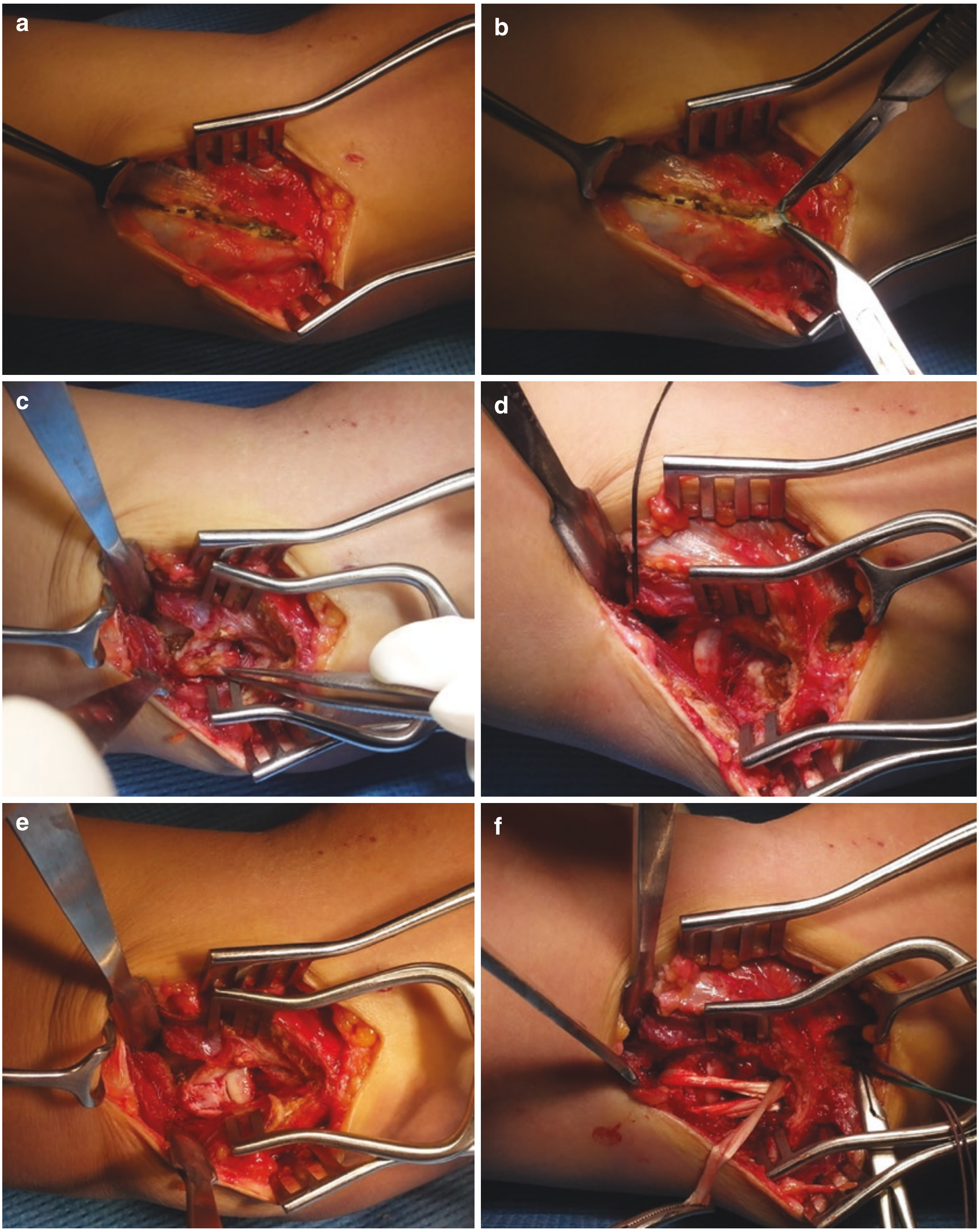

Fig. 31.4 (**a**) The previous surgical incision often can be used for the revision procedure. (**b**) Muscle fibers are split from the medial epicondyle to sublime tubercle. Previous suture materials can be removed. (**c**) In most cases, the initial graft tissue is still present and hypertrophied, as the UCL graft and native UCL are scarred together in a thick mass. (**d**) The graft often needs to be debulked to make new tunnels and pass a new graft. (**e**) The medial ulnar ridge is a consistent palpable ridge distal to the sublime tubercle and is a useful guide to the proper tunnel location of the sublime tubercle. (**f**, **g**) Three passage docking techniques with palmaris longus

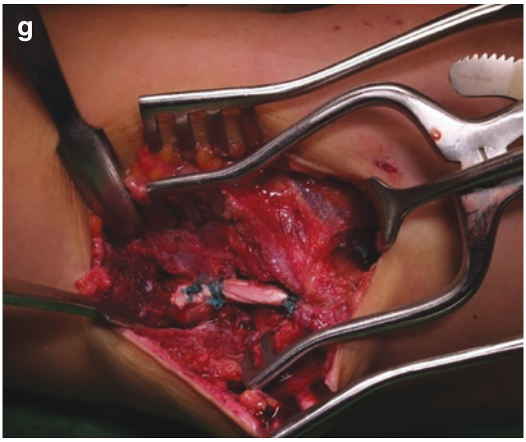

Fig. 31.4 (continued)

surgeon must thoroughly inspect the original tunnels for cortical thinning, bone loss, and/or fracture, which could make a classic bone tunnel technique a poor option.

The docking technique is commonly used in primary UCL reconstruction. Some believe there is less risk for medial epicondyle fractures using the docking technique, which requires one humeral tunnel with the ribs tied over a bone bridge [16]. Another theoretical advantage over a figure-of-8 technique is the preservation of more proximal cortical bone stock, which may allow for more options during revision surgery.

The previous incision is reused, and care is taken during ulnar nerve neurolysis and handling because the nerve is often scarred and adherent to surrounding tissues. Flexor-pronator muscle fibers are split from the medial epicondyle to sublime tubercle (Fig. 31.4b). In most cases, the initial graft tissue is still present and hypertrophied, as the UCL graft and native UCL are scarred together in a thick mass. The graft often needs to be debulked to make new tunnels and pass a new graft (Fig. 31.4c, d). After graft passage, the original graft and UCL tissue are closed to allow for added collagen and healing to the overall revision UCL construct, similar to the repair of an UCL in a primary procedure.

Malpositioned tunnels can result from poor surgical exposure and also from abnormal bone anatomy. The ulnar bone tunnels should ideally be located distal to the joint line and equidistant on both sides of the sublime tubercle with adequate bone bridges. Sublime tubercle morphology can change because of enthesophyte formation and, often, this abnormal bone is more hypertrophic posteriorly. The medial ulnar ridge is a consistent palpable ridge distal to the sublime tubercle and is a guide to proper tunnel location on the sublime tubercle [15] (Fig. 31.4e).

During surgery, small curettes can be used to identify prior tunnels on the ulna, both anterior and posterior to the sublime tubercle and inferior epicondyle on the humerus. If tunnel positions are normal and bone quality allows for an adequate bone bridge, then these tunnels are reopened (Fig. 31.4f, g). If the position of the original tunnels is inadequate, then these tunnels are ignored and new tunnels are created in the anatomic position (Fig. 31.6).

At the end of the procedure, it is important to let the tourniquet down prior to closure, to obtain hemostasis and prevent hematoma and formation of adhesion, especially around the ulnar nerve. With revision surgery, the scar tissue can bleed excessively, and placement of a small Hemovac drain may help prevent hematoma formation, although this has not been proven.

31.4.5 Techniques to Address Ulnar Bone Loss, Insufficiency, or Fracture

During revision surgery, ulnar-sided bone loss, fracture, or sublime tubercle insufficiency can be encountered. When the bone bridge is broken, another bone tunnel along the sublime tubercle on ulna may be possible (Fig. 31.7). If not, a cortical button technique on the ulnar side can also be used in the setting of ulnar cortical bone loss of fracture [17] (Fig. 31.8). In this technique, the single ulnar-sided drill hole is started on the sublime tubercle at the UCL insertion and aimed 30° posterolateral to avoid the posterior interosseous nerve. The cortical button is locked on the ulnar and then tensioned on the humeral side with a docking technique. Another ulnar-side revision

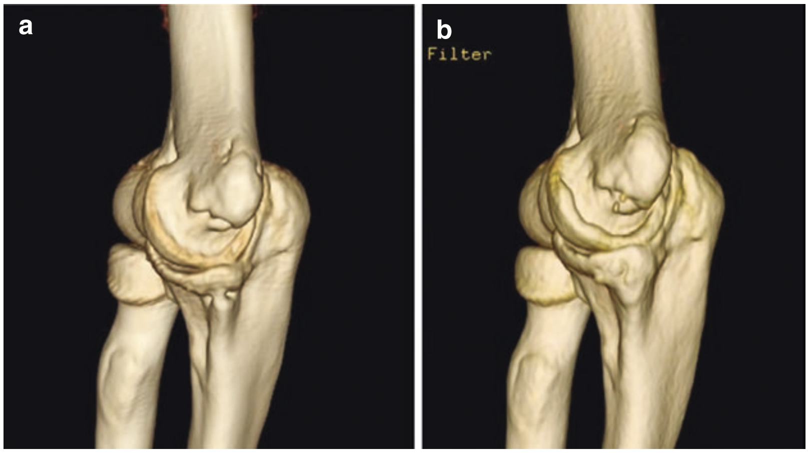

Fig. 31.5 Tunnel widening is less common in revision UCL reconstruction. (**a**) Initial three-dimensional C.T. (**b**) Ulnar tunnel is obliterated 4 years later

Fig. 31.6 If malpositioned tunnels are encountered and are significant distance from the normal position, then the original tunnels are ignored and new tunnels are created in the anatomic position

option for ulnar bone insufficiency is to use a single drill tunnel at the insertion and secure the graft with an interference screw [16].

Fig. 31.7 When the bone bridge is broken, another bone tunnel along the sublime tubercle on ulna can be possible

31.4.6 Complications and Management

Revision UCL reconstruction has a high rate of complications, because of the formation of scar tissue and adhesions, distorted anatomy, and the presence of a compromised soft-tissue envelope because of the primary procedure. The type of

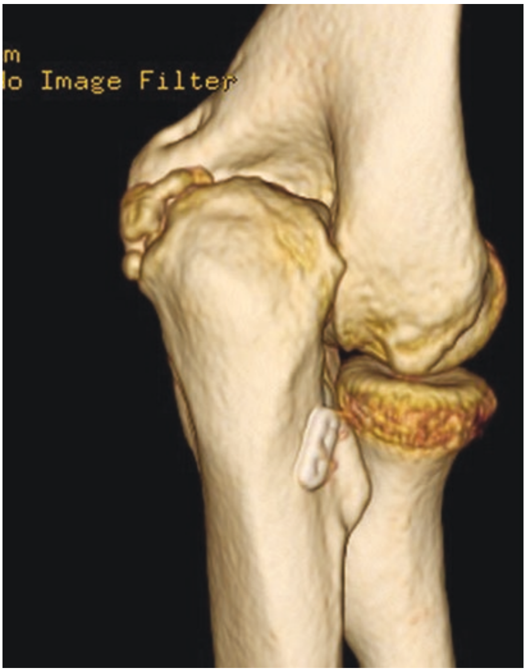

Fig. 31.8 Cortical button technique on the ulnar sided is useful for revision UCL reconstruction in the setting of ulnar cortical bone loss of fracture

complications seen is similar to those observed after primary reconstruction, including transient ulnar nerve neuropraxia, medial epicondyle fracture, stiffness, heterotopic ossification, graft or implant failure, and continuous pain [2, 5, 18].

31.4.7 Postoperative Care

A less aggressive postoperative rehabilitation protocol should be used after revision UCL reconstruction. Many aspects of rehabilitation are delayed after a revision procedure compared with a primary UCL reconstruction, including removal of the posterior splint (at 10 days vs. 5 to days postoperatively) and initiation of a throwing program (at 6 months vs. 4 months). Full recovery after revision UCL reconstruction compared with primary reconstruction is expected at 1.5 years vs. 1 year.

After primary UCL reconstruction, guidelines for injury prevention also recommend appropriate rest and recovery between pitching episodes. Some research has shown that splinting and rehabilitation work at 90° of flexion places more strain on a graft when compared to full extension to 50° [19]. Throwing at maximum distance (i.e., long toss) during the interval throwing program is discouraged because of alterations in kinematics causing increased graft strain [20].

31.4.8 Outcome

Data on outcome of revision UCL reconstruction are limited; however, research has shown that the results after revision surgery are not as successful as those after primary reconstruction. Dine et al. found that 5 of 15 pitchers (33%) returned to pre-injury level for at least one season after revision but noted a substantial rate of complications (40%) [6]. Interestingly, major league (MLB) pitchers had better odds of returning to play than minor league pitchers (75% vs. 14%).

The largest study to date on revision UCL reconstruction in MLB players reported on the outcomes of 33 pitchers. Of 29 pitchers who underwent revision surgery, 19 (65.5%) returned to play at the professional level [21]. Although pitchers who underwent revision UCL reconstruction had earned run averages and walks/hit per inning pitched, similar to those of the age- and position-matched control group, their careers were 0.8 years shorter and they had decreased number of wins and innings pitched.

Liu et al. reviewed a cohort of 235 MLB pitchers treated with UCL reconstruction and noted that 13% underwent revision surgery; 37% had the revision procedure within 3 years after the primary reconstruction [22]. Only 42% of pitchers returned to pitch >10 games, and those who returned to the professional level required 21 months to return. Pitchers who underwent revision reconstruction had a shorter career, pitched fewer innings, and had fewer total pitches per season than an age- and position-matched control cohort.

Wilson et al. reviewed available data for 271 professional pitchers who underwent UCL reconstruction from 2007 through 2014 [1]. They found that the average length of career after primary UCL reconstruction was 4.9 years, whereas the length of career after revision UCL surgery was only 2.5 years. Of the 271 pitchers included in the study 40 (15%) required some type of revision surgery.

The incidence of primary UCL reconstructions among professional pitchers is increasing; however, the rate of primary reconstruction requiring revision is decreasing [1]. There are some reasons; first of all, improved surgical techniques may have contributed. Enhancement of rehabilitation protocols and development of safe throwing exercises may have also improved the elbow UCL reconstruction revision rate among MLB pitchers. Another reason for the decrease in UCL reconstruction revision rate in recent years may be explained by the shorter follow-up period. Finally, in the early era of the procedure, a higher percentage of patients with chronic injuries were elected for revision surgery owing to persistent symptoms after reconstruction. As the procedure became common and was performed on more acute injuries, outcomes for primary surgery improved and revision rates decreased.

31.5 Summary

As the rate of primary UCL reconstruction increases, there has been a corresponding increase in the rate of UCL revision as well. Many of the same techniques used for primary reconstruction can be used in revision surgery; however, the technique may need to be modified or adapted on a case-by-case basis, which emphasizes the importance of careful preoperative evaluation.

When ulnar-side bone is compromised from prior surgery, revision can still be considered if the previous bone tunnels can be utilized, spanned, or avoided altogether. When the bone bridge is broken, another bone tunnel along the sublime tubercle on the ulna may be possible. When bone defects are substantial, a cortical button technique or interferential screw technique with a single ulnar tunnel can be considered.

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32

Failed Tennis Elbow Surgery Syndrome (FTESS)

In-Ho Jeon and Erica Kholinne

32.1 Introduction

The management of tennis elbow is largely conservative and surgical intervention is usually indicated for specific group of patients. When surgery is performed under appropriate surgical indication, the anticipated satisfactory rate is 90% and favorable results are recognizable within a year [1]. Patients may be left with residual pain. The management of failed tennis elbow surgery syndrome (FTESS) can be equally challenging to surgeons, pain specialists, and general physicians.

The management of failed tennis elbow surgery is relatively unknown. The aim of this chapter is to determine the causes of failed tennis elbow surgery and to provide a systemic management approach in order to address this problem.

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32.1.1 Failed Tennis elbow Surgery Syndrome (FTESS)

Failed tennis elbow surgery syndrome (FTESS) can be defined as a collection of patients' signs and symptoms associated with new or persistent pain in the lateral elbow following tennis elbow surgery. However, not all patients who present with persistent pain following tennis elbow surgery had a proper initial diagnosis, properly performed surgery, and pain necessarily due to the surgery. As FTESS is not specific to a particular diagnosis which causes the pain, it is not considered a disease entity and additional treatment may be not always benefit the patient. An appropriate assessment of the patient is needed to distinguish persistent pain following the surgery from differential diagnoses such as instability, radio-capitellar arthritis, plica and chondromalacia of the radial head or capitellum.

32.2 Clinical Evaluation

History taking is the first and most critical step in assessing this patient group. Initial duration of symptoms, traumatic episode, and treatment received should be reviewed. In many cases patients have not been given sufficient time to rehabilitate following the index surgery. Patients' compliance with the rehabilitation program also needs to be established [2]. If there is no change

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Table 32.1 Failed tennis elbow surgery syndrome classification

Type I Wrong patient and diagnosis	Type I a: Inappropriate patient selection for the initial surgical procedure leads to a poor outcome (e.g. patients' psychosocial circumstances such as litigation and workers' compensation; unreasonable patient expectations) Type I b: Inadequate imaging studies or incomplete preoperative assessment
Type II Wrong surgery	Type II a: Failure to address all aspects of the patient's pathology (e.g. incomplete resection of pathologic tissue, missed intra-articular pathology) Type II b: Technical problems associated with the index procedure (e.g. iatrogenic injury)
Type III Wrong time	Inadequate time for proper rehabilitation

Table 32.2 Summary of factors for failed tennis elbow surgery syndrome (FTESS)

Preoperative factors	Patient factors – Psychological: Depression, hypochondriasis, noncompliance with rehabilitation program – Social: Litigation, worker's compensation – Cervical spine pathology Surgical factors – Revision surgery – Tennis elbow with associated pathology (e.g. instability)
Intraoperative factor	Inadequate removal of pathologic tissue, iatrogenic injury
Postoperative factors	New pathology Complications of surgery Myofascial pain development Complex regional pain syndrome Neuroma

in symptoms after 6–9 months following the index surgery without any compliance or compensation issues [3], then the problem may be further explored. The subsequent pivotal question is whether the presenting symptoms are any different from the initial symptoms for which the index surgery was performed. Table 32.1 shows the classification of FTESS.

32.3 Etiology

Based on the time frame of the procedure, the etiology of FTESS is summarized in Table 32.2.

32.4 Diagnostics

32.4.1 Type I: Wrong Patient and Diagnosis

32.4.1.1 Type Ia: Wrong Patient

Diagnosing tennis elbow in the wrong patient is a common pitfall. During history taking and examination, psychological assessment may be conducted on patients for suspected depression, hypochondriasis, or uncooperativeness. A systematic review in spinal surgery has demonstrated that depression is a strong prognostic indicator of a negative outcome after surgery [4]. Depressed patients generally feel more pain and weakness, as well as return to work at a significantly lower rate compared with their non-depressed counterparts. There is also some speculation that occupation may contribute to the cause of tennis elbow. A review of 108 patients with tennis elbow who were also litigants showed disappointing outcomes following surgical and non-surgical treatment [5]. The "mesenchymal syndrome" should always be considered as well, in which patients appear to develop multiple related conditions including lateral and medial epicondylitis, Achilles tendinopathy, rotator cuff pathology, and carpal tunnel syndrome due to genetic predisposition to abnormal collagen formation. Furthermore a careful look at the cervical spine is necessary to differentiate the pain arising from cervical spine compared to those from lateral epicondylitis. The clinical overlap between cervical radiculopathy and lateral epicondylitis should be understood by all practitioners [6].

32.4.1.2 Type Ib: Wrong Diagnosis

As a rule of thumb, a lack of response after local injection of anesthetic agent in the area of maximum tenderness confirms a type Ib failure. Conversely a complete relief after local anesthetic injection suggests a type IIa failure. Lateral elbow pain is the most common presentation of elbow pain. The exact cause of the pain should be reviewed with a focus on differential diagnoses such as lateral epicondylitis, synovial plica, osteochondritis dissecans, radio-capitellar arthritis, and posterolateral rotatory instability. In terms of trauma, lateral epicondylitis is associated with a minor repetitive strain. This should be distinguished from radial tunnel syndrome. A reliable triad in diagnosing radial tunnel syndrome is [1] pain resulting from direct palpation of the arcade of Frohse, [2] pain aggravated by resisted supination, and [3] relieved by local anesthetic injection [1]. A negative result from electromyography will confirm the diagnosis of radial tunnel syndrome. In rare cases, posterior interosseous nerve strangulation by cyst or compression should be considered as well (Fig. 32.1).

Lateral elbow pain in a relatively young patient may be associated with osteochondritis dissecans or plica. Synovial plica is carefully assessed by the snapping of the radio-capitellar joint during the prono-supination movement (Figs. 32.2 and 32.3) and is confirmed by MRI and a diagnostic arthroscopy [7]. An anterior plica will typically aggravate painful snapping during pronation-flexion, while a posterior plica will give symptoms in supination-extension position. Intra-articular injection of 4–5 ml of an anesthetic agent can help to rule out synovial plica if response is negative. Underdiagnosed synovial plica may present concurrently with tennis elbow because of the continuity of the enthesis and radio-capitellar capsule. The key point is to notice whether there is any presence of painful lateral elbow joint snapping, observed and felt with palpation at the joint line during elbow movement [8]. Improper patient selection should be taken into account for those with compensation issues, poor motivation, or compliance [9].

32.4.2 Type II: Wrong Surgery

32.4.2.1 Type IIa: Inadequate Removal of Pathology

"Finish what you started" is a wise word as incomplete surgery treatment is the most common cause of failed tennis elbow surgery [1, 2]. This is especially common when a minimal invasive surgery was attempted and resulted in inadequate removal of pathologic tissue. A systematic "inside-out" approach based on the radial head equator as the reference is important to avoid this. Nirschl and Pettrone reported 27 out of 35 patients underwent secondary surgery to address the residual lesion, which resulted in a successful outcome in 83% of cases (Fig. 32.4). In type IIa cases, clinical examination will reveal classic symptoms consistent with lateral epicondylitis.

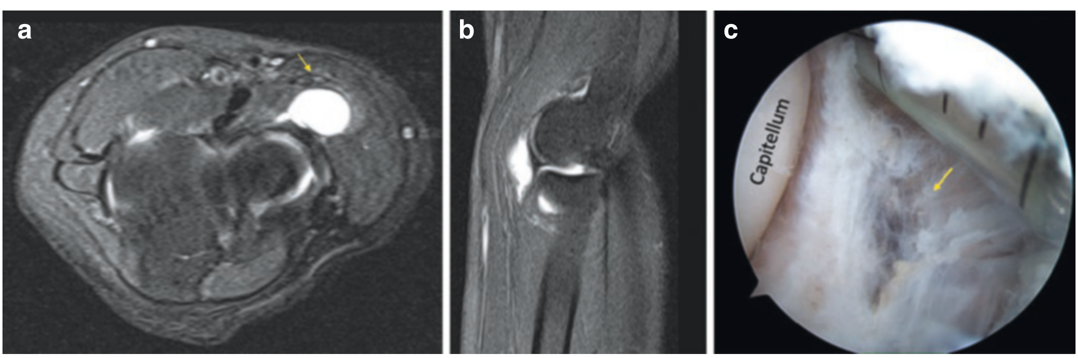

Fig. 32.1 (patient no: 57130885) A 48-year-old lady presenting with a persistent lateral elbow pain for more than 7 months. She was initially diagnosed with tennis elbow and underwent conservative treatment. The T2 weighted MRI (**a**, **b**) shows a ganglion cyst in front of the radial head which compresses the posterior interosseous nerve (yellow arrow). Arthroscopic figure (**c**) from a proximal anteromedial portal view shows cyst decompression through cyst wall (yellow arrow) debridement

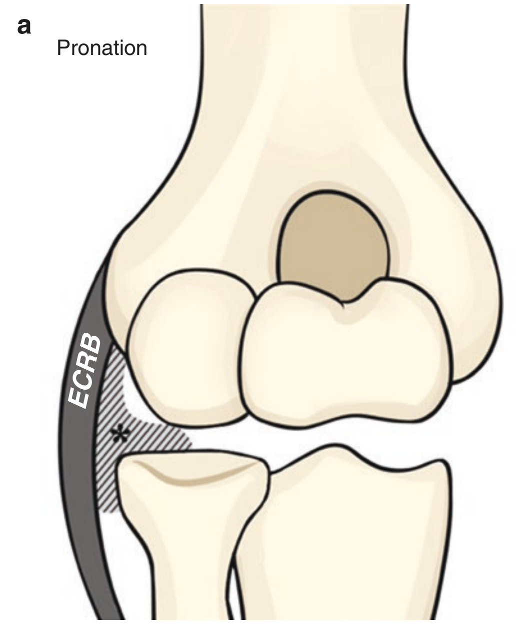

Fig. 32.2 Illustration shows the pathology of symptomatic plica. An articular capsule tear changes the normal tension of the annular ligament, resulting in "piston-like" movement that leads to a hypermobile plica (*), which occupies the radio-capitellar joint in the pronation position (**a**) and is released from the radio-capitellar joint in the supination position (**b**). ECRB = Extensor carpi radialis brevis

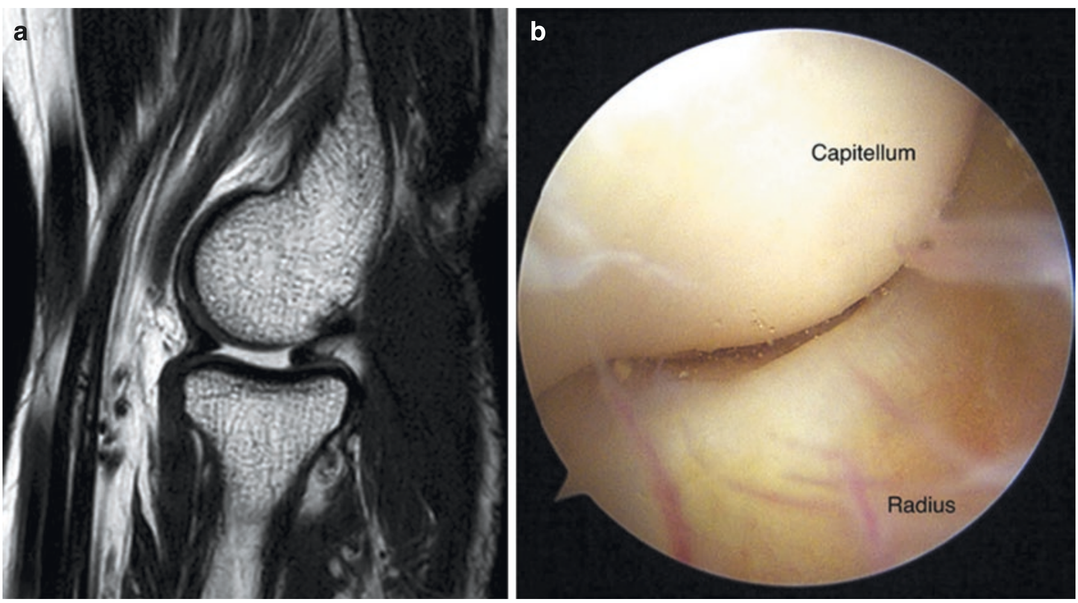

Fig. 32.3 A 56-year-old lady presenting with a persistent lateral elbow pain for more than 6 months which failed conservative treatment. The T2-weighted MRI showed a posterior plica at the radio-capitellar joint (**a**) which correspond to the arthroscopic view which show a meniscocapsular complex which partially radial head (**b**). The patient underwent resection of the upper portion of the annular ligament as a part of modified Bosworth procedure. The procedure converts once a type III to type I meniscocapsular complex. *C* capitellum, *RH* radial head

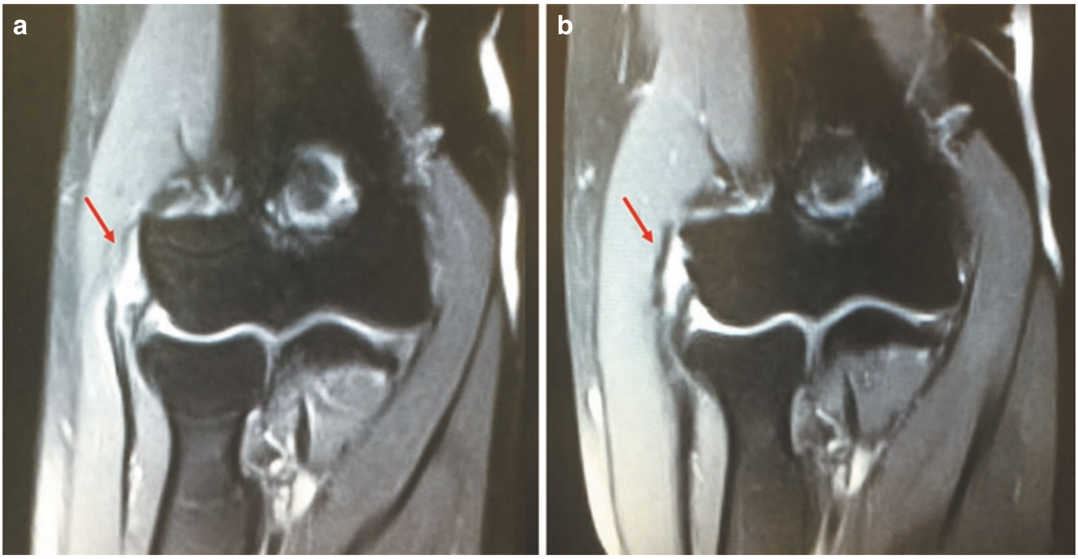

Fig. 32.4 T2 weighted MRI shows a high intensity signal underneath the ECRB origin which presented before the surgery (**a**) and which remained after tennis elbow surgery (**b**) indicating incomplete treatment

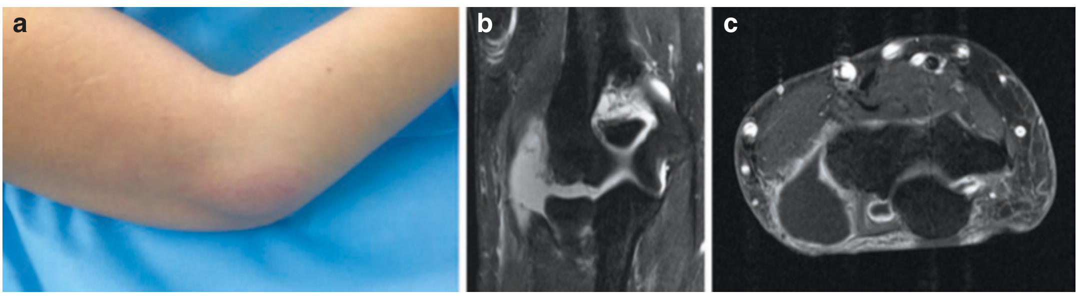

Fig. 32.5 Image shows a large palpable mass at the lateral aspect of the elbow (**a**). MRI shows pseudocyst caused by synovial fistulas (**b** and **c**)

32.4.2.2 Type IIb: Iatrogenic Cause

The presenting symptoms are different from those before the index surgery. The diagnosis is more commonly associated with the surgical treatment itself. An example of type IIb is synovial fistulas (Fig. 32.5), which can result from excessive excision of pathologic tissue. One can expect a large defect of the lateral aspect of the elbow following debridement of synovial fistulas. Anconeus muscle transposition is a viable option for soft tissue filling in salvaging failed tennis elbow surgery (Fig. 32.6) [10].

The other iatrogenic complication is ligament insufficiency (Fig. 32.7). Ligament insufficiency results from iatrogenic injury to the lateral ulnar collateral ligament (LUCL) from either an open or arthroscopic tennis elbow surgery. The debridement of pathologic tissue may be “too generous” when it includes the overly common extensor origin [11]. Additionally, an aggressive debridement of common extensor origin or posterolateral plica with the overly capsule and anconeus muscle may lead to subtle instability. This will subsequently destabilize the elbow joint. In an arthroscopic

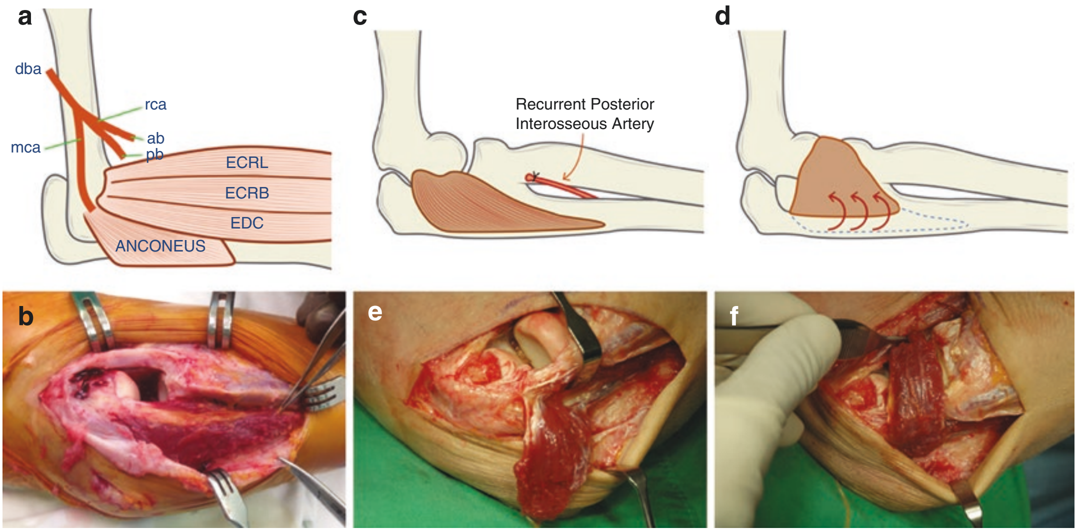

Fig. 32.6 Illustration of the vascular supply to the lateral elbow muscles (**a**): *DBA* deep brachial artery, *MCA* medial collateral artery, *RCA* radial collateral artery, *AB* anterior branch, *PB* posterior branch, *ECRL* extensor carpi radialis longus, *ECRB* extensor carpi radialis brevis, *EDC* extensor digitorum communis. Excessive soft tissue defect (**b**) was debrided and treated with anconeus muscle transposition (**c**–**f**)

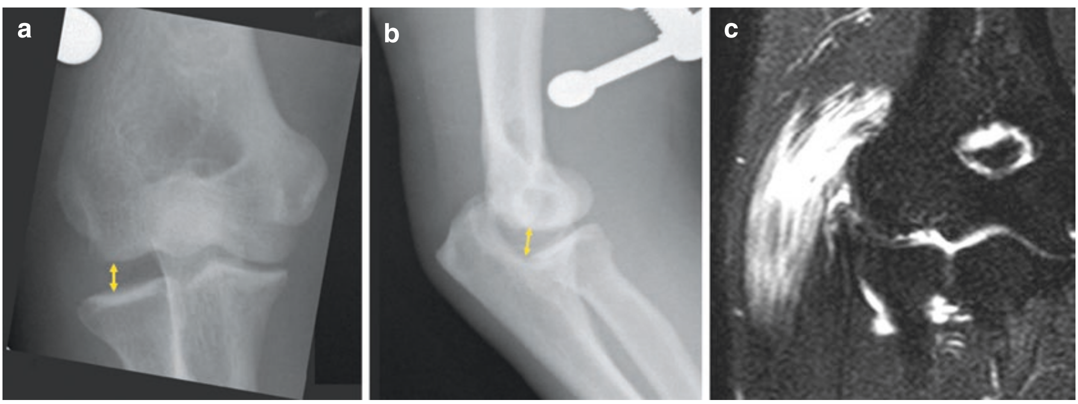

Fig. 32.7 Instability following tennis elbow surgery reveals positive provocation for the varus stress and pivot shift tests (**a**, **b**). MRI shows non-visualized LUCL (**c**)

approach, the debridement of capsule and common extensor tendon origin maneuver posterior to the radial head equator may put the LUCL at risk because the common extensor origin and lateral collateral ligament complex merged together in a narrowed space.

32.4.3 Type III: Wrong Time

Postoperative rehabilitation of tennis elbow surgery is the last but not least factor in determining treatment success. Generally, the elbow will be protected in an immobilizer for 1 week which allows the active use of wrist, hand, and shoulder. Gentle active range of motion exercise will start the following week. We recommend to the patient to maintain the arm at the side position as this will reduce any varus force to the affected elbow until the third week when the endurance and muscle-strengthening exercise start. The patient is allowed to start sport-specific exercise from 6 weeks. Full strength will only return from 4 to 6 months after surgery, hence it is only then full racquet and competitive throwing sport activities are recommended. Active communication between the patient, surgeon, and therapist is key to ensure proper rehabilitation takes place following surgery.

32.5 Treatment

Once the cause of the persistent pain has been determined, the question arises as to what indication was warranted to perform a revision surgery. A revision surgery may be warranted (absolute indication) for those patients with obvious instability or fistula. A relative indications to the revision surgery are [1] recurrent episode of incapacitating with subtle instability and [2] severe pain persists or worsen despite 6 months of rest. Perhaps there is also an uncertainty on how much time is allowed before additional intervention may be considered. The length of time from surgery to recovery is not often reported; therefore, the threshold time before intervention in a failed tennis elbow case is controversial. A review of the literature suggests successful outcome from surgical procedure will be evident within the first 3 months. Posch et al. [12] reported that only one of the 43 patients improved more than 1 year following the index surgery. However, Morrey suggested that 6 months waiting time is reasonable for the “honest” patient [3]. Conversely, if symptoms have changed after the index surgery, particularly if an instability pattern is diagnosed, it is not reasonable to expect improvement, hence surgery is offered. In a type Ib failure, a “wait and see” approach is generally taken. Further investigation is mitigated if local anesthetic injection does not relieve the symptoms. In a type IIa failure when the lesion is “missed,” surgical treatment is offered to the patient after 6 months of waiting time. In a type IIb failure, especially when instability has occurred, surgery should be offered as soon as the diagnosis is made. Figure 32.8 depicts the algorithm for managing failed tennis elbow surgery.

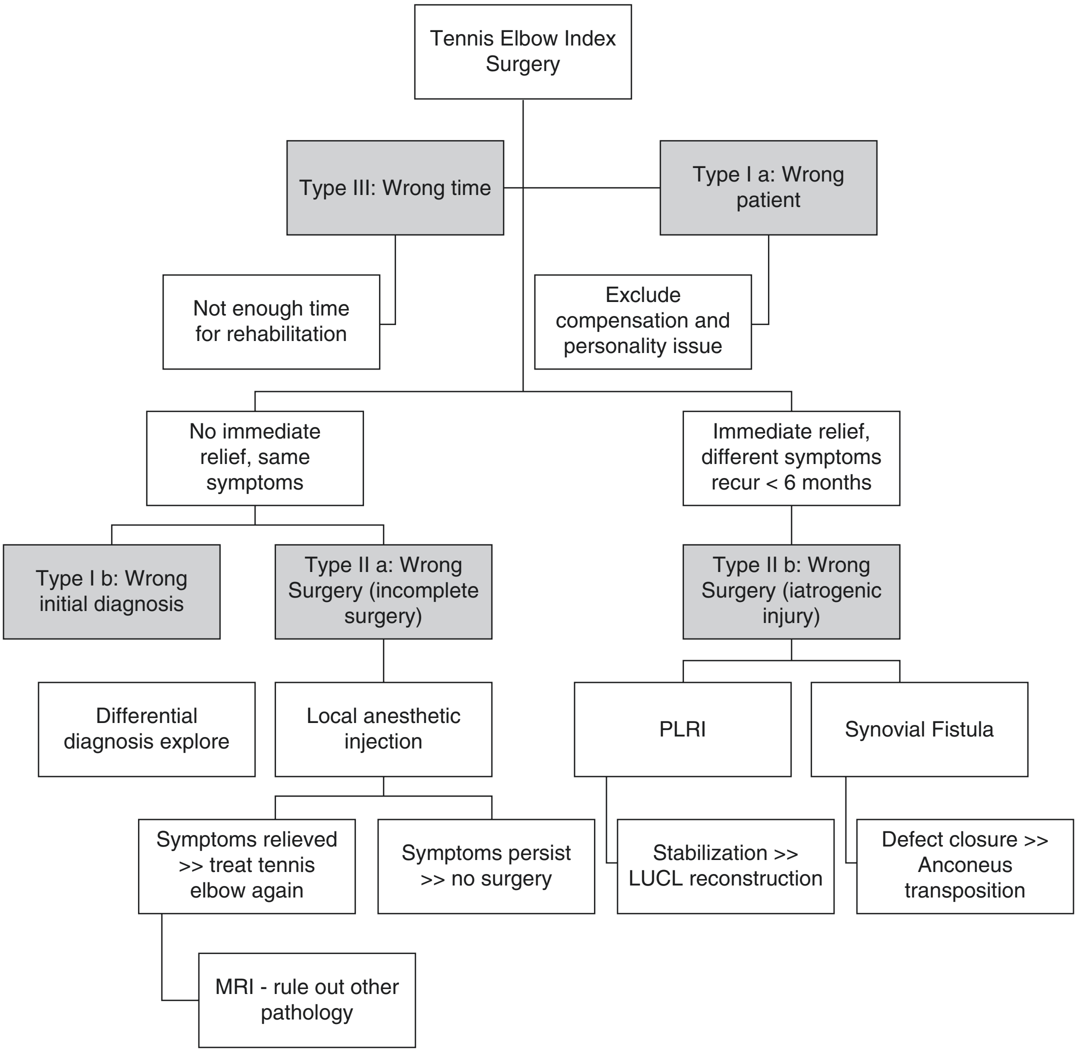

Fig. 32.8 Algorithm for the management of FTESS

32.6 Conclusions

Failed tennis elbow surgery syndrome can be perceived from different perspectives. From the surgeon's perspective, it is when surgery fails to deliver relief to the patient. However, to the patient, it is when surgical treatment fails to alleviate their problem, which may differ from person to person. Hippocrates once said, "it is far more important to know what person the disease has than what disease the person has." If we merely look at the disease but not the person, we may not be able to understand the reasons why the initial surgery has failed. When dealing with failed tennis elbow surgery, one should always remember to give the patient "enough time" to recover, treat the "right pathology" of the "right patient" with the "right diagnosis." The algorithmic approach with these simple concepts in mind will ease the way we deal with failed tennis elbow surgery.

Key Points

1. Revision surgery for failed tennis elbow surgery syndrome should only be considered in patients who have proven pathology with

diagnostic studies and a failure to respond to conservative treatment.

2. If poor surgical outcomes are due to definite or clear errors in surgical strategy or surgical technique associated with the index procedure, appropriate revision surgery may offer a reasonable chance for improved outcome.
3. For surgical failures due to errors in diagnosis or inappropriate patient selection for index surgery, revision surgery offers minimum chance for improved outcome.
4. In the absence of relevant specific anatomical and pathological findings, pain itself is not an indication for revision surgery.
5. A reasonable improvement and return to normal activities of daily living can be achieved by discussing realistic expectations prior to the revision surgery.

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Distal Biceps Tendon Endoscopy

33

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33.1 Basic Science

An understanding of the basic sciences of anatomy and pathology of the distal biceps is key to obtaining a good outcome with endoscopy.

33.1.1 Anatomy

As an important flexor of the elbow and the main supinator, the biceps brachii muscle is composed of two distinct muscle bellies which are continuations of a long and short head. The bellies interdigitate, but continue as the long and short components of the distal biceps tendon (DBT), with equal contributions, and insert into the radial bicipital tuberosity (BT), proximally and distally, respectively [1, 2]. In some cases, however, they may insert as a single tendon in a single C-shaped attachment area or with a predominantly short tendon contribution [3]. The DBT footprint has been described as 'ribbon-shaped' or 'oval' and up to 88% of people may have a variable ridge, radial to the DBT insertion [4, 5].

The BT is a protuberance 3–4 cm distal to the radial head, on the ulnar side. On average, it is 16 mm thick, 23 mm long, and 13 mm wide [3]. The BT varies in shape and size, as do the footprints of the individual heads, which can cause impingement against the ulna during repetitive rotation of the radius, especially as the radioulnar space is significantly reduced in pronation [3, 6]. Further narrowing of radioulnar space from postoperative thickening of the tendon and certain fixation/augmentation techniques can also cause impingement, but could be avoided by using a reattachment site at the proximal aspect of the tuberosity and avoiding these techniques [3].

The DBT arises from the musculotendinous junction and runs through the cubital fossa to insert more distally into the radial tuberosity. Importantly for portal placement, the distal biceps tendon originates 3 cm proximal to the anterior elbow crease and inserts 3–5 cm distal to this crease. The length of the entire tendon is 7–12 cm and is in close proximity to multiple neurovascular structures [3, 7]. Also arising from the musculotendinous junction, primarily from

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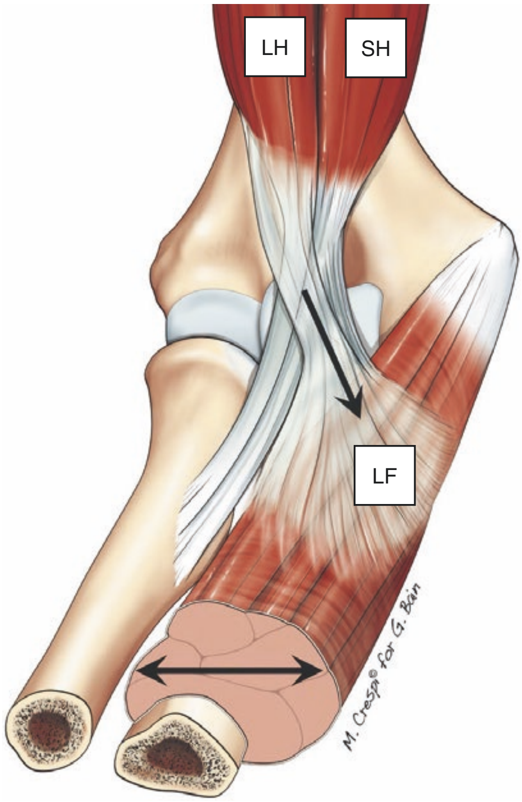

Fig. 33.1 The distal biceps tendon has a long head (LH) and a short head (SH). The lacertus fibrosus (LF) arises from the LH and encircles the SH. It then coalesces with the forearm fascia, which inserts into the subcutaneous border of the ulna (Copyright Dr. Gregory Bain and Max Crespi)

the long head, is the lacertus fibrosus, which is a layered aponeurosis on the medial aspect of the DBT (Fig. 33.1). Similarly, it also encases the proximal forearm flexors, as well as both the medial and lateral aspects of the anterior ulna. It divides the tendon into three zones (preaponeurotic, aponeurotic, and postaponeurotic) and protects the medial neurovascular bundle within the cubital fossa [1]. As the aponeurosis prevents retraction of a ruptured DBT, it is often stretched or torn in retracted DBT tears. As the tendon spread out as broad attachment into the radial tuberosity, the fibres rotate 90°.

The brachial artery supplies the DBT proximally, while the distal supply is from the volarly located recurrent radial artery (4 mm proximal and 15 mm volar to the tuberosity) [8]. There is a hypovascular zone of 2.14 cm close to the tendon insertion, which may play a role in tendon rupture and disease. The radial artery may run dorsal to the DBT and is an important structure which may be at risk of potential injury during endoscopy [9]. The lateral aspect of the DBT is the safe side in the lower arm as the radial nerve is further lateral, and even though the cephalic vein and the lateral cutaneous nerve of the forearm run along the upper lateral aspect. The medial side of the DBT carries a risk of injury to the brachial artery and vein and the median nerve. The DBT lies deep to the radial vasculature in the upper forearm and is in close proximity to the superficial radial nerve (SRN) and the posterior interosseous nerve (PIN) in its lateral aspect, while the ulnar and radial vessels are closely related to its medial aspect (Fig. 33.2) [8].

Between the biceps and the brachialis is the teardrop shaped bicipitoradial bursa, which encases the entire DBT. Effusions within the bursa commonly accumulate on the radial aspect of the DBT, as it is adherent to the ulnar aspect of the tendon.

33.1.2 Pathology

There are several pathological conditions involving the distal biceps which may coexist or overlap, or perhaps even be sequelae of, including:

1. Biceps tendinopathy: a disease of the tendon, often occurs together with biceps enthesopathy.
2. Biceps enthesopathy: a disease of the tendon insertion.
3. Bicipitoradial bursitis: a collection of fluid which can range from a small effusion around the insertion site to a considerable amount of fluid within the tendon, the tendon sheath, and the cubital fossa. Most conditions of the distal biceps have a degree of bicipitoradial bursitis.
4. Partial tears: ranging from microscopic to complete single head tears, most commonly involving the distal short head. There are also intrinsic tears which occur due to chronic tendinopathy, and extrinsic tears which occur secondary to impingement between the ulna and a hypertrophic radial tuberosity (Figs. 33.3 and 33.4).
5. Complete tears.

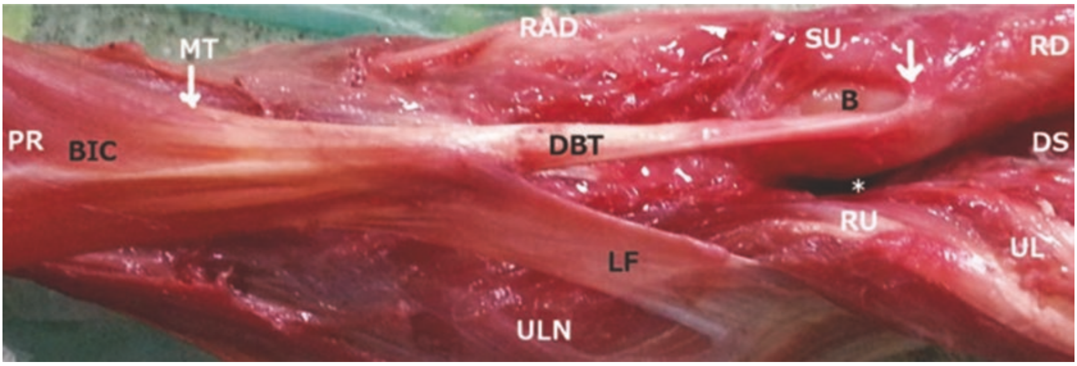

Fig. 33.2 Cadaveric dissection showing the DBT spanning from the musculotendinous junction (MT) to the bicipital tuberosity (right arrow). A bare area (B) is surrounded by the supinator (SU) and DBT. (RU (asterisk) radioulnar space, LF lacertus fibrosus, BIC biceps muscle, UL ulna, RD radius, ULN ulnar aspect, RAD radial aspect, DS distal and PR proximal) (Copyright Dr. Deepak Bhatia)

Fig. 33.3 A coronal CT scan of a patient with a partial thickness tear of the DBT. A hypertrophic radial tuberosity is present in both which predisposes to impingement against the ulna (Copyright Dr. Gregory Bain)

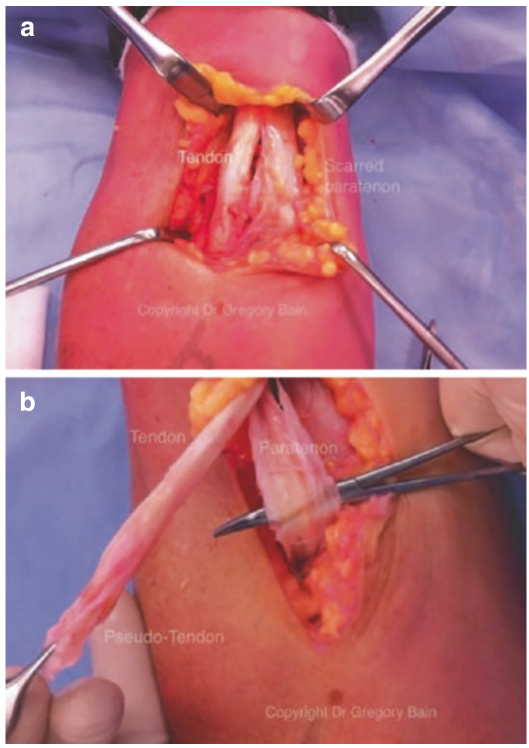

Fig. 33.4 A chronic DBT tear. (**a**) The scarred DBT and lacertus fibrosus. (**b**) The tendon has been dissected out to explore the paratenon and pseudotendon (Copyright Dr. Gregory Bain)

33.2 Clinical

All diseases of the distal biceps are more common in men, whereas partial tears and tendinosis are more common in women. Women also very rarely present with an acute, complete rupture, but rather more insidiously at an older age. They are also more likely to have underlying metabolic disorders such as hypothyroidism, diabetes, or renal disease [10].

33.2.1 Presentation

In **complete tears**, patients sometimes report hearing a characteristic 'pop' in their elbow, most commonly following eccentric contraction of the biceps. This type of tear is likely to occur in patients with pre-existing pathological changes. In **tendinopathy**, patients present with a deep-seated anterior elbow ache, worsened by activity. It could occur due to a single aggravating event or repetitive supination and flexion. Both tendinopathy and partial tears are typically a source of significant pain, usually related to secondary bursitis or impingement from a hypertrophic radial tuberosity (Fig. 33.3). A complete tear, however, may instead present with weakness or cramping, following an acutely painful event which settles over time.

33.2.2 Examination

Complete tears will have acute pain and bruising that will settle after 2 weeks. The hook test, which is highly sensitive, can be used for diagnosis. The patient is positioned with their shoulder abducted, their elbow bent to 90°, and their forearm supinated against resistance [11]. By palpating the cubital fossa from lateral to medial, the examiner attempts to hook the biceps tendon, while the patient's forearm is in supination against resistance. If the distal biceps tendon is not present, this is a positive test. The patient will also have significant weakness to resisted supination, but as the brachialis is intact, there usually will not be marked weakness during flexion of the elbow.

The ruptured tendon could also potentially be palpated under the skin, and during observation of active or passive flexion/extension, the biceps could be observed for an equal rise and fall, and compared to their normal side. Tendon retraction may not always occur if the lacertus fibrosus is still intact or if there are adhesions to the surrounding tissue.

The hook test could still be performed and will be abnormal, but as the distal biceps is still present, it cannot be reported as 'positive' or 'negative'. Instead, the examiner will test for yield when the biceps is hooked, with a substantial loss of tension compared to the contralateral side and can be interpreted according to Table 33.1. This occurs due to a mechanical abnormality even if the tendon is still in continuity and will be painful for the patient. Pain during resisted supination at the tendon insertion and localised tenderness occurs because of the tension on the remaining attachment. If there is impingement of a prominent radial tuberosity and hypertrophic bursa, then there may also be pain and crepitus present with passive and/or active pronation (Fig. 33.3).

When tested at 90° of elbow flexion and full forearm supination, flexion and supination against resistance are usually preserved. However, when the musculotendinous unit of the biceps is at its shortest, it is difficult for force to be generated, so weakness can be identified in partial

Table 33.1 Interpretation of the hook test. (Reproduced from: J Phadnis& G Bain in *Surgical Techniques for Trauma and Sports Related Injuries of the Elbow*, vol. 1, ed. By G. Bain, D. Eygendaal& R. P van Riet, (Springer, Heidelberg, 2020), p. 424, https://doi.org/10.1007/978-3-662-58931-1_56)

Grade	Findings	Features of tendon
N	Normal	Unyielding, taut, and symmetrical with contralateral arm
A1	Abnormal	Yielding, taut, and symmetrical with contralateral arm
A2	Abnormal	Lax and asymmetrical with contralateral arm
A3	Abnormal	Absent

Fig. 33.5 The hook test shortens the biceps muscle tendon unit and accentuates weakness and discomfort when the arm is at the side and the shoulder flexed and abducted. This is a helpful test for diagnosis of tendinosis and partial tears (Copyright Dr. Gregory Bain)

tears, but this is also more painful for the patient. The shoulder needs to be in 90° of flexion, the elbow is in full flexion, the forearm is supinated, and resisted flexion and supination strength are tested (Fig. 33.5).

33.2.3 Imaging

Acute complete distal biceps rupture is a clinical diagnosis which does not usually require imaging. However, confirmatory imaging may be used to definitively diagnose tendinosis and partial tears.

33.2.3.1 X-Rays

A large radial tuberosity may be seen on routine plain radiographs, which can be the cause of impingement, along with calcific spiculations when enthesopathy is present. Bony avulsions are so rare that routine radiographs are not required for typical cases.

33.2.3.2 Ultrasound

Dynamic assessment of impingement can be performed with ultrasound by a trained musculoskeletal radiologist.

33.2.3.3 MRI

Biceps tendon pathology and footprint are best appreciated with the flexion, abduction, and supination (FABS) view on MRI (Fig. 33.6). Soft tissue changes can also be identified, such as bursitis, effusions, peri-tendinous ganglia, and altered intra-tendinous signal intensity. The sensitivity of a partial tear diagnosis, however, is much lower compared to a complete tear (59% vs 100%), and even more difficult is tear size quantification [12].

33.2.3.4 4D-CT

Dynamically in real time, in 6 degrees of freedom, evidence of radial tuberosity impingement against the ulna can be identified, and the source of pain determined as being at the tuberosity or

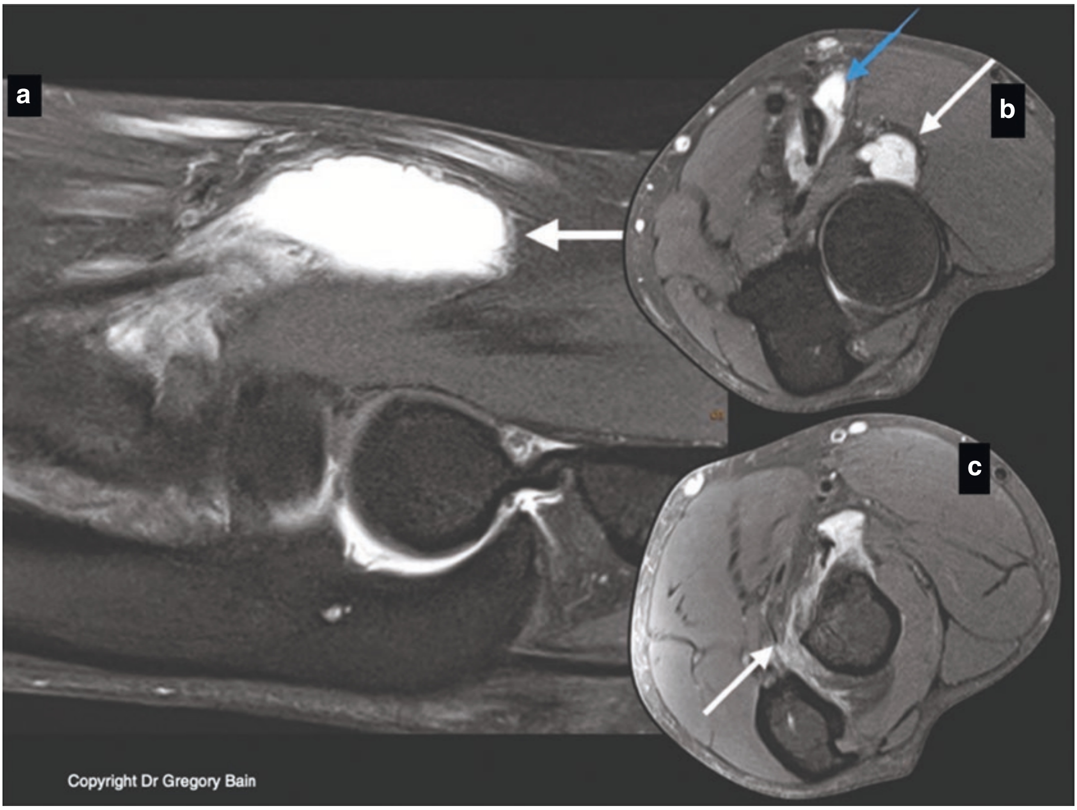

Fig. 33.6 (**a**) Sagittal MRI of biceps tendinopathy with partial tearing. There is extensive fluid collection (white arrow). (**b**) Axial MRI indicating fluid within bicipitoradial bursa (white arrow) and the tendon sheath (blue arrow). (**c**) Axial MRI highlighting bicipitoradial bursitis and tendon insertion stranding (Copyright Dr. Gregory Bain)

mechanical impingement [13]. CT is also useful for characterisation of the bony structures.

33.3 Treatment Principles

The classification used is summarised in Table 33.2. Complete tears are often surgically repaired to restore supination and flexion power, whereas tendinosis and partial tears are initially conservatively managed with activity modification and physiotherapy. Optimisation of any underlying medical conditions should also be prioritised. Following this, although there is no defined non-operative treatment duration, it is reasonable to reassess in 6 months for clinical improvement, or if patients have over 50% footprint uncovering, they are better treated surgically. Patients who present with weakness on resisted strength testing are also likely to need further surgical management and those with a clear traumatic history, compared to those with an insidious onset or an underlying metabolic condition.

Non-surgical treatments include heat, massage, and ultrasound-guided corticosteroid injections, usually in combination with eccentric training. It has been previously reported that ultrasound-guided corticosteroid injections have resulted in resolution of symptoms in up to 73% of patients [14]. There has also been a recent trend towards treating tendinopathy with platelet-rich plasma in combination with dry needling, and one study is showing some promising results with all patients having an improvement in their functional scores at 6 weeks [15].

Table 33.2 Classification of distal biceps pathology. (Reproduced from: J Phadnis& G Bainin *Surgical Techniques for Trauma and Sports Related Injuries of the Elbow,* vol. 1, ed. By G. Bain, D. Eygendaal& R. P van Riet, (Springer, Heidelberg, 2020), p. 428, https://doi.org/10.1007/978-3-662-58931-1_56)

Grade	Injury	Findings	Hook test grade	MRI findings	Recommended management
0	Bursitis, tendinopathy	Atraumatic, tender, swollen Common in older women with comorbidities	N	Bursitis, tendinopathy, fluid	Non-surgical, bursectomy, biopsy
1A	Low-grade partial defect (<50%)	Pain and weakness against resistance	N, A1	Effusion, bursitis, footprint irregularity	Debridement
1B	Isolated head rupture	Weakness against resistance	A1	Isolated head avulsion	Repair of head rupture
1C	High-grade partial defect (>50%)	Pain and weakness against resistance	A1	Incomplete footprint detachment	Detachment and reattachment of tendon
2	Complete tendon rupture with lacertus fibrosis intact	Tendon medialised by intact lacertus fibrosis Significant weakness of supination	A2	Complete footprint detachment, tendon within sheath	Repair
3	Complete tendon and lacertus fibrosis rupture with retraction	Retracted muscle Significant weakness of supination	A3	Complete footprint detachment, retracted muscle, and tendon	Repair
4A	Chronic rupture	Tendon medialised by intact lacertus fibrosis Significant weakness of supination	A1, A2	A2: Complete footprint detachment, tendon within sheath A pseudotendon may bridge the native tendon to the footprint (A1)	Repair
4B	Chronic retracted rupture	Retracted muscle Significant weakness	A3	Complete footprint detachment, retracted tendon within fibrous cocoon	Repair in flexion or with tendon graft

33.3.1 Single Portal 'Dry' Endoscopy

The first anterior portal was described through a 2.5 cm incision placed 2 cm distal to the elbow crease, using retractors to protect neurovascular structures [2]. A modification of this technique for endoscopic-guided footprint repair utilises a 3–5 cm midline longitudinal incision approximately 4 cm distal to the elbow crease [16]. Other techniques used fluoroscopic guidance with an incision 5 cm proximal to the elbow crease for the repair [17].

Retractors are used to maintain the working space, so no fluid and no pressure are required (Fig. 33.7). It avoids excessive fluid distension and subsequent extravasation into soft tissues

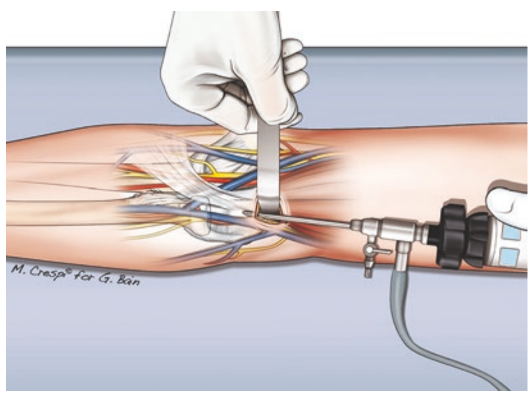

Fig. 33.7 Endoscopic setup demonstrating a Langenbeck retractor maintaining the endoscopic open space and scope placement to identify the biceps tendon (Copyright Dr. Gregory Bain and Max Crespi)

[18, 19]. Without disruption to the tissue planes, it also makes potential subsequent open procedures easier.

The patient is positioned in supine with the arm on an arm table. A sterile tourniquet is applied to the upper arm and full range of elbow motion should be allowed. With the arthroscopic stack positioned on the opposite side of the table and the scrub nurse at the end of the arm table, the surgeon is positioned in the patient's axilla, and the assistant opposite. The tourniquet can be inflated once the arm is exsanguinated with a sterile Esmarch bandage.

Starting 3 cm distal to the anterior elbow crease, a 2.5 cm longitudinal incision is made between the pronator teres and brachioradialis. A posterior accessory portal can also be made by passing a Wissinger rod between the radius and ulna, to exit in the posterior forearm at the radial border of the ulna. This is called the inside-out technique and is similar to curved clamp advancement in the Boyd-Anderson biceps repair technique [19].

Prior to commencement of the procedure, an examination under anaesthetic is performed to assess elbow stability and range of motion. Once the skin is incised, the lateral cutaneous nerve of the forearm is identified superficial to the brachioradialis on the radial aspect of the wound but below the forearm fascia. The development of an inter-nervous plane between brachioradialis and pronator teres is carefully undertaken, and digital dissection is used to identify the DBT. A small, transverse bursal portal is then made at the apex of the bursa on its radial aspect for the introduction of an arthroscope (4 mm, 30° or hooded 4.0 mm Storz, Germany, which can retract tissues and expand the working space) (Fig. 33.8a). Keeping lateral to the DBT allows the surgeon to avoid the median nerve and the brachial artery while visualising the biceps footprint and tuberosity. Once in the bursa, if necessary, 10 ml air can be insufflated to aid the view.

33.3.2 Tendinopathy and Partial Tears

The DBT, tuberosity, and bursa can be visualised and assessed dynamically with forearm rotation or with an arthroscopic hook probe (Fig. 33.9a). A nylon tape can be placed around the tendon to assess the functional aspects, and it is examined for evidence of delamination, synovitis, fraying, and partial tearing (Figs. 33.8b and 33.9b). In order to minimise the risk of soft tissue being caught in the aperture, a 3.5 or 4.5 mm full radius shaver can be used without teeth, and without suction, to debride tenosynovitis and low-grade fraying. Acute single head tears or significant partial tendon ruptures can be repaired surgically as they are similar to an acute complete tear (Fig. 33.10). It is also recommended to complete the tear for degenerative partial tears to release the DBT and to debride the degenerate tissue and tuberosity, before repairing the tendon. This could be done using Mayo curved scissors, positioned in the 'proximal axilla' of the tendon insertion, or by using a scalpel blade or cautery (Fig. 33.8c).

33.3.3 Complete Tears (Fig. 33.11)

Usually treated with open surgery, endoscopy has even proven to be useful in helping to debride the tuberosity, particularly if a footprint repair is performed to allow for the tendon to heal to the bone surface (Fig. 33.12) [16, 20]. The shaver is used to debride the degenerate tissue and tuberosity and can be inserted through the anterior portal or through a posterior accessory portal (Figs. 33.8d and 33.9c). An endoscopic-assisted single excision footprint repair can then be performed or using whichever method is preferred.

Using a 2.5 mm drill, starting from radial as possible on the volar aspect of the tuberosity, two oblique holes are created to exit at the dorsal

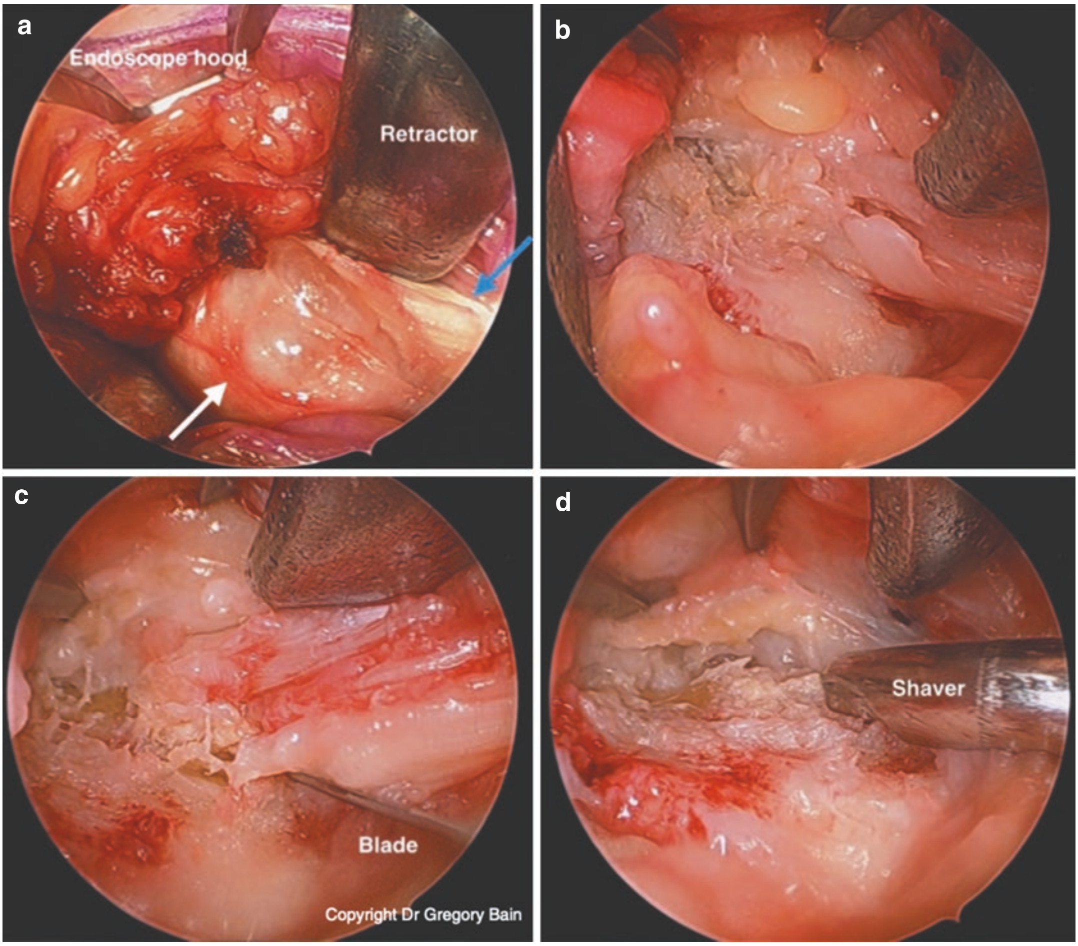

Fig. 33.8 Dry endoscopy (**a**) tendinopathic DBT (blue arrow) with fluid collection and synovitis (white arrow). To expand the space, right-angled retractor and a hooded endoscope were used. (**b**) The footprint is uncovered with a significant partial tear on dynamic testing. Note the discoloured diseased tissue. (**c**) The tendon is completely released at its axilla using a scalpel blade. (**d**) A full radius shaver is used to debride the footprint and to prepare for repair (Copyright Dr. Gregory Bain)

ulnar edge (Fig. 33.9d). Slight pronation helps to lateralise the drill holes, which is useful in preventing button impingement on the repaired DBT.

Proximal blunt dissection can be used to retrieve the ruptured tendon through the same portal used to expand the tract. The tendon end can be debrided and prepared with two number 2 whipstitches, such that there should be four suture limbs exiting at the tendon end. Following this, an epidural needle loaded with a number 1 looped monofilament suture (loop at the tip of the needle) is passed through the drill hole, letting the loop advance. The loop can be endoscopically visualised and retrieved using a pre-placed clip (Fig. 33.9e). A different coloured suture loop is

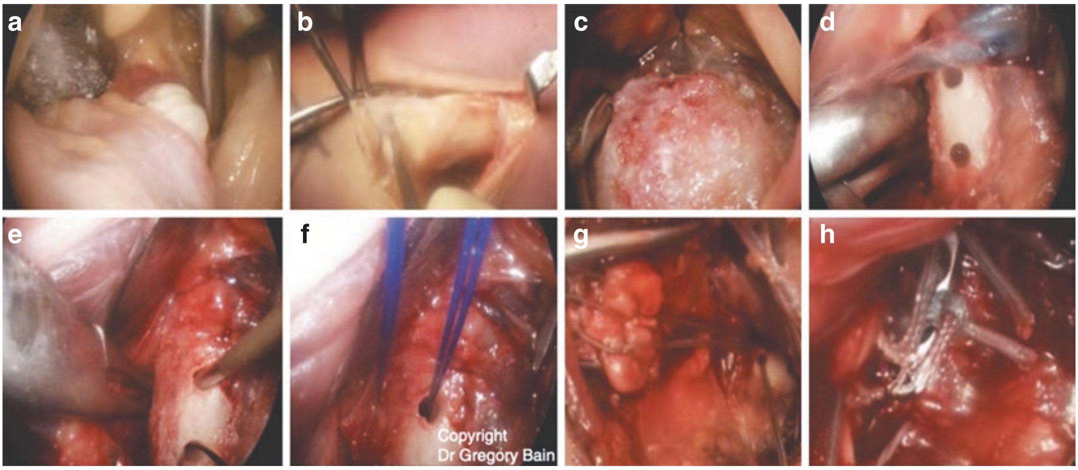

Fig. 33.9 Endoscopic footprint repair for an acute complete tear. (**a**) The torn but minimally retracted biceps tendon is visualised. (**b**) The torn tendon is retrieved and prepared outside the wound. (**c**) A motorised shaver is used to prepare the tuberosity. (**d**) Two drill holes (2.5 mm), from volar to dorsal (exit posterior and lateral) are made in the footprint. (**e**) A pre-loaded monofilament loop in an epidural needle is used for suture transfer. The pre-placed clip simplifies the later retrieval. (**f**) Different coloured sutures are used to avoid confusion during transfer. (**g**) The tendon is transferred down to the footprint using suture pairs which exited the tendon. (**h**) Endobutton on the anterior surface of the radius is used to secure the repair (Copyright Dr. Gregory Bain)

Fig. 33.10 Rupture of only the long head; the short head is intact (Copyright Dr. Gregory Bain)

passed through the second drill hole and the procedure is repeated (Fig. 33.9f). The suture transporting the short head should be distal and the long head proximal. The radial whipstitch sutures should then be placed into the distal drill hole loop, while the proximal drill hole loop should contain the radial whipstitch. The sutures are then passed through an Endobutton (Smith & Nephew PLC, London) after being sequentially shuttled through the drill holes. The proximal holes should contain the proximal sutures and the distal hole, the distal sutures. To fully reduce the tendon onto the footprint Traction is placed on the distal sutures, while the proximal sutures are tied (Fig. 33.9g). The repair is complete when the distal knot is tied (Fig. 33.9h).

33.3.4 All-Endoscopic Technique

With the patient supine and elbow flexed at 20° on the arm table, gravity inflow fluid is used to minimise fluid extravasation into the forearm, following initial air arthroscopy. Visualisation and repair/reconstruction of the DBT require 2–3 portals [7, 21, 22]. The main viewing portal is the 'parabiceps portal' (PBP) at the level of the tuberosity. This is at the lateral aspect of the musculotendinous junction of the DBT (2–3 cm proximal to the elbow crease). The sheath is introduced at an angle 20° inferiorly towards the radial tuberosity through a 4 mm incision and should pass 7–8 cm without resistance. The distal anterior portal (DAP) is the main working portal and is proximal to the tuberosity (4 cm distal to the elbow crease). The brachioradialis is retracted

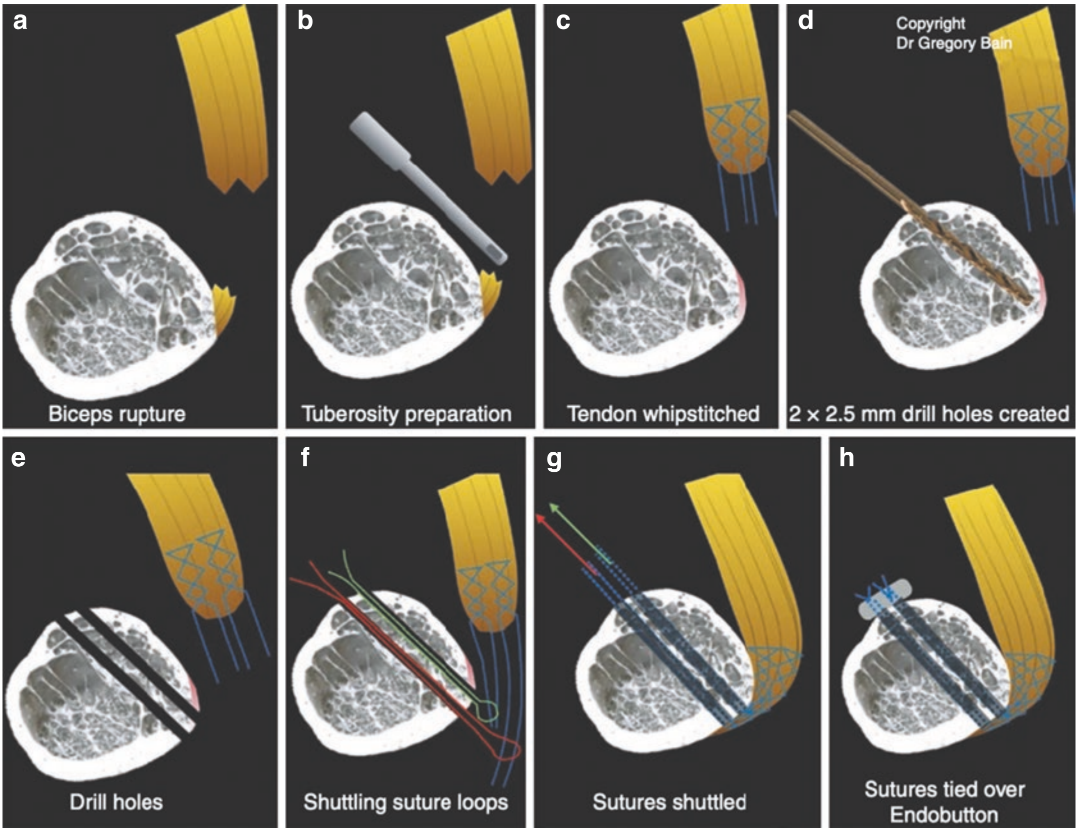

Fig. 33.11 Step-by-step diagrams of the footprint repair. (**a**) A biceps rupture is identified and visualised. (**b**) The torn tendon is retrieved and prepared outside the wound and whipstitched (**c**). (**d**) & (**e**) Two drill holes (2.5 mm), from volar to dorsal (exit posterior and lateral) are made in the footprint. (**f**) A pre-loaded monofilament loop in an epidural needle is used for suture transfer. Different coloured sutures are used to avoid confusion during transfer. (**g**) The tendon is shuttled down to the footprint using suture pairs which exited the tendon. (**h**) Endobutton on the anterior surface of the radius is used to secure the repair (Copyright Dr. Gregory Bain)

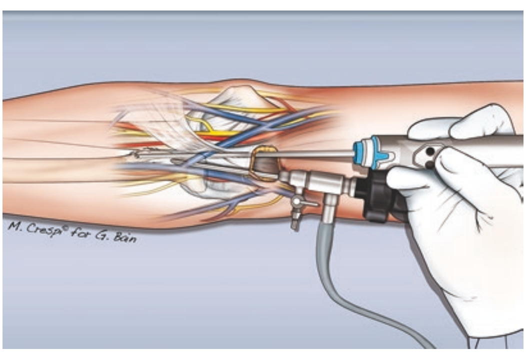

Fig. 33.12 Endoscopic debridement of radial tuberosity (Copyright Dr. Gregory Bain and Max Crespi)

radially and flexor carpi radialis and radial artery ulnarly. The DAP is close to the superficial branch of the radial nerve, so careful dissection and cannula use are recommended. Another portal in the midline of the forearm, the mid-biceps portal (MBP), is created 1–2 cm proximally to the PBP, which allows access to the retracted DBT (Fig. 33.13). The tendon can be hooked with a probe and advanced distal to the tuberosity to visualise the proximal tendon. Oedematous tissue is commonly found with acute DBT ruptures, so gentle retraction is advised. If the DBT is non-retracted, then it can be visualised 2–3 cm proximally to the tuberosity, debrided to healthy tendon, and a suture loop passed around it. If the DBT is retracted beyond the cubital fossa, then an empty sheath could be visualised through the MBP [21]. The stump is retrieved and via a sub-

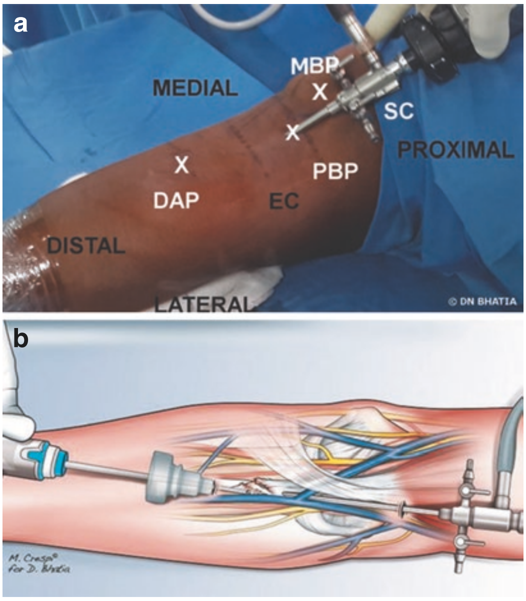

Fig. 33.13 All-endoscopic DBT repair. (**a**) Clinical case (PBP parabiceps portal, MBP mid-biceps portal, DAP distal anterior portal, SC arthroscope, EC elbow crease) (Copyright Dr. Deepak Bhatia), (**b**) diagram of resection in bursa (Copyright Dr. Deepak Bhatia and Max Crespi)

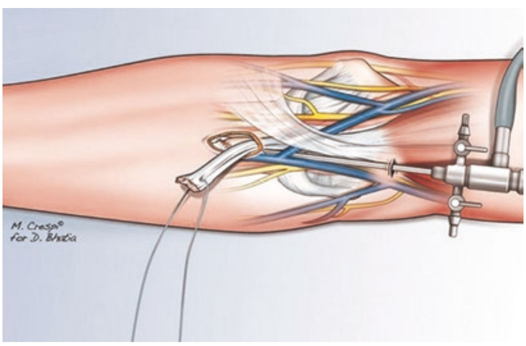

Fig. 33.14 Acute complete DBT rupture: the tendon is delivered from the DAP portal (Copyright Dr. Deepak Bhatia and Max Crespi)

cutaneous tunnel is shuttled into the PBP. Through the DAP, a shuttling suture is passed to the PBP, which is used to shuttle the DBT through the cubital fossa and out the DAP (Fig. 33.14). During forearm rotation, the tuberosity is debrided using a shaver and a burr (Fig. 33.15).

Suture anchors, cortical buttons, and interference screws can all be used endoscopically. To minimise postoperative impingement, the DBT is reattached at the proximal aspect of the tuberosity [3]. As the bursal walls are largely uninterrupted, this technique requires only minimal retraction, which prevents complications such as neuropraxia and heterotopic ossification [23].

33.3.5 Dual Suture Anchor Technique

Two suture anchors (single or double loaded), separated by 1 cm, are inserted into the tuberosity (Fig. 33.16). The DBT is whipstitched by one of the sutures from each of the anchors and the other suture is shortened. The whipstitch is extended proximally by the proximal suture for a further 5–8 mm and the distal anchor suture is stitched to the distal 5–8 mm of the DBT (Fig. 33.17). The shortened sutures are pulled and draw the DBT to the tuberosity and non-sliding knots are tied with a knot pusher.

33.3.6 Endobutton Technique

This is based on the origin of the Endobutton technique [24]. A Beath pin is inserted into the proximal tuberosity adjacent to the native DBT footprint, and a 4 mm sleeve is also passed through. A bicortical tunnel over the Beath pin is drilled with a 4.5 mm reamer and soft tissue is debrided (Fig. 33.18a, b).

The DBT tendon is whipstitched for 2–5 cm and the free sutures are threaded through the Endobutton. The sutures are brought out through the peripheral holes to permit a sliding movement on tensioning. The Beath pin is used to shuttle the Endobutton through the tunnel, and the button is then flipped over to secure (Fig. 33.18c).

The DBT is drawn into the tunnel by pulling the free sutures alternately. Non-sliding knots are used to tie the sutures (Fig. 33.18d).

33.3.7 BicepsButton and Interference Screw Technique

The BicepsButton (Arthrex) is used in combination with a PEEK interference screw. The advan-

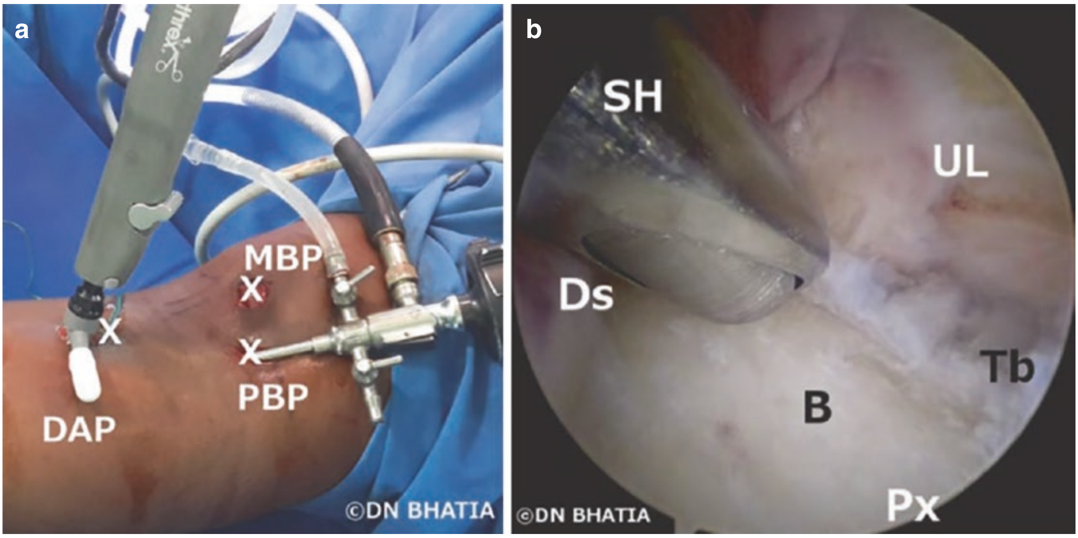

Fig. 33.15 Debridement of the tuberosity (Tb). (**a**) The shaver is in the working DAP portal and the scope in the viewing PBP portal. (**b**) View of the shaver (SH) (DS distal, B bare area, Px proximal) (Copyright Dr. Deepak Bhatia)

tage of using it is that when positioning the DBT into a larger unicortical tunnel there is a sliding mechanism, the button insertion requires a smaller far cortical screw, and there is an added fixation mechanism.

Tunnel placement: A 4 mm sleeve is passed via the DAP cannula, and a 3.2 mm drill pin is inserted perpendicularly into the tuberosity. A 8 mm reamer is used to drill a unicortical tunnel over the Beath pin. A shaver is used to debride the soft tissues at the periphery of the tunnel.

The DBT tendon is whipstitched for 1–2 cm using number 2 suture (Fiberloop, Arthrex). The free sutures are threaded through one hole of the BicepsButtonTM and brought out through the other hole to permit a sliding movement on tensioning. The inserter advances the button through the tunnel, and the button is then flipped over the far cortex to achieve fixation.

The free sutures are alternately pulled; the sliding mechanism advances the DBT distally, until the DBT is drawn into the tunnel. The sutures are tied with non-sliding knots.

A 7 × 10 mm PEEK screw from the kit is used to attach the tendon within the 8 mm tunnel.

Endoscopic assessment of the repair is performed. An external hook test is also performed.

33.3.8 Tips and Tricks

1. Careful portal placement is important:
   (a) An external mark on the sheath at 7 cm ensures deeper structures as not encountered.
   (b) A 2.9 mm scope in the PBP portal is suggested.
   (c) If the muscle fibres of the brachialis are visualised, the scope has been advanced too deeply and the sheath needs to be withdrawn and reinserted with less angulation.
   (d) Using an outside-in technique is suggested to ensure that the DAP is in line with the distal aspect of the tuberosity and adjacent bursa.
   (e) The bicipitoradial bursa should be entered laterally to the tendon at its apex, to ensure safe distance from neurovascular structures.
   (f) Blunt retractors should be used to maintain the workspace.

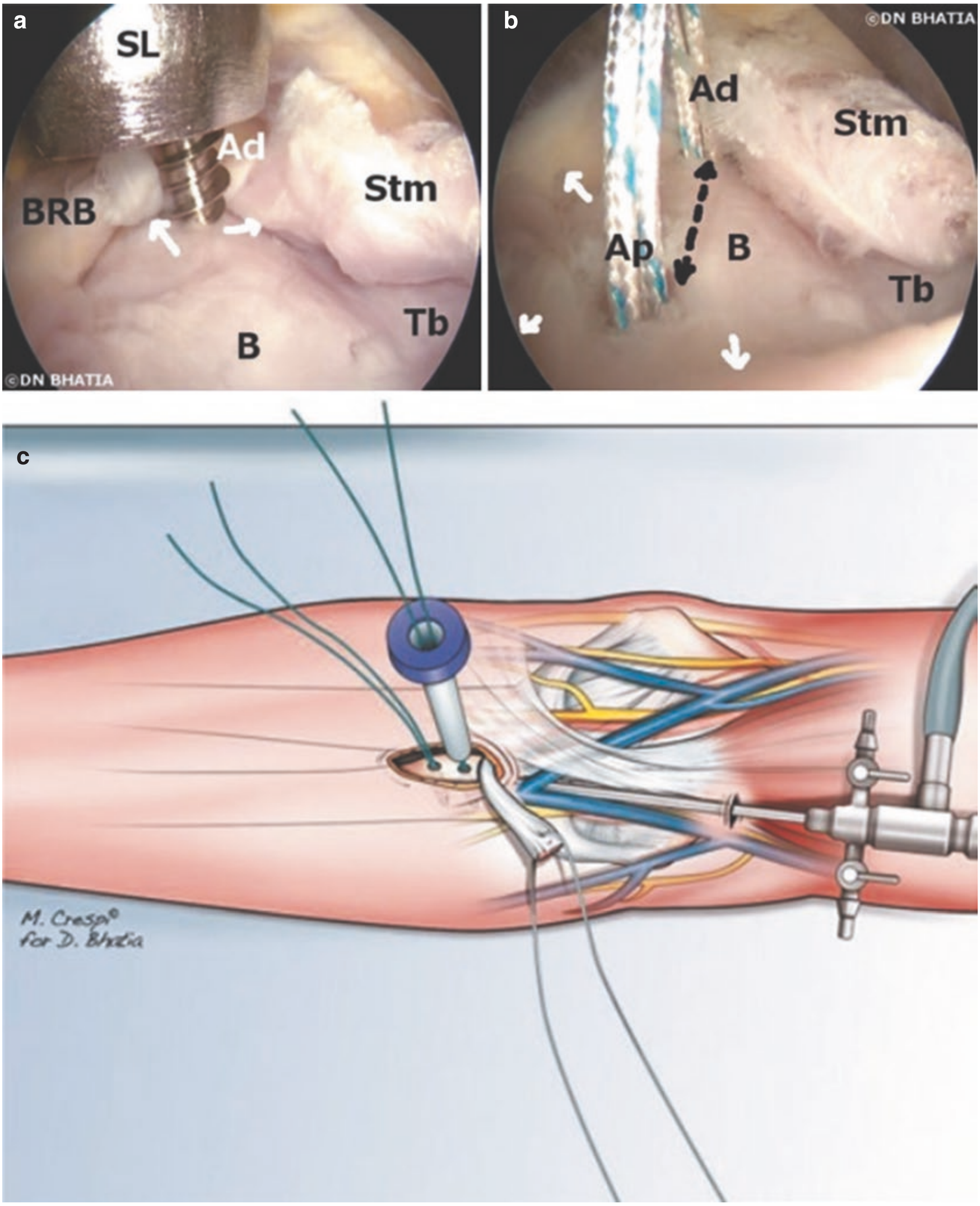

Fig. 33.16 Anchor placement in the tuberosity. DAP working portal, PBP viewing portal. (**a**) A 2.8 mm suture anchor (Ad) is inserted into the bare area via a sleeve (SL) (arrows demonstrate the proximity of the adjacent bursa to the tuberosity). (**b**) 1 cm proximal to the distal anchor (Ad), a second anchor (Ap) is placed (Copyright Dr. Deepak Bhatia). (**c**) The anchor sutures are retrieved from the DAP (Copyright Dr. Deepak Bhatia and Max Crespi)

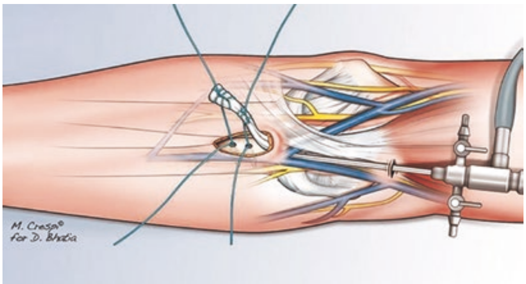

Fig. 33.17 DBT repair. (**a**) The DBT is whipstitched using one suture from each anchor (Copyright Dr. Deepak Bhatia and Max Crespi)

2. Air insufflation prior to placement of DAP portal and reduced fluid inflow during steps that are performed externally are important to prevent compartment syndrome.
3. Using a nylon tape or a probe to dynamically assess the footprint can help identify the tear and release of the tendon.
4. Correct reattachment of DBT in recreating the footprint prevents impingement by placing suture anchors close to the footprint as possible. Similarly, pronating the forearm before drilling for the repair can prevent Endobutton impingement.

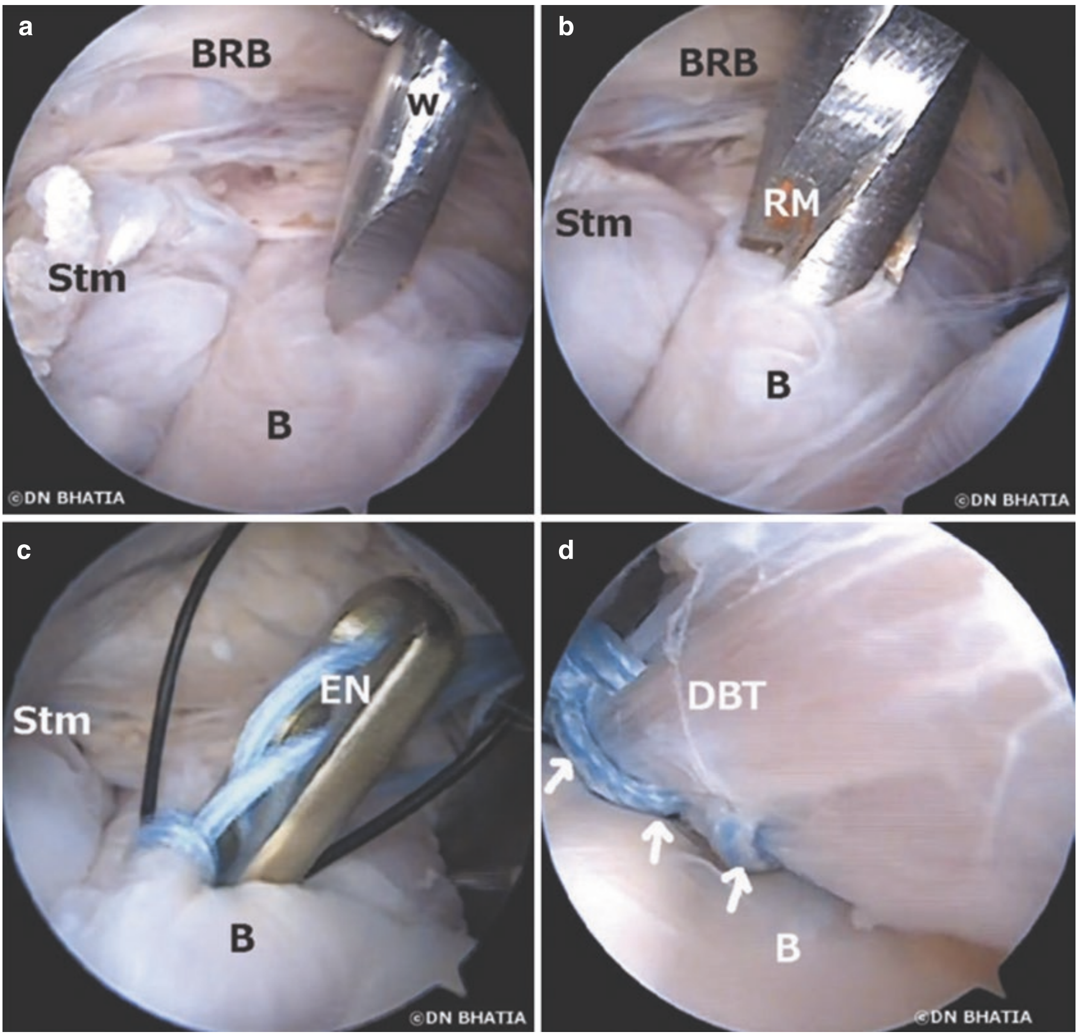

Fig. 33.18 Endobutton repair from the DAP working portal (PBP viewing portal). (**a**) Adjacent to the tuberosity (Stm), a Beath pin (W) is passed through the central bare area (B). (**b**) A 4.5 mm reamer (RM) is passed over the pin, and a bicortical tunnel is drilled in the radius. (**c**) The Endobutton is flipped over the dorsal cortex after being shuttled through the tunnel. (**d**) The Endobutton sutures are pulled and move the DBT into the tunnel (Copyright Dr. Deepak Bhatia)

33.3.9 Pitfalls

1. Compartment syndrome: Endoscopy is performed in a closed extra-articular space which communicates with the forearm compartment and has been found to increase compartment pressures [23]. Gravity inflow decreases this risk, but not as much as air endoscopy.
2. Neurovascular damage: There are multiple neurovascular structures which surround the DBT which are at risk. The risk is minimised by carefully placing the PBP close to the DBT, below the musculotendinous junction, and identifying each of the structure such as the superficial radial nerve and radial artery. Do not use sharp levered retractors that could injure the posterior interosseus nerve at the radial aspect of the tuberosity [25].
3. Suboptimal tendon-bone contact: This can result from failure of sutures to slide within the implants. The resultant gap can interfere with healing and can increase the risk of re-rupture. The dual-anchor technique has been proven to have optimal tendon-bone contact area [23].

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34 Distal Biceps Reconstruction with Allograft for Chronic Tears

Nick F. J. Hilgersom, Bertram The, and Denise Eygendaal

34.1 Description

Long standing or chronic complete tears of the distal biceps tendon, especially in combination with a torn lacertus fibrosus, may be difficult to address using a direct biceps repair technique due to proximal migration and loss of elasticity of the biceps. In those cases, reconstruction using an allograft is an option.

34.2 Key Principles

Various allograft types and fixation techniques (both proximal and distal) exist for distal biceps tendon reconstruction in chronic tears. Choice of allograft type and fixation technique is dependent on the amount of tendon retraction and surgeon's preference.

34.3 Expectations

Without surgical repair of a complete tear of the distal biceps tendon a significant reduction in flexion (7–30%) and supination strength (37–50%) can be expected [1–3]. Therefore, in acute complete ruptures surgical fixation is the preferred method of treatment, except in low-demand elderly patients. In this subgroup, nonsurgical treatment can be justified if these patients are willing to accept diminished function and strength.

Available literature on allograft reconstruction of distal biceps tendon tears, mainly Achilles allografts, shows that it is a safe and effective surgical technique yielding good outcomes and patients satisfaction with full restoration of range of motion [4, 5]. Frank et al. compared delayed primary repair and autograft reconstruction (semitendinosus) of the distal biceps tendon and found that both techniques result in equal strength, range of motion, and complication rates, but slightly worse functional outcomes in the autograft-group [6]. Hence, distal biceps tendon reconstruction using an allograft can be a good option when direct repair is impossible.

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34.4 Indications

- Symptomatic complete tears of the distal biceps tendon not amenable to direct repair.
- Mechanical failures or re-ruptures of previous fixed distal biceps tendons.

34.5 Contra-Indications

- Any complete rupture of the distal biceps tendon that seems compatible for primary repair during surgery in up to 60° of elbow flexion.
- Determine if the risks outweigh the advantages of a distal biceps tendon reconstruction using an allograft in the elderly or those with low functional demands. Nonoperative treatment is very well justified in the low demand or high surgical-risk patient.

34.6 Special Considerations

The definition of "chronic" in chronic distal biceps tears is unclear in literature and is defined from as short as 3–6 weeks after injury. In addition, it is not just the time between injury and surgery that determines if allograft reconstruction is indicated but also the amount of proximal migration. Detailed preoperative assessment, including physical examination and ultrasonography or magnetic resonance imaging (MRI), is recommended to identify those patients that may require surgical planning for allograft reconstruction.

Distal biceps tendon tear characteristics that may contribute to the need for allograft reconstruction:

- *Time*: >6 weeks between injury and surgery will likely cause the muscle and tendon to retract, as well as adhere to surrounding tissues, causing difficulty to obtain enough length for primary repair.
- *Complete tears*: As diagnosed per physical examination (hook-test, passive forearm pronation test, biceps-crease interval) or with imaging studies (ultrasonography or MRI).
- *Torn lacertus fibrosis*: As diagnosed per physical examination (bicipital aponeurosis flex-test) or with imaging studies (ultrasonography or MRI). When intact, the aponeurosis limits tendon retraction. When torn, the tendon can migrate proximally significantly more.
  - The bicipital aponeurosis flex-test: The patient is asked to make a fist and flex his wrist with the forearm in a supinated position. Then, actively flex the elbow to approximately 45–90° of flexion. The bicipital aponeurosis, when intact, can be easily palpated on the medial side of the elbow.
- *Tendon retraction*: As measured with imaging studies (ultrasonography or MRI). The gap between the proximal and distal tendon stumps helps determine the need for allograft reconstruction (Fig. 34.1). Gaps up to 2 cm may be amenable using the native lacertus fibrosis as an autograft. Gaps larger than 2 cm are likely to require graft reconstruction.

Use abovementioned criteria to see if surgical planning for allograft reconstruction is required. Always evaluate during surgery if the tendon is suitable for direct repair, with elbow flexion up to 60°. Successful repairs of chronic biceps tears in extreme flexion have been reported; however, in some instances the gap between the biceps tendon stumps is simply too big or the tendon tissue is of too poor quality [7]. In those cases of chronic complete rupture impossible to address using a direct repair, reconstruction using allografts has been successfully used by several authors in small series.

34.7 Graft Type

Advantages of allografts over autografts are the absence of donor-site morbidity and the availability of longer, more robust graft tissue. Allografts may take longer to incorporate than autografts, but the biomechanical properties are

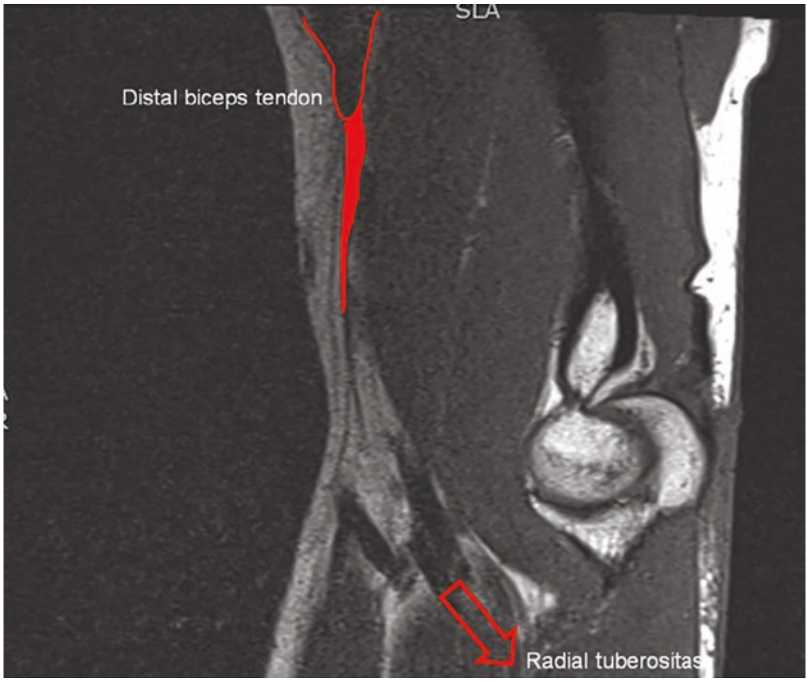

Fig. 34.1 T1-weighted sagittal view MRI showing proximal tendon stump retraction in a chronic distal biceps tendon tear case

ultimately similar. Potential disadvantages of allografts are potential graft rejection, disease transmission, limited availability, and high cost.

Allografts that have been used are Achilles, hamstring, tibialis anterior, and fascia lata. The current trend seems to be using Achilles tendon allograft for distal biceps tendon reconstruction as it provides long and broad graft tissue and is readily available [4, 5].

34.8 Surgical Technique

34.8.1 Approach

The two approaches used for graft reconstruction of the ruptured distal biceps tendon are the same as used for primary distal biceps tendon repair, except that commonly an additional anterior incision proximal to the elbow is required to identify and release the proximally migrated biceps tendon:

1. The single anterior incision technique.
2. The two-incision technique.

Regarding complications and functional outcomes there are no significant differences between the approaches [8, 9]. Both techniques are described below (paragraph 8.4).

34.8.2 Graft Fixation

Various techniques have been described for both proximal (allograft—native tendon) and distal (allograft—radius) graft fixation:

– Proximal graft fixation techniques: Pulvertaft-weave +/− tendon-wrap, various grasping suturing techniques.
– Distal graft fixation techniques: Bone tunnels, cortical button, suture anchors, or interference screws.

Distal graft fixation using bone tunnels or cortical button yields significantly lower complication rates compared to suture anchors and intraosseous screws [8].

34.8.3 Special Instructions, Positioning, and Anesthesia

- Supine patient position.
- General anesthesia +/− plexus block. General anesthesia, including muscle relaxation, to obtain as much native tendon length as possible.
- Preferably no use of a tourniquet (may limit distalization or distal migration of the proximal biceps tendon stump).

34.8.4 Key Procedure Steps

34.8.4.1 Single Anterior Incision Technique

The technique preferred by the authors of this chapter is the single anterior incision technique assisted with an additional anterior incision proximal of the elbow over the tendon stump, with use of Orthocord-sutures (®DePuy Synthes) for proximal tendon fixation and a cortical button for distal tendon fixation (Fig. 34.2).

First, a longitudinal incision is made, starting 1 cm distal to the transverse elbow crease. The lateral antebrachial cutaneous nerve (LABCN) is actively searched for and protected. Next, Henry's leash is identified and ligated. Then, the radial tuberosity is identified and the distal biceps tendon rupture is confirmed. The radial tuberosity is debrided of bicipital bursa and any native tendon remnants. While working on the radial tuberosity keep the forearm in supination and avoid the use of Hohmann retractors on the lateral side of the radius to protect the posterior interosseous nerve (PIN).

A second longitudinal incision is made more proximal on the distal upper arm over the proximal tendon stump, which can often be palpated

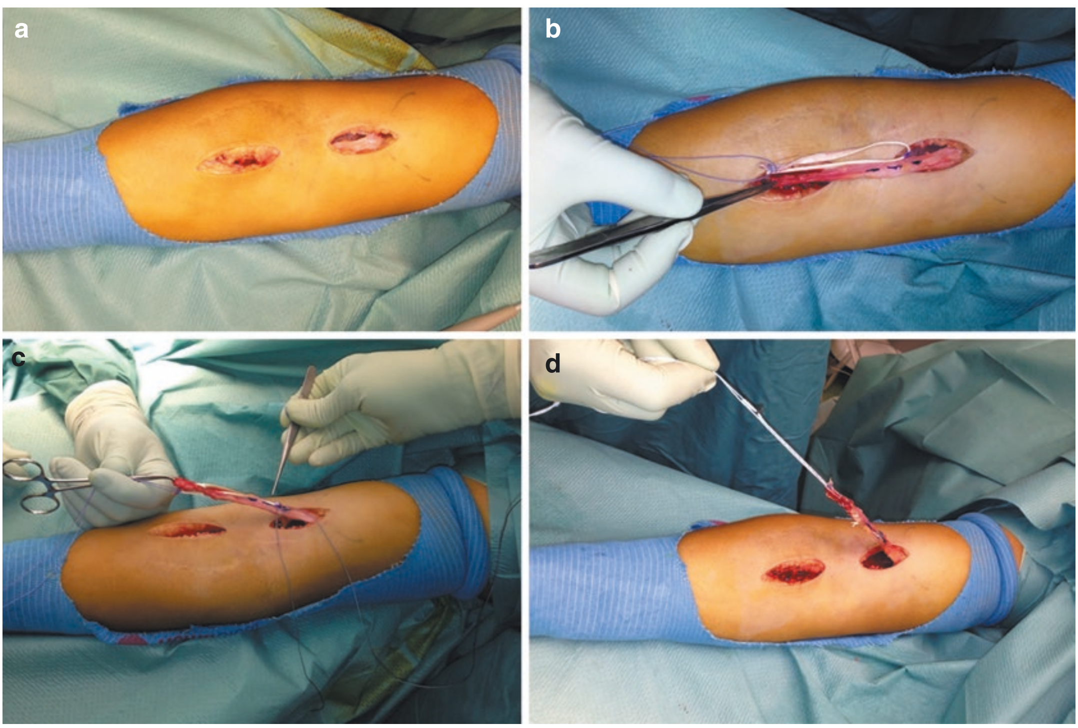

Fig. 34.2 Single anterior incision technique. (**a**) Single incision technique with the second proximal incision. (**b**) Determining the required graft length for the reconstruction. (**c**) Incorporation of a palmaris longus tendon graft in the native distal biceps tendon stump utilizing the Pulvertaft-weave technique and Orthocord-sutures. (**d**) The final tendon-graft-button construct

using blunt dissection with a finger from the first incision. The proximally retracted biceps tendon is identified and carefully released from surrounding scar tissue. In this stage, be particularly aware of the musculocutaneous nerve which is commonly adhered to the tendon as well. After careful release of the tendon and biceps muscle an attempt is made to see if the rupture is amenable to primary repair. If possible, a direct repair using a cortical button technique is performed. If not possible, an allograft reconstruction is performed.

At our institution fascia lata allografts are commonly used for tendon reconstruction, but according to surgeon's preference other types of allograft can be used. Proximally the tendon graft is fixated to the native tendon using Orthocord-sutures, which are of sufficient length to allow reinforcement of the entire construct: the suture is incorporated in the allograft from the proximal fixation to the native stump throughout the entire graft, then to the button and back to the proximal interface. We use four of these rows for maximum strength. Before we incorporate the button construct, we determine the length of the tendon graft that is required to get tension on the graft with the elbow in 30° of flexion (Figs. 34.2 and 34.3). The graft is cut to the appropriate length. Before attaching the button to the allograft, the drill hole is made.

A Kirschner-wire is introduced at the level of the radial tuberosity. It is safer not to try and introduce the wire at the native footprint, since the posterior interosseous nerve may be injured when breaching the overlying cortical wall. This is especially true when aiming both radially and distally during placement of the k-wire. The first cortex is opened with an 8 mm burr, the second cortex using a 4.5 mm burr.

Then, the reconstructed biceps tendon is attached to the button (central 2 holes) through a knotless loop construct using the same sutures that were used to perform the proximal fixation. Without cutting the sutures the construct is further reinforced by using the same running locking (Krackow) technique all the way up to the proximal interface. Leading and trailing sutures are attached to the button (outer 2 holes) and placed through the bone tunnel exiting the dorsal forearm (Fig. 34.4). The allograft is then pulled into the bone tunnel and the appropriate tension is confirmed. The button is flipped once it clears the second cortex. Intraoperative imaging can be used to check for interposition between the button and radius.

After surgery, the elbow is put into a cast for 2 weeks before initiation of exercises. We do not use resistive loading on the biceps during the first

Fig. 34.3 Graft-reconstructed distal biceps tendon with use of a fascia lata allograft integrated using a tendon-wrap technique and orthocord-sutures. (In this case, an extended single anterior incision was used because of sharp penetrating injury to the distal biceps tendon with associated nerve injury)

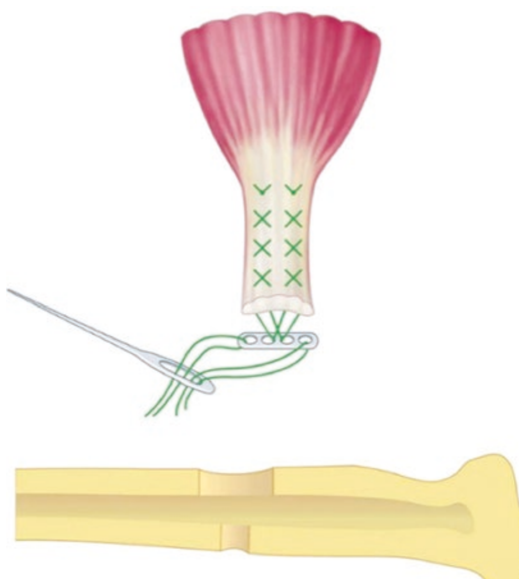

Fig. 34.4 Schematic representation showing cortical button fixation to the distal biceps tendon stump

12 weeks and recommend to avoid peak-loading for the first 6 months.

34.8.4.2 Two-Incision Technique

The two-incision technique was first described by Boyd and Anderson, and later modified by Morrey, in order to avoid contact with the ulna and reducing the risk of radioulnar synostosis.

First, a 3–4 cm transverse incision is made over the antecubital fossa. The LABCN is actively searched for and protected. Commonly a second transverse incision is required more proximal on the distal upper arm over the retracted tendon stump. The proximally retracted biceps tendon is identified and carefully released from surrounding scar tissue. In this stage, be particularly aware of the musculocutaneous which is commonly adhered to the tendon as well. After careful release of the tendon and biceps muscle a set of grasping sutures is placed into the distal tendon stump. At this point it is determined whether the rupture is amenable to primary repair or an allograft reconstruction is required.

The type of allograft tendon is subject to surgeon's preference. Proximally the tendon graft is fixated to the native tendon using Orthocord-sutures, which are of sufficient length to allow reinforcement of the entire construct: the suture is incorporated in the allograft from the proximal fixation to the native biceps stump throughout the entire graft, leaving four strands distally for fixation to the radial tuberosity. Part of this process is determining the adequate length of the reconstructed tendon. We determine the adequate allograft tendon length with the elbow in 30° of flexion.

Next, in similar fashion as the single incision technique the radial tuberosity is identified following the original biceps tendon tract using blunt digital dissection. Then, the forearm is fully supinated and a curved hemostat is passed medially to the radial tuberosity, aiming laterally to avoid contact with the periosteum of the ulna and minimize the risk of radioulnar synostosis. It is passed through the extensor muscles. A 3–4 cm posterolateral incision is made where the skin tents over the tip of the forceps. The forearm is now pronated to place the PIN away from the operative field and allow blunt dissection down onto the radius. The surface of the radial tuberosity is debrided, a through to accept the tendon stump and three 2 mm drill holes are created. A braided suture is then pulled retrograde using a blunt hemostat through the posterolateral incision and out the anterior incision, to be used as a suture retriever for the strands exiting the reconstructed tendon.

The sutures attached to the distal end of tendon are retrieved and passed through the radius to the dorsolateral incision and tied over bone. Take care the tendon is not rotated and tie the corresponding medial suture strands and lateral suture strands together.

After surgery, the elbow is put into a cast for 2 weeks before initiation of exercises. We do not use resistive loading on the biceps during the first 12 weeks and recommend to avoid peak-loading for the first 6 months. The rehabilitation program after surgery is equal for both the single incision and two-incision surgical techniques.

34.8.5 Tips, Pearls, and Lessons Learned

- Have an allograft available as plan B if preoperative evaluation indicates that primary repair may not be possible.
- Assess the availability of ipsilateral autologous palmaris longus tendon.
- Always evaluate if the tendon is suitable for primary repair during surgery before moving on to allograft reconstruction.
- Protect the LABCN by actively searching for it and releasing it along its course.
- Protect the PIN:
  - Hold the forearm in full supination while working on the radial tuberosity.
  - Avoid using Hohmann retractors on the lateral side of the radius and use long Langenbeck retractors instead.
  - Do not attempt to drill from the native footprint in a distal and radial direction, but rather use a non-anatomical reconstruction shifting the tendon insertion more anteriorly.

- Thoroughly irrigate the wound after drilling to remove any osseous debris reducing the risk of developing heterotopic ossifications.
- Ensure a small gap (2 mm) between the cortical button and attached tendon to allow flipping of the button.
- Use indomethacin 3 weeks 3 × 25 mg a day as prophylaxis for heterotopic ossification.

34.8.6 Pitfalls

- Incomplete release of the LABCN from the retracted tendon may cause traction neuritis of the LABCN.
- During release of the tendon and biceps muscle to attempt a primary repair take care of the musculocutaneous nerve.
- Do not fix the tendon-allograft construction in full extension, as this will result in under tensioning of the graft.
- Lesion to the PIN due to Hohmann retractors on the lateral side or mal drilling of the K-wire through the opposite cortex.

34.9 Rehabilitation

A similar phased rehabilitation protocol is used for primary, delayed primary, and graft-reconstructed distal biceps tendons [10].

Phase 1—weeks 0–6—soft tissue healing and passive range of motion: The goal of this phase is to optimize soft tissue healing and acquire full extension. Weeks 0–2 the elbow is put in an upper arm cast for absolute rest. The amount of elbow extension may be limited by the surgeon depending on construct tension during surgery. Weeks 2–6 the elbow is placed into a locking-elbow brace and patients start with gravity-assisted range of motion exercises under physiotherapist supervision. Active elbow flexion and supination are prohibited.

Phase 2—weeks 6–12—active range of motion: The goal of this phase is to acquire full active range of motion. Patients are allowed to perform active non-bearing range of motion exercises under physiotherapist supervision.

Phase 3—months 3–6—progressive loading: The goal of this phase is to return to activities of daily living. Patients are now allowed to actively perform elbow flexion against resistance. Each patient starts a graduated loading program under physiotherapist supervision.

Phase 4— > months 6—work- or sport-specific rehabilitation: The goal of this phase is to focus on patient-specific needs to allow them to fully return to work or sports. This phase may be initiated once 90% strength compared with the contralateral side is achieved.

34.10 Outcomes and Complications

Allograft reconstruction of the distal biceps tendon provides good functional outcomes and patient satisfaction [4, 5]. Comparing (delayed) direct repair with graft reconstruction of the distal biceps tendon shows similar strength, range of motion, and complication rates, but slightly worse functional (subjective) outcomes for graft reconstruction [6].

The complication rate after graft reconstruction is approximately between 10% and 21% [4–6]. Complications after graft reconstruction are similar to direct repair of the distal biceps tendon, including LABCN neuropraxia, PIN injury, superficial radial nerve neuropraxia, wound infection, flexion contracture, heterotopic ossification, synostosis, and re-rupture. The complication rate is thought to be higher initially (<3 weeks) after delayed repair compared to direct repair, due to more difficult surgical dissection and release of the retraction proximal biceps tendon stump, atrophied biceps muscle belly, and scar tissue around the proximal radius which makes a proper exposure of the tuberosity more difficult.

In terms of esthetics patients should be informed that the contour of the biceps muscle cannot commonly be restored in symmetry to the contralateral arm due to the chronicity of the injury (tendon retraction, muscle atrophy). The biceps-crease interval has been shown to be significantly greater in the reconstruction group compared to the direct repair group. In part, due to the elongation of the graft over time. The altered biceps muscle contour does not result in significant differences in flexion or supination strength. In general, patients seem to be satisfied with the results despite the persisting altered contour of the biceps muscle [5, 6].

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Open Tennis Elbow Surgery

35

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Abbreviations

ECRB	Extensor carpi radialis brevis
ECRL	Extensor carpi radialis longus
ECU	Extensor carpi ulnaris
EDC	Extensor digitorum communis
ER	Epicondylus humeri radialis
LCL	Lateral collateral ligament
LUCL	Lateral ulnar collateral ligament
PLRI	Posterolateral rotatory instability

35.1 Description

The term 'epicondylopathy' is preferable to 'epicondylitis' as it is more descriptive of the underlying pathology. It usually originates with microtears at the origin of extensor carpi radialis brevis (ECRB) tendon. The extensor digitorum communis (EDC) tendon may also be involved in up to 30% [1]. Histology reveals an absence of inflammatory cells, angiofibroblastic hyperplasia and disorganised collagen. Lateral epicondylopathy is generally a self-limiting condition. Before an operative procedure is considered, conservative measures should have been tried for at least 6 months. Persistent elbow pain, concomitant neck pain or severe pain 12 months following symptom onset is associated with a poor long-term outcome [2]. Other pathologies such as (concomitant) PLRI—especially after multiple steroid infiltrations or previous surgical procedures [3, 4]—exostosis or extra- and intraarticular pathologies such as plica synovialis or PIN entrapment should be thoroughly investigated for.

A recent meta-analysis identified ligament lesions as the most common intraoperative findings in tennis elbow surgery with lateral ligament patholaxity in 64%, LUCL injury (26%), RCL and LUCL injury (9%) and RCL injury (1%) [5].

Several methods of open surgery for lateral epicondylopathy have been described. There has been a trend towards arthroscopic intervention in recent years with no significant differences in medium- to long-term outcomes compared with open procedures [6, 7].

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35.2 Clinical Presentation

Local tenderness over the extensor carpi radialis brevis (ECRB) or extensor digitorum communis (EDC) origin at the lateral epicondyle is typical. Pain provocation with resisted wrist extension with the elbow in full extension is a reliable test (Cozen Test). If forearm pain is a significant feature, irritation of the posterior interosseous nerve (PIN) should be ruled out. Physical findings such as painful resisted supination or a diagnostic infiltration with local anaesthetic (e.g. in the supinator arch) can be useful tools.

35.3 Key Principles

The aim of surgical treatment of lateral epicondylopathy is to completely resect the insertion of the ECRB and its associated degenerative tissue from the distal humerus.

We do not perform a denervation routinely. Rose et al. found 80% good or excellent results following only denervation as treatment for recalcitrant tennis elbow in case of positive response to a diagnostic block of the posterior branches of the posterior cutaneous nerve of the forearm [8].

Lateral humeral epicondyle denervation by Wilhelm proposed a disinsertion of the extensor muscle group rather than specific resection of a peripheral nerve, including also decompression of the radial nerve within the radial tunnel [9].

Uncertainty remains regarding PLRI after tennis elbow surgery since retrospectively it is unclear if a pre-existing PLRI concomitant with tennis elbow was missed and lacked surgical addressing—or was iatrogenic following damaging of the LUCL during tennis elbow surgery [4].

35.4 Anconeus Flap

One advantage of open tennis elbow surgery is the option to add an anconeus flap [10]. We use it as an adjunct in case of failed tennis elbow surgery or revision cases [11–14].

35.4.1 Outcome

It is important to note that 95% of cases respond to conservative treatment. Following failed conservative therapy for at least 6 months, however, operative therapy is effective in 70–85% of cases [15, 16].

35.4.2 Indications

The main indication for surgery is pain of significant intensity and associated functional impairment with limitations of activities of daily living or occupation. It is important that conservative treatment has been tried for at least 6 months prior to considering surgical treatment. Further imaging may be necessary to rule out additional pathologies which may need surgery.

35.4.3 Relative Contraindications

Surgery should be avoided in other syndromes with confounding presentations: supinator syndrome (radial tunnel syndrome), posterolateral rotatory instability (PLRI) (ECRB resection can, however, be performed simultaneously with treating instability), bicipitoradial bursitis or rheumatic diseases with enthesopathies.

35.4.4 Special Considerations

The course of the ECRB tendon can be identified only after elevating the aponeurosis of the common extensor tendons (EDC). The upper border of the ECRB is the muscular insertion of the ECRL tendon. The diamond-shaped origin of the ECRB extends from the upper edge of the capitulum to its centre or the radiocapitellar 'midline' [17] (Fig. 35.3b). Staying anterior to the midline prevents injuring the LUCL as the primary stabiliser of the elbow joint. This procedure also thereby prevents damage to the PIN.

35.4.5 Pitfalls

The ECRB tendon is not reliably identifiable from the epifascial layer. Knowledge of landmarks for the points of insertion is therefore essential. Especially the integrity of the LUCL and its anatomic course next to the surgical site should be respected.

35.4.6 Key Procedural Steps

Supine position, arm table and tourniquet are preferred by the authors. The bony surface landmarks are marked: radial head, capitulum (Fig. 35.1a). After incision over the midline of the radiocapitellar joint and the lateral epicondyle, subcutaneous dissection and preparation down to the fascia are performed. Incise the fascia and the aponeurosis of the common extensors in midline for 2–3 cm developing the interval between the EDC and ECU and keep the muscular origin of the ECRL intact (Fig. 35.1b). It is important to stay anterior to the midline of the radiocapitellar joint avoiding damage of lateral ligament complex. Dissect the tendinous insertion at the profound side of the EDC to establish the interval to the ECRB. The aponeurosis is detached from the epicondyle in a L-shaped fashion, raised and developed tangentially from posterior to anterior proximal to the epicondylar ridge to the muscular origin of the ECRL. A 2–3 mm soft tissue bridge at the ridge of the ER is preserved for easier later refixation of the EDC fascia. After the underlying ECRB tendon is visualised (Fig. 35.2), the tendon can now be completely resected distally over 10–20mm, and from the upper margin of the capitulum to the midline of the radiocapitellar joint (Fig. 35.3a). The radiocapitellar joint can now be seen and the upper margin of the lateral ligamentous complex is identified. Using passive movement of the elbow joint, the function and integrity of the lateral ligament complex can now be assessed. It is important not to injure these stabilising structures. Remaining pathological tissue can be further resected at this point. Denervation or decortication is optional and at the discretion of the surgeon. Finally, the mobilised aponeurosis/EDC tendon flap is anatomically readapted again and fixed to the remaining bridge at the origin with a continuous, resorbable suture (e.g. Vicryl 0, Ethicon, Johnson& Johnson, Warsaw, Indiana).

Postoperatively, we immobilise the patient only for pain control in an immobiliser for 1 week. Active mobilisation is immediately

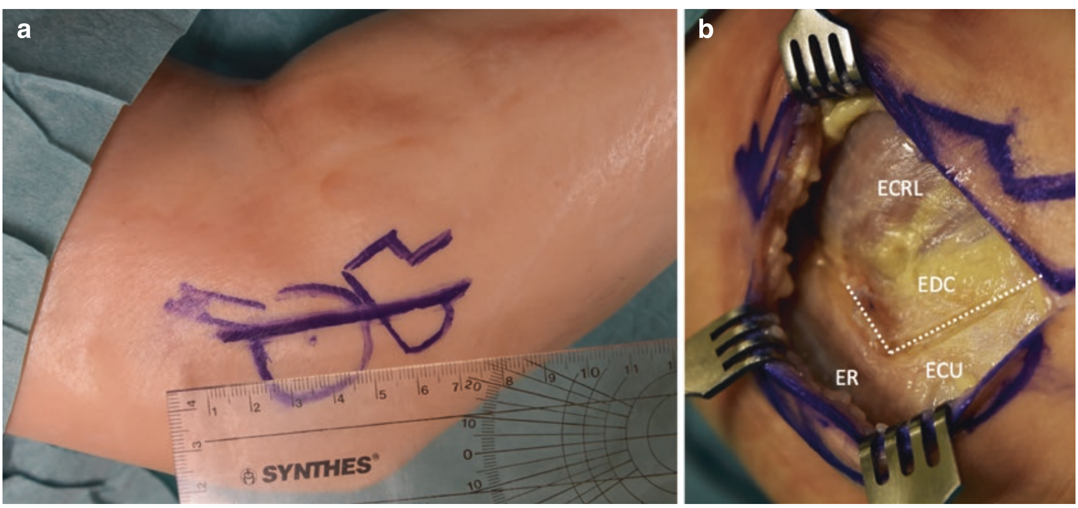

Fig. 35.1 (*Copyright Institute of Anatomy, University of Bern, Switzerland):* Anatomical landmarks for the Kocher approach (**a**). The ECRB tendon is covered by the extensor aponeurosis of EDC and ECU (**b**). Note the muscular origin of the ECRL anterior. The fascia is incised in an L-shaped fashion between EDC and ECU

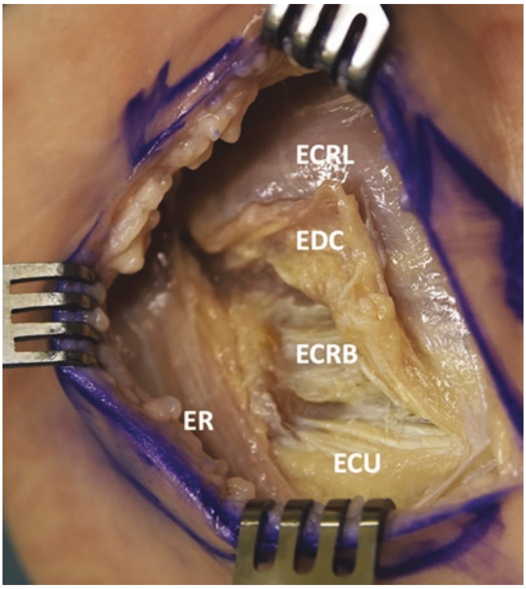

Fig. 35.2 (Copyright Institute of Anatomy, University of Bern, Switzerland): ECRB origin after EDC is lifted anteriorly

allowed without active dorsal extension of the wrist against resistance for 4 weeks.

35.4.7 Bail-Out and Rescue Procedures

If the lateral collateral ligament complex is accidentally detached, the residual tendon of the EDC must be posteriorly elevated, the LUCL reinforced with a non-absorbable suture, and reinserted with transosseous sutures or using an anchor ideally above the 'most isometric' point (2 mm proximal to the capitellar centre of rotation) [18].

Key Points

1. The term 'epicondylitis' is misleading since there are no histopathological signs of inflammation.

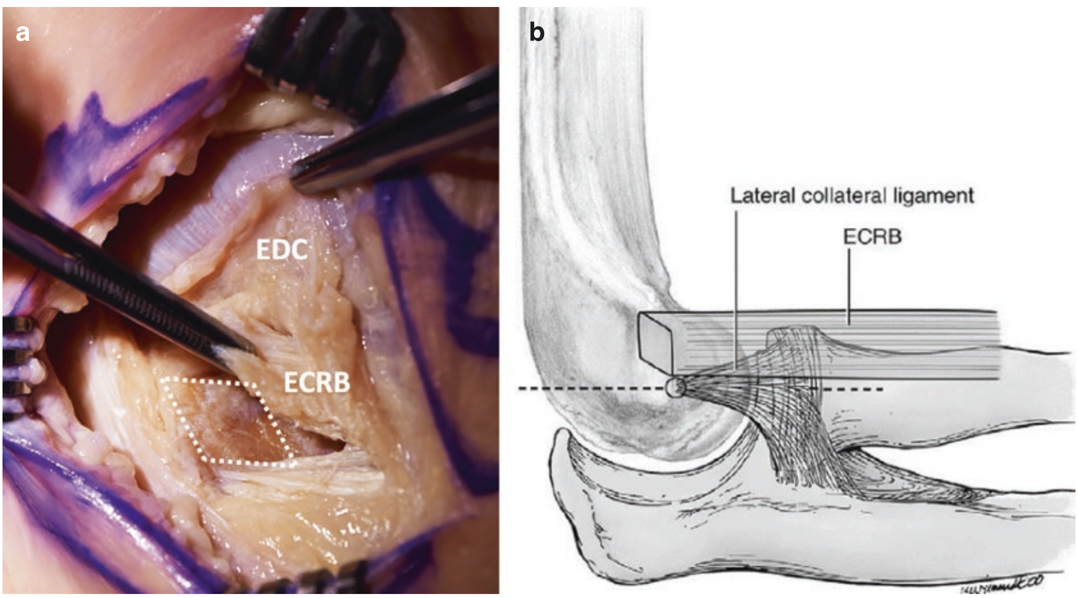

Fig. 35.3 (Copyright Institute of Anatomy, University of Bern, Switzerland): ECRB dissection off the ER reveals its diamond-shaped origin (**a**). After resection of the altered ECRB tendon, the radiocapitellar joint becomes visible. Note the proximity to the lateral ligament complex (**b**)

2. Lateral elbow tendinosis is a mostly self-limiting pathology over the course of 12–24 months; therefore, conservative treatment option is recommended first line.
3. Concomitant PLRI may be a reason for failed conservative treatment.

Questions

1. Which of the following structures is at most risk in open tennis elbow surgery?
   (a) PIN
   (b) ECRL
   (c) LCL
   (d) LABC nerve
2. Which are concomitant pathologies of lateral elbow tendinosis to be actively searched for?
   (a) PLRI
   (b) Triceps tendinosis
   (c) PIN entrapment
   (d) Synovial plica syndrome
3. Which treatment option is superior for treating lateral elbow tendinosis?
   (a) Denervation
   (b) Conservative treatment
   (c) Open ECRB release
   (d) Arthroscopic ECRB release

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36 Medial Ulnar Collateral Ligament (MUCL) Repair with Internal Brace Augmentation

Jeffrey R. Dugas and Shalen N. Kouk

36.1 Introduction

The anterior band of the medial ulnar collateral ligament (MUCL) is the main static stabilizer of the medial elbow and vital in preventing valgus opening of the elbow joint [1, 2]. Injury to the ligament is common in throwing athletes and is traditionally treated with ligament reconstruction, which will be discussed in the following chapters. We believe that UCL repair with Internal Brace augmentation is an excellent treatment option for the proper patient. This technique is ideal in a thrower with an acute injury, specifically to the proximal or distal bony insertions [3–5]. Patients with low grade partial tears should attempt conservative treatment which includes rest, bracing, gradual advancement to a throwing program, and potential platelet-rich plasma injections [3]. Generally, acute on chronic injuries with poor ligament tissue quality, on MRI or intraoperatively, will not be good candidates for repair. Any bony ossicles or bony avulsions should also steer the management towards reconstruction as this can lead to ligament compromise [4, 6]. Prior to surgery, all patients should be consented for reconstruction along with repair, in order to have a second option for treatment if the ligament quality is poor. We also proceed with an ulnar nerve transposition if the patient has any symptoms of ulnar neuritis. Finally, patients should understand that the rehabilitation, while shorter than reconstruction, is still time-intensive and will require close monitoring with the physician, trainers, and physical therapists [2].

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36.2 Surgical Technique

The patient is positioned supine on the operating table with the arm on a hand table. An examination under anesthesia should be performed to ascertain if there are any range of motion limitations, specifically extension. A tourniquet is placed high on the arm prior to draping. The arm is prepped and draped in a standard fashion and the tourniquet is inflated to 250 mmHg. Two bumps, one under the lateral elbow and a larger one under the hand are used to support the arm. An 8 cm incision is made over the medial epicondyle, approximately 1/3 proximal and 2/3 distal, extending in line with the arm and forearm. The incision should appear straight with the arm in extension. Dissection is carried down through the subcutaneous tissues to the medial epicondyle. The medial antebrachial cutaneous nerve is identified and protected as it crosses from volar to dorsal. Once the volar and dorsal skin flaps are raised, the cubital tunnel is incised with a knife, in line with the course of the ulnar nerve. Once the nerve is visualized, it can be protected while the fascia is opened proximally and distally. A

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vessel loop can be placed around the nerve to help with control and allow for full release. Proximally, the nerve should be free of any soft tissue constraints posterior to the medial intermuscular septum. Distally, the flexor carpi ulnaris fascia should be incised in line with muscle fibers superficially and split bluntly. Any deep fascial bands should be released as well. While releasing the nerve, there are often small vascular leashes that need to be cauterized with bipolar cautery. It is important to clearly visualize and protect the motor branches to the FCU during the ulnar nerve release.

Once fully mobilized, the ulnar nerve can be retracted posteriorly and the medial ulnar collateral ligament can be visualized. A key elevator can first be used to clear the sublime tubercle of any soft tissue. Then using a 15 blade, the fascia of the flexor digitorum profundus can be incised and the muscle belly elevated off of the anterior band of the MUCL. It is vital that the fibers of the ligament are not inappropriately transected. Once the muscle is elevated, a small retractor can be placed over the sublime tubercle to fully visualize the MUCL (Fig. 36.1). The ligament is then split in line with its fibers from the sublime tubercle to the medial epicondyle. Ensure that the incision extends to the anterior edge of the medial epicondyle, and not posteriorly, as to not inappropriately release the ligament's posterior insertion on the epicondyle. The ulnohumeral joint can be visualized at this point as well as any

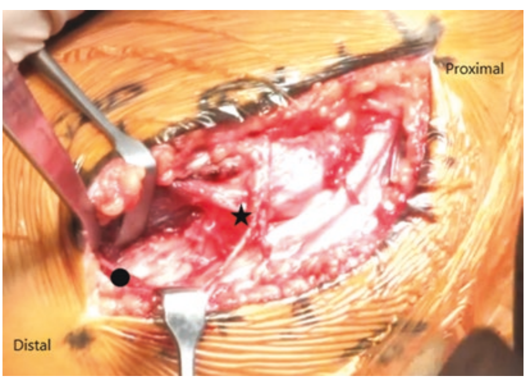

Fig. 36.1 View of the UCL after dissection of the soft tissues. The sublime tubercle (circle) and medial epicondyle (star) are identified

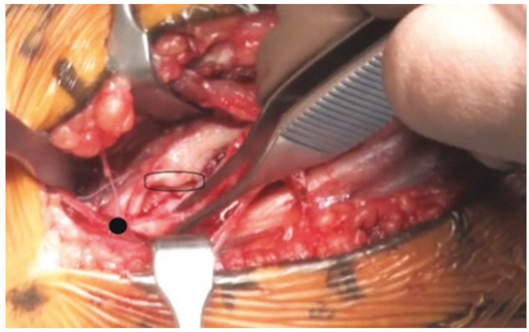

Fig. 36.2 View of the UCL after longitudinal split of the ligament. The sublime tubercle (circle) and avulsed distal portion of the ligament (oval) are identified

degenerative tissue (Fig. 36.2). Using a combination of scalpel and rongeur, all poor quality ligamentous tissue is excised and the MUCL ligament injury is evaluated. If any unexpected bony ossicles, poor tissue quality, mid-substance tearing, or iatrogenic damage is encountered, the repair should be abandoned in favor for a reconstruction. A bleeding bony bed is prepared either proximally or distally, depending upon the type of injury.

Repair of the MUCL begins with drilling of the first tunnel at the site of the injury (in this case distal). The ArthrexInternalBrace Kit is used for all our repairs. In this case, the distal insertion of the MUCL on the sublime tubercle is identified, approximately 6 to 8 mm distal to the joint, and the 2.7 mm drill is used to make the pilot hole, aiming distally and posteriorly to avoid entering the joint. Once drilled, the collagen coated FiberTape and #0 FiberWire are loaded into the eyelet of the first 3.5 mm PEEK SwiveLock anchor. The hole is tapped and the anchor is placed. The ligament is repaired to its insertion using the #0 FiberWire from the anchor site with slight varus stress of the elbow in approximately 60 degrees of flexion (Fig. 36.3). The longitudinal split is then repaired with the remainder of the #0Fiberwire suture (or other non-absorbable suture), in an interrupted simple fashion. The humeral anchor site is drilled at the proximal insertion of the MUCL, again, ensuring not to be too posterior. This is again tapped, and the second anchor is then loaded onto the FiberTape ends and inserted into the drill hole with the

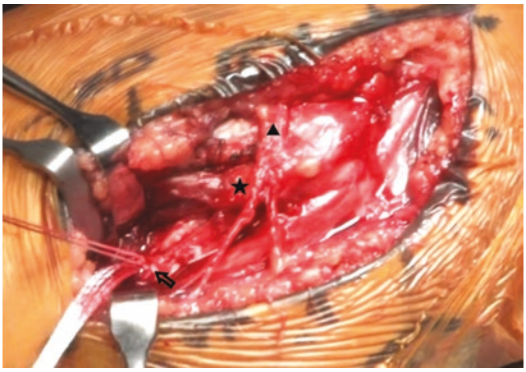

Fig. 36.3 View of the UCL after repair of the ligament. The medial epicondyle (star), medial antebrachial nerve (triangle), and repair suture at the sublime tubercle (arrow) are identified

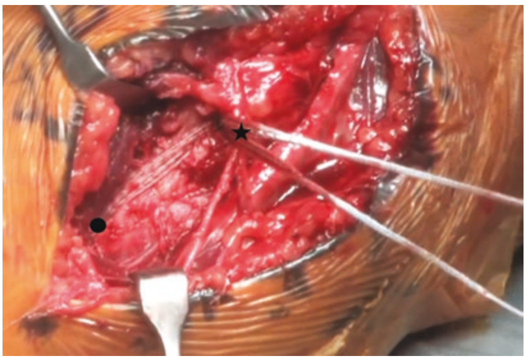

Fig. 36.4 View of the UCL after augmentation with Internal Brace. The medial epicondyle (star) and sublime tubercle (circle) are on either end of the Internal Brace laid over top of the UCL

elbow in slight varus. Before fully advancing the anchor into the bone, tension is assessed by confirming full range of motion of the elbow. The length of tape can be adjusted at this time, erring on slight laxity instead of overconstraint if anisometric. Once appropriate tension in the tape is achieved, the second anchor is advanced into the tunnel. The InternalBrace and ligament are then sutured together with interrupted FiberWire sutures to create a unified repair. Range of motion and tension are again assessed confirming appropriate repair with augmentation (Fig. 36.4).

The ulnar nerve is transposed over top of the flexor mass and held with a fascial sling from the previously exposed medial intermuscular septum. The wound is copiously irrigated and the tourniquet is let down to achieve hemostasis. Closure of the FCU fascia distally with two #0 Vicryl sutures is performed to prevent propagation of the fascial split. The cubital tunnel is closed with #0 Vicryl, the subcutaneous tissue with #2-0 Monocryl and the skin with #3-0 Prolene in a running fashion. Clean and sterile dressings are applied and the patient is placed in a hinged elbow brace, locked in 90 deg. of flexion.

36.3 Rehabilitation

Post-operative management is considered accelerated in comparison to a standard UCL reconstruction protocol. Our institution follows a five-phase program that aims to return the patient to competitive throwing at 6–7 months following surgery [2].

Immediate Post-op (week 1): Elbow locked in 90 degrees of flexion, focusing on hand and wrist motion to prevent stiffness.

Controlled Mobility (weeks 2 through 6): Elbow motion gradually increased with goal of full motion by the end of week 5. Full extension is essential for a thrower to regain proper throwing mechanics. The patient may begin the Thrower's Ten [2] program in weeks 5 or 6, based upon their motion and improvement.

Intermediate (weeks 7 through 8): Elbow brace is discontinued and patient is started on two-handed plyometrics and advanced Thrower's Ten [2] program. Patient should progress to one-handed plyometrics by the beginning of week 9 and continuing until the end of week 10.

Advanced (weeks 10 through 13): Progress strengthening and begin interval throwing program at the end of week 10. Patients may start an interval hitting program at week 10.

Return to Activity (weeks 17+): Completion of throwing program with no symptoms of pain, full range of motion, and satisfactory functional outcomes. Goal to return to play at 6–7 months.

36.4 Outcomes

There have been several studies over the past several years that have demonstrated good biomechanical properties and clinical outcomes after UCL repair with augmentation. We showed that UCL repair with augmentation had equal time-zero strength and ultimate failure loads when compared to reconstruction [7]. Another study in 2018 by Dugas et al. demonstrated that UCL repairs with augmentation had significantly less gap formation a time zero as well as at the 100th and 500th cycles when compared to reconstructions [8]. Bachmeier et al. recently published a biomechanical study comparing UCL repair alone, UCL repair with Internal Brace augmentation, and UCL reconstruction with palmaris graft. They found that the UCL repair with augmentation provided statistically improved torsional resistance, loading capability, and decreased gap formation when compared to reconstruction and repair alone [1]. Dugas et al. in 2019 published a study prospectively evaluated 111 overhead athletes at least one year after repair of the UCL with augmentation and found that athletes were able to return to competition at a mean time of 6.7 months [4]. Paletta et al. in 2020 reported a 94% return to play at a mean time of 7.5 months in a cohort of 78 high school and college baseball players [9]. Dugas et al. reported five complications from their cohort of 111 patients, with three related to either ulnar neuritis or instability, one due to heterotopic ossification and one due to painful retained suture [4].

36.5 Conclusions

UCL repair with InternalBrace augmentation is a reproducible surgical procedure that has good biomechanical and clinical outcomes when appropriately indicated in the overhead throwing athlete.

Key Points

- Appropriate dissection and visualization of the MUCL are imperative for repair. When elevating the flexor mass, ensure that the muscle fascia is incised, not the fibers of the ligament.
- Fully evaluate the ligament to ensure that it is of good quality to repair. Proceed with reconstruction if tissue quality is poor, there are bony ossicles or fragments, or there is significant mid-substance or iatrogenic injury.
- Tunnel placement on the sublime tubercle and medial epicondyle must be at the insertion of the ligament to allow for isometric repair and augmentation.
- Confirm full range of motion and appropriate tension of the Internal Brace prior to fixing the second anchor. If anisometric, avoid overconstraining the joint and loosen the FiberTape.

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37 Medial Ulnar Collateral Ligament (MUCL) Reconstruction Using the Docking Technique

Evan E. Vellios, Christopher L. Camp, and Joshua S. Dines

37.1 Description

The rate of medial ulnar collateral ligament reconstruction (MUCL) continues to increase in overhead athletes resulting in numerous modifications to the original technique described by Jobe in 1986 [1]. MUCL reconstruction using the docking technique allows for the safe and reproducible establishment of anatomic valgus stability of the elbow in the overhead throwing athlete via docking of the chosen graft into a single humeral tunnel. Advantages to this technique include reduced bone removal from the ulna and medial epicondyle of the humerus, decreased injury to the flexor-pronator mass, optimal graft tensioning, and decreased handling of the ulnar nerve [1, 2].

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37.2 Key Principles

- Assess intra-articular pathology (i.e. posteromedial olecranon osteophytes) via elbow arthroscopy at the time of MUCL reconstruction.
- Tendon graft reconstruction of MUCL using a common flexor-pronator muscle mass split.
- Avoidance of obligatory ulnar nerve manipulation/transposition.
- Decrease risk of iatrogenic medial epicondyle fracture via reduction of humeral bone tunnels (1 vs. 3 in traditional Jobe technique).
- Simplified graft tensioning and fixation methods.

37.3 Expectations

- Return to preinjury level of play in greater than 90% of patients including elite athletes [2].
- Return to competitive pitching/throwing at roughly 1-year post-op.

37.4 Indications

- Valgus instability of the throwing elbow in athletes with complete or high-grade partial tears of the UCL and subjective inability to

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perform at the desired level due to medial elbow pain with attempts at throwing [1].
- Throwing athletes with partial UCL injuries who have failed conservative treatment with a graduated muscle strengthening and throwing program [3].

37.5 Contraindications

- Asymptomatic partial UCL tears in throwing and non-throwing athletes.
- Patients with severe ulnohumeral osteoarthritis.

37.6 Special Considerations

- Graft options for MUCL reconstruction include palmaris longus autograft, hamstring autograft, and soft-tissue allograft. Our preferred graft choice is ipsilateral palmaris longus autograft; however, this may be absent in some patients. Clinical examination should be performed prior to surgery documenting the presence/absence of the desired graft and preparations by the surgeon should be made accordingly.

37.7 Special Instructions, Positioning, and Anesthesia

- Supine with a hand table, if performing concomitant elbow arthroscopy prior to MUCL reconstruction the arm can be placed across the chest in an arm holder [1].
- Positioning the patient supine allows for performance of elbow arthroscopy prior to MUCL reconstruction in order to address concomitant intra-articular pathology or assess dynamic ligament stability [2].
- Regional anesthesia with sedation.
- Nonsterile tourniquet placed as high on the arm as possible.

37.8 Equipment Needed

- Looped stainless steel wire on a curved needle.
- No. 1 Ethibond and No. 0 Vicryl suture.
- Tendon stripper for graft harvest.
- 1.5 mm, 3.5 mm, and 4.5 mm burrs.

37.9 Tips, Pearls, and Lessons Learned

- Preserve branches of the medial antebrachial cutaneous nerve to prevent formation of a painful neuroma.
- Split the common flexor-pronator mass rather than detach it from its humeral insertion.
- Place the 4.5 mm humeral socket anterior and inferior on the medial epicondyle to allow for anatomic restoration of the ligament's humeral insertion.
- Place the 3.5 mm ulnar sockets (anterior and posterior) centered at the sublime tubercle to allow for anatomic restoration of the ligament's ulnar insertion.
- Space all bony sockets with no less than a 1 cm bone bridge to avoid fracture.
- Be precise when tensioning the second graft limb. If graft is cut too short, then it will run out before fully seating in the 4.5 mm socket. If graft is cut too long, then it will be overly laxed when fully seated in the 4.5 mm socket.
- Always tension the graft with the elbow in 30 degrees flexion, full supination, and with applied varus stress.

37.10 Difficulties Encountered

- Advanced imaging (MRI and CT scan) should be obtained in order to evaluate existing humeral and ulnar bone stock in the revision setting.
- Make sure to carefully identify location of ulnar nerve in patients with history of prior

MUCL reconstruction, cubital tunnel release, or ulnar nerve transposition.

- Those patients with pre-existing symptoms of ulnar neuropathy or dynamic ulnar nerve instability shoulder undergo concomitant cubital tunnel release with transposition at the time of MUCL reconstruction.

37.11 Key Procedural Steps 1, 2

Elbow arthroscopy through standard portals is performed in order to address any intra-articular pathology prior to MUCL reconstruction. The arm holder is then removed and the arm is laid flat on a hand table. Graft harvest is then performed according to the preference of the treating surgeon (ipsilateral palmaris longus autograft will be described here).

A roughly 1 cm transverse incision is made at the volar wrist crease directly over the desired tendon. A No. 1 Ethibond suture is then placed at the end of the tendon in Krakow fashion. The tendon is cut distally and a tendon stripper is then used to release the tendon proximally. The graft is then placed in saline soaked gauze on the back table and the volar wrist incision is closed. Attention is then turned to reconstruction of the MUCL.

The arm is exsanguinated and a tourniquet is inflated to 250 mmHg. An approximately 8 cm curvilinear incision centered on the medial epicondyle is created extending from the distal 1/3 of the medial intermuscular septum to roughly 2 cm distal to the sublime tubercle (Fig. 37.1).

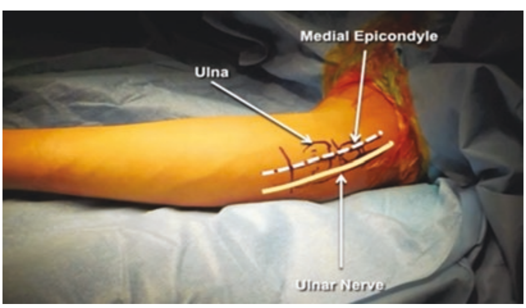

Fig. 37.1 Medial approach to the elbow highlighting key anatomic landmarks; ulna, medial epicondyle, path of the ulnar nerve, and planned incision (dashed line)

Dissection is carried down to the level of the flexor-pronator fascia being careful not to damage subcutaneous branches of the medial antebrachial cutaneous nerve. The common flexor-pronator mass is then sharply split in its posterior 1/3 and blunt dissection is carried down to the level of the MUCL and ulnohumeral joint capsule (Fig. 37.2). The anterior bundle of the MUCL is then incised longitudinally exposing the underlying joint (Fig. 37.2). Attention is then turned to preparation of the ulnar tunnels.

Subperiosteal dissection is carried out along the anterior and posterior aspects of the sublime tubercle taking care to protect the ulnar nerve (Fig. 37.2). A 3.5 mm burr is then used to create two converging tunnels on either side of the sublime tubercle with a 1–2 cm bone bridge between them. Confirmation of tunnel convergence can be made with a small curved curette. A No. 0 Vicryl suture is then passed through the tunnels using a free needle and looped stainless steel wire. This will be used later to help with graft passage through the ulnar tunnels. Attention is then turned to preparation of the humeral docking site.

A 4.5 mm burr is used to create a 15 mm deep socket on the anterior inferior surface of the medial epicondyle at the center of the MUCL's anatomic footprint (Fig. 37.2). Care is taken to protect the ulnar nerve and avoid penetration of the burr through the posterior (far) cortex. A 1.5 mm burr is then used to create two small sockets separated by a bone bridge of at least 1 cm and converging with the original 4.5 mm socket (Y shaped configuration). These 1.5 mm sockets should begin anterior to the medial intermuscular septum. Socket convergence can be confirmed via contact of the 1.5 mm burr with a small curved curette placed in the main 4.5 mm docking tunnel. A No. 0 Vicryl suture is then passed through each 1.5 mm socket and out the 4.5 mm docking socket using a free needle and looped stainless steel wire. The looped ends of the sutures should be exiting the 4.5 mm docking tunnel, while the free ends should be exiting the 1.5 mm suture tunnels. Prior to graft passage, the native MUCL and joint capsule are closed with the elbow in 30 degrees of flexion, maximal fore-

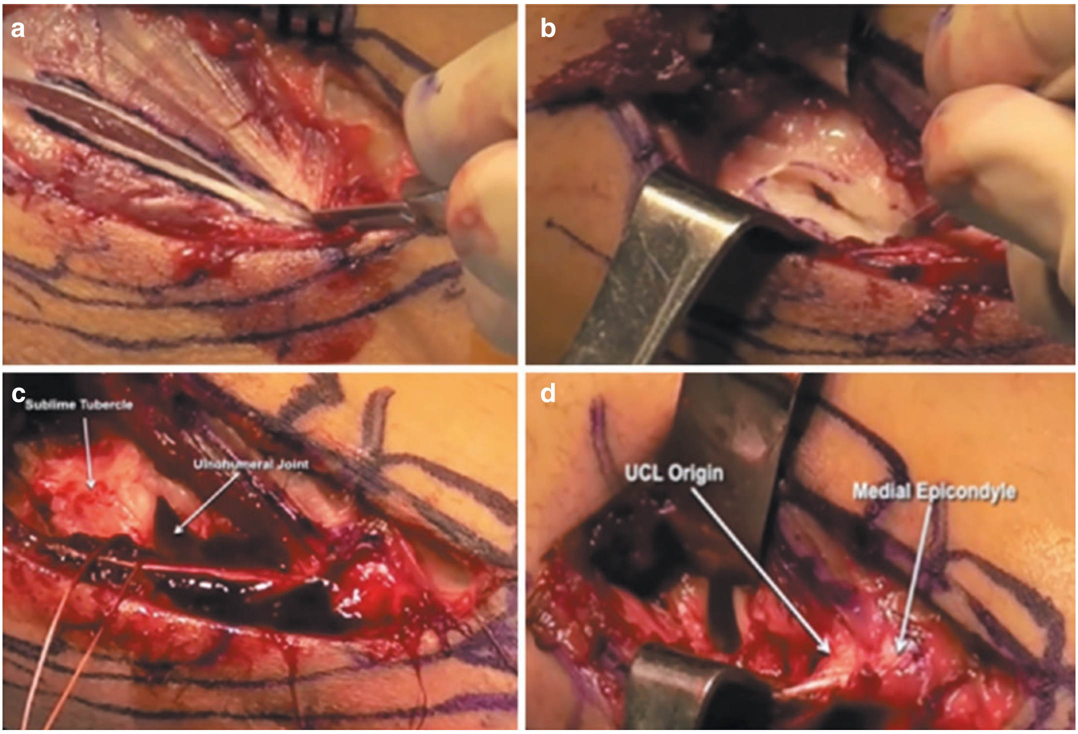

Fig. 37.2 (**a**–**d**) FCU splitting approach (**a**), longitudinal incision of native MUCL and underlying capsule (**b**), exposed sublime tubercle for ulnar sided tunnel (**c**), exposed medial epicondyle for humeral tunnel (**d**)

arm supination, and applied varus stress. The elbow will be held in this position by an assistant for the remainder of the procedure. Attention is now turned to passage of the graft. The looped No. 0 Vicryl suture in the ulnar tunnel is used to pass the distal end of the graft with Krakow sutures from anterior to posterior (Fig. 37.3). This same distal end is then passed into the 4.5 mm humeral docking socket and the corresponding sutures are pulled out through the posterior 1.5 mm humeral tunnel. As tension is maintained on the sutures existing the posterior humeral tunnel the remaining graft is tensioned toward the 4.5 mm socket and a marking pen is used to mark the location of the graft at the entry site. A No. 1 Ethibond suture is then passed in Krakow fashion beginning at this marked entry point and traveling roughly 1 cm distally toward the free end. The excess graft is then excised and the looped 0 Vicryl passing suture is used to pass the free ends of the Ethibond suture through the 4.5 mm humeral socket and out the anterior 1.5 mm humeral tunnel effectively docking the graft (Fig. 37.3). The graft is then tensioned by pulling on the Ethibond sutures exiting the anterior and posterior 1.5 mm humeral tunnels and the graft is cycled via repetitive elbow flexion and extension. Finally, the elbow is placed back in approximately 30 degrees of flexion, maximal supination, and applied varus stress as the sutures are tied together over the humeral bone bridge. A free needle is then used to bury the residual suture knot beneath the fascia of the common flexor-pronator mass to decrease irritation of the subcutaneous tissues (Fig. 37.3). The wound is then irrigated, closed in layers, and placed in a well-padded long arm posterior splint in approximately 60–75 degrees of flexion.

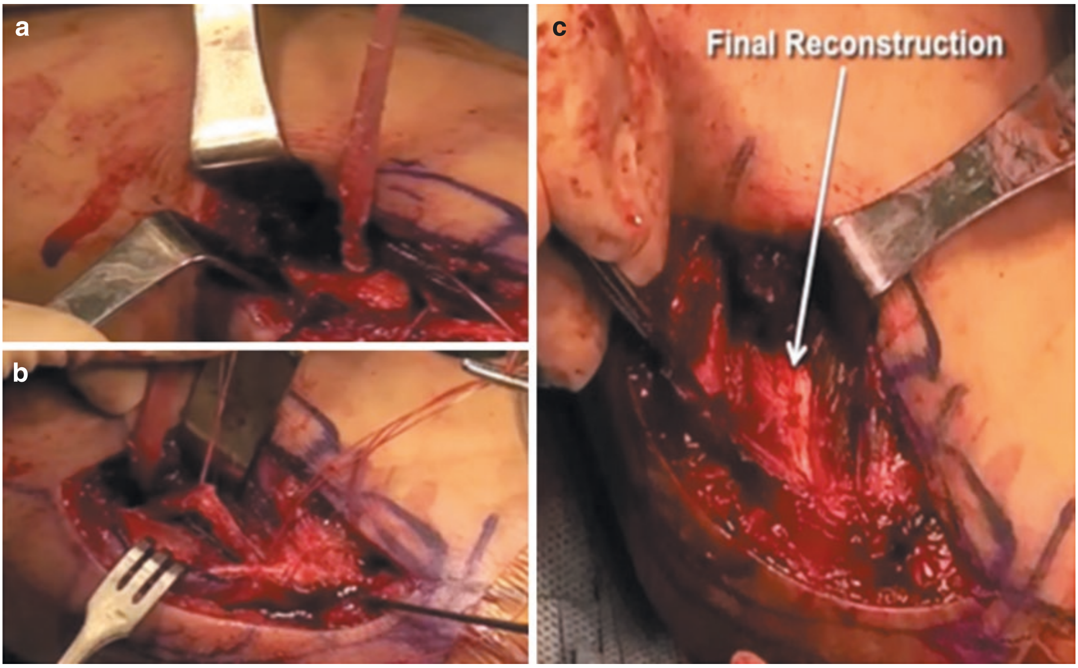

Fig. 37.3 (**a**–**c**) Passage of graft through ulnar tunnel from anterior to posterior (**a**), docking of anterior limb of graft following tensioning (**b**), final reconstructed MUCL (**c**)

37.12 Bailout, Rescue, and Salvage Procedures

- In the event that the bone bridge between the two 1.5 mm humeral tunnels breaks a burr can be used to widen the aperture and a soft tissue tenodesis screw may be inserted for humeral fixation [4].
- If poor ulnar bone is available or fracture of the 3.5 mm ulnar tunnels occurs, ulnar fixation of the graft can be achieved via placement of a soft tissue tenodesis screw or via the use of an intramedullary or extramedullary button.

37.13 Pitfalls

- As the ulnar nerve is not routinely visualized, the surgeon must remain mindful of its location during the drilling of bone tunnels in order to avoid iatrogenic injury.
- Careful and precise placement of bone tunnels is required to ensure proper coalescence in the desired anatomic locations.

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Medial Ulnar Collateral Ligament (MUCL) Reconstruction Using the Anatomic Technique

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Key Points

- Anatomic MUCL reconstruction technique more closely reflects native anatomy compared to previous techniques.
- The anatomic technique has demonstrated higher load to failure compared to the docking technique in biomechanical models.
- Increased tendon-to-bone contact through multipoint fixation and the ability to sequentially re-tension grafts are possible with this technique.
- Initial biomechanical studies are promising, but further clinical investigation is needed.

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38.1 Pre-operative Planning and Positioning

Pre-operative planning includes a thorough history and physical exam of the elbow. Typical imaging studies include plain radiographs and an MRI. Intraoperatively, patients should be positioned supine with the arm out on an arm board. The entire arm should be prepared for surgery including the ipsilateral anterior wrist for graft harvest.

38.2 Graft Harvest

When present, palmaris longus autograft is our preferred graft; however, gracilis autograft or allograft may also be used. Harvesting the palmaris longus autograft begins with a 1-cm over the tendon at the proximal wrist crease. Exposure and identification require minimal superficial dissection as the tendon is located immediately below the skin. Care should be taken to dissect only as deep as is necessary to harvest the tendon to avoid injuring other structures of the wrist. The distal portion of the tendon is sutured, cut, and a small, standard tendon stripper is passed proximally to procure the graft.

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38.3 Incision and Exposure

Important anatomic landmarks of the elbow should be marked out including the medial epicondyle (ME) and the ulnar nerve. A 6–8 cm incision is made beginning 2 cm proximal to the ME and extending 4–6 cm distal to the ME. Care is taken to identify and preserve branches of the medial antebrachial cutaneous nerve. The fascia of the common flexor mass is identified and split in line with its fibers. This split is generally centered over the sublime tubercle, which can be palpated through the flexor musculature. Blunt dissection is carried out through the underlying muscle taking care to minimize damage to the muscle. Continued dissection down to the sublime tubercle allows for easy identification of the MUCL. The MUCL is sharply incised in line with its fibers to expose the joint line.

38.4 Preparation of Humeral Socket on Medial Epicondyle

The following steps outline the novel anatomic technique which was first described in 2019 [1]. The humeral footprint of the MUCL at the anterior–inferior surface of the medial epicondyle is identified subperiosteally. A 4.0-mm diameter socket is created using a drill or burr at the center of the humeral footprint at a depth of 15 mm. Great care is taken to protect the ulnar nerve and to prevent penetration of the far cortex as the socket is directed proximal and posterior. Two small (2-mm) perforating tunnels that converge with the single 4.0-mm socket are created from the anterior humerus. The two 2-mm tunnels should be just anterior to the medial intermuscular septum and at least 10 mm apart from one another. The free ends of an unassembled, all-suture adjustable suspensory loop device (Tightrope, Arthrex Inc) are passed from the smaller 2-mm tunnels out through the larger 4-mm socket using two separate shuttling sutures. The palmaris autograft is then folded over in half, and the suspensory loop is assembled around the mid-portion of the graft. Tensioning of the suspensory loop is performed in order to reduce the graft 10 mm into the humeral socket, which is two-thirds of the total socket depth, thus leaving additional space for sequential tensioning after graft fixation onto the ulna (Fig. 38.1a).

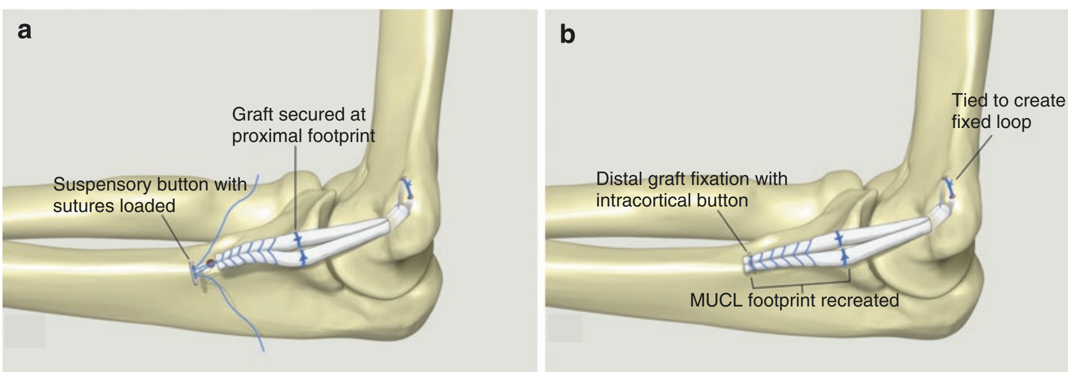

Fig. 38.1 MUCL reconstruction using the anatomic technique. (**a**) The graft is attached and reduced into the humeral socket on the medial epicondyle via suspensory loop fixation. (**b**) All-suture anchors are placed in the ulna and are (**c**) secured onto the graft at the proximal MUCL footprint. (**c**) A looped suture is utilized to whipstitch the graft, and this is fastened onto a cortical button, (**d**) which is then secured at the distal MUCL footprint. ([1], © 2018 MAYO)

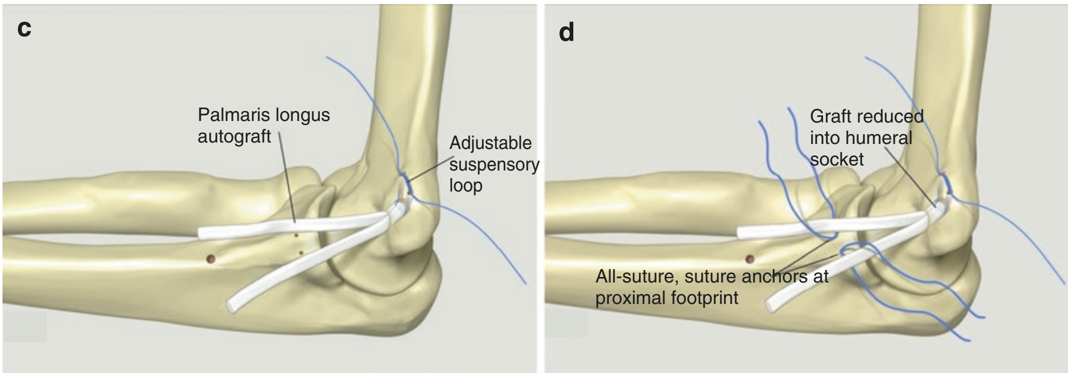

Fig. 38.1 (continued)

38.5 Preparation of Proximal Ulnar Footprint

Attention is then turned to the ulnar side. Two 1.3-mm all-suture anchors (FiberTak; ArthrexInc) are placed just distal to the joint line (5 mm) at the anterior and posterior aspects of the proximal native MUCL footprint. These two all-suture anchors are spaced approximately 5 mm apart, tagged, and set aside (Fig. 38.1b). A No. 2-0 absorbable suture is utilized for closure of the native MUCL and capsule. The suture is placed prior to graft passage; however, it is not tied down and secured until after graft passage is completed.

38.6 Preparation of Distal Ulnar Footprint and Graft Fixation

For creation of the distal footprint, a closed-loop No. 0 nonabsorbable suture (FiberLoop; ArthrexInc) is utilized to suture the two distal limbs of the graft in a whipstitch fashion, and excess graft length is then excised. The looped suture is then cut to create two free suture ends which are fastened onto an intramedullary cortical suspensory button (Arthrex Inc) (Fig. 38.1c). Next, the proximal sutures from the all-suture anchors near the joint line are passed around each limb of the graft, with the anterior sutures passed around the anterior limb and the posterior sutures around the posterior limb.

Following graft tensioning and cycling, the elbow is maintained at 30° of flexion with a slight varus load applied, and the sutures from the proximal footprint anchors are secured around each limb of the graft. This creates the proximal aspect of the triangular-shaped, native MUCL footprint on the ulna. For distal fixation, a 3.2-mm drill hole is created at the distal apex of the ulnar footprint in a unicortical fashion. After successful deployment of the cortical button, the sutures are then tensioned to reduce the graft onto the ulna. A final closed-loop construct is created at the distal end by tightening the sutures over the top of the graft and tieing them securely. On the humeral side, the proximal suspensory loop is once again tensioned, and the suture ends are tied over the bone bridge on the medial epicondyle to create the proximal closed-loop construct (Fig. 38.1d). The No. 2-0 absorbable suture, previously placed in the native MUCL and capsule, is then tightened and secured to ensure that the graft remains extra-articular.

38.7 Internal Brace Augmentation

If desired, this construct can easily be supplemented with a suture tape. The tape follows the path of the graft. It would be passed with the graft through the loop on the humeral side before the graft is reduced into the humeral socket. The free ends of the graft can be loaded onto the intracortial button on the ulnar side before it is deployed into the ulna.

38.8 Postoperative Management

The patient is placed in an elbow splint following surgery with the elbow positioned at approximately 70° of flexion and neutral rotation. At postoperative Week 1, the patient is transitioned from the splint to a hinged elbow brace. Range of motion is initially limited to 30–90° and advanced to 15–105° between Weeks 3 and 5. Afterwards, free motion is allowed and the brace is discontinued at 6 weeks postoperative. At this time, formal physical therapy focuses on elbow ROM and shoulder and wrist strength and ROM. Physical therapy is advanced as tolerated until Week 16 when a formal throwing program is initiated and advanced. The patient is permitted to begin throwing from the mound only once they are able to consistently throw long toss at 120 ft without pain. Throwing from the mound is advanced over the course of 2–3 months with the ultimate goal of return to play 12 months postoperatively. Complication rates specific to the anatomic technique have yet to be investigated; however, anatomic technique complications are likely similar to those seen with other techniques (i.e. ulnar neurapraxia, reoperation, superficial infection) [2].

38.9 Conclusion

The anatomic-based reconstruction approach has been successfully applied to other injured ligaments in the body, such as anterior cruciate ligament and medial collateral ligament reconstruction [3–5]. This described technique allows a more anatomic reconstruction geometry that more closely mirrors native MUCL anatomy. Biomechanical evaluation of the anatomically repaired MUCL has demonstrated that the average load required for failure is 31.9 N m, which is superior to the commonly used techniques and is most similar to that of the native ligament [1, 6, 7]. Several unique advantages of the anatomic technique compared to the commonly used MUCL reconstruction techniques are listed in Table 38.1 [8]. Ultimately, the higher load to failure and close replication of native ligament anatomy in terms of the ulnar footprint and overall geometry may confer greater potential benefit, and future clinical studies are technique optimization are warranted.

Table 38.1 Advantages of utilizing the novel anatomic technique for UCL reconstruction [1]

Ulnar side	Humeral side
Increased tendon-to-bone contact	Decreased suture burden in the socket
Multipoint fixation	Allows for measurement of graft diameter prior to drilling the socket
Larger surface area (may be target for biologic augmentation)	Increased tendon-to-bone contact in the humeral socket, which may promote healing
No ulnar tunnel (may reduce risk to ulnar nerve injury)	Sequential re-tensioning of graft after fixation
Potential for larger graft size without additional bone removal	
For revision setting, prior ulnar tunnels can be spanned and avoided	
Sequential re-tensioning of graft after fixation	

Multiple Choice Questions

1. Which of the following is NOT a potential advantage of the anatomic technique for MUCL reconstruction?
   - (a) Decreased suture burden in the humeral socket
   - (b) Increased tendon-to-bone contact
   - (c) **Decreased number of fixation devices**
   - (d) Sequential re-tensioning of graft after initial fixation
2. Based on the current literature comparing the biomechanics of the anatomic and docking techniques which of the following is true?
   - (a) Rotational stiffness was significantly lesser in the docking technique
   - (b) **Ultimate load to failure was significantly greater in the anatomic technique**
   - (c) A and B are both true
   - (d) A and B are both false
3. What is the goal return to play time following MUCL Reconstruction?

(a) 4 months
(b) 6 months
(c) **12 months**
(d) 24 months

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39 Osteochondral Autograft Transplantation Surgery (OATS) for Capitellar Osteochondritis Dissecans (OCD)

Michael D. Galetta, Monica M. Shoji, and Luke S. Oh

Key Points

- A 45° flexion AP radiograph demonstrates abnormalities of the capitellum suggestive of osteochondritis dissecans better than a standard AP radiograph in full extension.
- It is important to assess whether or not the lateral wall of the capitellum is intact ("contained") or disrupted ("uncontained") since its status has implications on surgical techniques and prognosis.
- A CT scan may be useful if radiographs or MRI does not offer definitive information regarding whether the lesion is contained or uncontained.
- When obtaining a donor plug for an osteochondral autograft transfer from the lateral femoral condyle of the knee, harvest superiorly to the sulcus terminalis.
- When planning for an osteochondral autograft transfer from the knee to the elbow, obtaining plain radiographs of both the elbow and the knee is useful to assess the status of the growth plates.

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39.1 OCD: Etiology and Epidemiology

Osteochondritis dissecans (OCD) of the humeral capitellum is a necrotic osteochondral lesion which can cause pain and/or mechanical maladies of the elbow (decreased range of motion, catching, locking, etc.) [1, 2]. While capitellar OCD has been documented since 1887 by Dr. Franz König [3], its etiology remains unclear. Some providers describe an idiopathic nature of OCD, while others attribute OCD to family history or genetic predisposition [2]. The most plausible theories describe microtrauma from repetitive radiocapitellar joint loading, in an area of diminished vascularity, leading to necrotic subchondral bone, mechanical failure, articular cartilage injury, and/or loose body formation [2].

Reported incidence rates for capitellar OCD are highest among adolescent gymnasts and overhead-throwing athletes [4], with increased predisposition for males than females [5]. Lesion location may vary throughout the capitellum, but most lesions have been found in its posterolateral aspect [6]. Lesions are reported to develop between 30° and 56° anterior to the humeral axis

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[6–8], with gymnasts' lesions located more posteriorly than overhead throwers' lesions [4].

39.2 Treatment

Treatment for OCD can be either conservative or operative. Primary decision-making variables include skeletal age, lesion stability, and clinical exam [2, 9–11]. Standard elbow and knee radiographs (anteroposterior and lateral views) as well as MRI are the imaging modalities of choice for assessing and staging OCD lesions. A 45° flexion AP elbow radiograph is better than a standard AP elbow radiograph in full extension in order to detect abnormalities suggestive of osteochondritis dissecans. It is important to assess the physes on both the elbow and knee on plain radiographs if considering OATS for surgical management. For MRI, the T2 weighted images in particular help to determine if the lesion may be unstable. A CT scan may be useful if radiographs or MRI does not offer definitive information regarding the status of the lateral wall of the capitellum in order to determine whether the lesion is contained or uncontained.

For low-grade stable lesions, conservative treatment is recommended, consisting of activity modification, rest, tincture of time, and/or immobilization until adequate healing [11, 12]. Conservative measures are more likely to fail in skeletally mature patients with radial head enlargement from repetitive valgus overloading [10]. Symptoms persisting for 3–6 months portend a poor prognosis with nonoperative treatment and usually indicate need for surgical management [9, 11, 13]. High-grade, unstable lesions, or loose bodies are indications for surgical treatment [11, 13], especially in the presence of mechanical dysfunction or pain which inhibits normal activities [2, 9].

39.2.1 Surgical Management

Surgical management for OCD has historically included many different procedures, including microfracture/marrow venting, drilling, fixation, or articular cartilage reconstructive procedures (i.e., OATS, osteochondral allograft implantation, autologous chondrocyte implantation). Indications for each type of procedure are based on lesion size, overlying cartilage health, symptom duration, and amount of extension into the lateral capitellum [2, 11, 12]. The chosen surgical procedures are often determined from arthroscopic findings of lesion size, location, and stability. Smaller lesions are typically treated with debridement and/or loose body removal, while larger lesions may require osteochondral grafting [9].

OATS remains the authors' primary treatment method of choice for large unstable lesions or lesions not responding well to conservative treatment [2, 14]. Relative contraindications for OATS include painless stable lesions, traumatic cartilage shear injuries, Panner's disease, or excessively large lesion size—especially if the lateral wall is heavily compromised [14]. When indicated, reconstructive procedures such as OATS have higher reported success rates than that of microfracture, drilling, or fixation [2]. Further, in a comparative study, OATS outperformed all other surgical managements for capitellar OCD, resulting in a 94% return to sport rate [15]. The ability to replace both the compromised subchondral bone and cartilage by using an osteochondral graft is hypothesized to explain this relative success [12]. It is for these reasons that OATS remains the treatment of choice for many physicians treating capitellar OCD. We will now offer a detailed description of the open OATS procedure, accompanied by recommendations from the authors' experience.

39.3 Open OATS: Surgical Walkthrough

The OATS procedure involves harvesting one or multiple osteochondral grafts from an autologous donor site. While techniques such as the mosaicplasty using multiple osteochondral plugs have been described, the authors' preference is to use a single plug when possible, and two plugs if needed. Various autologous donor sites have been described in the literature, including the knees, ribs, radial head, and lateral olecranon tip [9, 16]. The authors' preferred donor site is the ipsilateral knee at the lateral femoral condyle superior to the sulcus terminalis. If the patient is younger than 14 years old, we recommend obtaining preoperative knee radiographs to assess the physis of the knee.

39.3.1 Recipient Site Exposure

The open OATS procedure begins with exposure of the capitellar OCD lesion. We prefer the anconeus-split approach, which allows excellent access posteriorly to the capitellum. This approach begins with a skin incision longitudinally directly over the capitellum. The anconeus fascia is incised in line with the skin incision and an intramuscular interval is developed via blunt dissection in line with the muscle fibers. Then, the capsule is identified and sharply incised to expose the capitellar articular surface. The capsule is typically opened along the posterior edge of the lateral ulnar collateral ligament (LUCL). With varus stress applied to the elbow and maximum pronation of the forearm, visualization and access to the capitellum are able to be achieved. In rare cases, particularly when the OCD lesion is more anterior or medial, the proximal attachment of the LUCL may need to be peeled off the lateral epicondyle in order to ensure adequate visualization and access, with subsequent repair of the proximal LUCL with an anchor at the end of the procedure. When additional exposure is required for those capitellar OCD lesions that are more anterior or medial, other techniques have been proposed in the literature, such as lateral epicondyle osteotomy or an extended Kocher's approach. Although these other techniques for improving surgical exposure are viable options, we have found that peeling off the proximal LUCL and repairing it with an anchor at the end of the procedure has been the easiest and most reliable technique in our hands.

39.3.2 Recipient Site Preparation

Once adequate exposure of the capitellum is achieved, the lesion is identified and inspected. A probe is used to delineate the transition between healthy and unhealthy cartilage to define the borders of the OCD lesion. Loose bodies/fragments in the radiocapitellar joint are removed as needed. If preoperative imaging demonstrated the presence of loose bodies in the posterior, anterior, or medial compartment of the elbow, then an arthroscopy may be required to remove these loose bodies in locations that would not be accessible through the open anconeus-split surgical exposure.

The diameter and shape of the OCD lesion are measured in order to appropriately size the necessary autograft (Figs. 39.1 and 39.2). Our preference is to use a single donor plug to replace the OCD lesion. However, if the size or shape of the OCD lesion requires two donor plugs, then meticulous measurements are required to successfully execute the surgical strategy for either a stacked ("Snowman" technique) or overlapping donor plugs ("MasterCard" technique). A cylindrical OATS Recipient Site Harvester chisel (Fig. 39.3) that best matches the diameter of the OCD lesion is selected (either 6, 8, or 10 mm) and then used to harvest the lesion (Fig. 39.4) measuring 10 mm in depth. When removing the

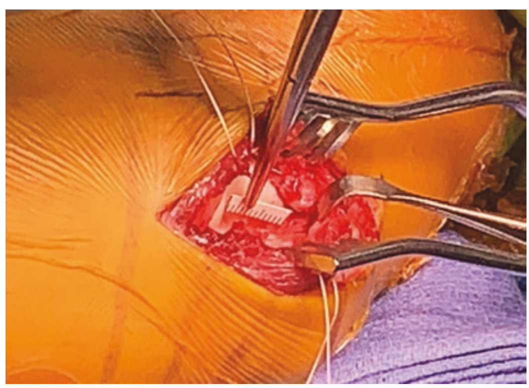

Fig. 39.1 Measuring width of native capitellar OCD lesion

injured capitellar cartilage and subchondral bone, extreme care must be taken to stay perpendicular to the articular surface while using a mallet to insert the Recipient Site Harvester into the capitellum. This orientation is necessary to: (1) maintain the orientation of the plug to be flush with the surrounding articular cartilage, (2) be able to capture the cartilage and subchondral bone within the Recipient Site Harvester. If there is motion of the Recipient Site Harvester during insertion into the capitellum, too much space may be created between the Recipient Site Harvester and the surrounding outer perimeter of the capitellum, which will result in "rocking" of the Harvester and loss of the ability to capture the plug inside the Harvester, and (3) prevent penetration of the lateral or posterior walls of the capitellum which may compromise the ability to implant the donor plug in a stable fashion [2, 9, 17].

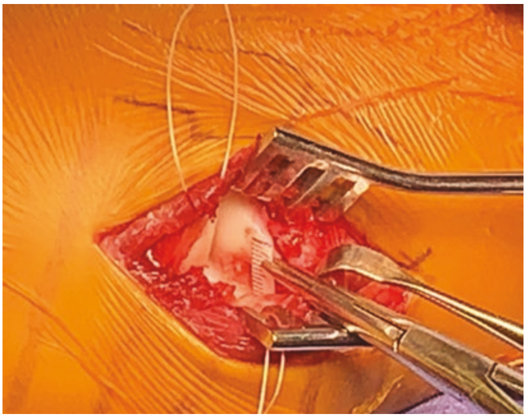

Fig. 39.2 Measuring the height of the native capitellar OCD lesion

39.3.3 Donor Site Autograft Harvest

An open arthrotomy of the ipsilateral knee is used to access and harvest the donor osteochondral autograft from the non-weight bearing portion of the lateral femoral condyle. A small lateral parapatellar approach (Fig. 39.5) allows adequate exposure of the lateral femoral condyle. With the knee in full extension, the typical size of the incision extends along the lateral edge of the patella from the level of the equator of the patella to the inferior pole of the patella. After dissecting through subcutaneous tissue to expose the lateral retinaculum, a small arthrotomy is made in line with the skin incision. An approximately 1 cm

Fig. 39.3 Graft harvester and recipient harvester for OATS procedure (OATS Single Use Kit, Arthrex Inc., Naples, FL)

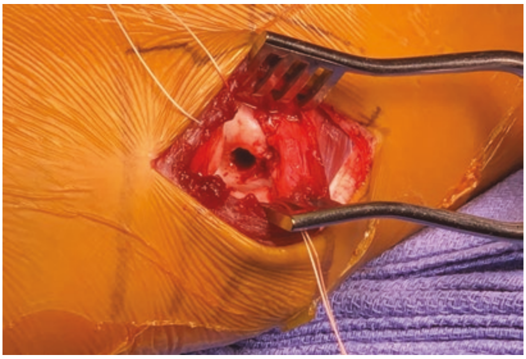

Fig. 39.4 Capitellum after preparation for donor graft

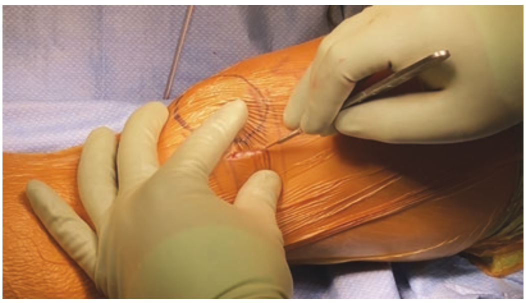

Fig. 39.5 Lateral parapatellar approach

Fig. 39.6 Donor graft harvest from the lateral femoral condyle

cuff of retinaculum is left on the patella when making the arthrotomy to allow for repair at the end of the procedure. We prefer to use a Z-retractor that is placed medially in the intercondylar notch in order to retract the patella, and an Army-Navy retractor (or a thinner Thyroid retractor, depending on the size of the patient) placed laterally in order to expose the proximal aspect of the lateral femoral condyle. When harvesting the donor site, it is critical to stay superior to the sulcus terminalis, which demarcates the less-weight bearing portion of the lateral femoral condyle. Intraoperative radiographs can be used to demarcate the physis as needed to avoid iatrogenic injury during the donor site harvest. The corresponding size plug is then harvested, with care taken to stay perpendicular to the condylar surface when using the OATS Donor Site Harvester chisel (Fig. 39.6). The osteochondral plug that was removed from the capitellum is then implanted into the donor site defect in the lateral femoral condyle. Since the donor site is on the less-weight bearing region of the lateral femoral condyle, the goal of inserting the plug obtained from the capitellum into the donor site defect is not to restore the cartilage surface in the lateral femoral condyle. Rather, it is to offer a back-fill to the donor site defect in order to reduce bleeding. In the past, one of the highest complications that required a reoperation was knee hematoma formation that resulted in surgical evacuation of hematoma with irrigation and debridement. Typically, the osteochondral plug from the capitellum needs to be pushed into the donor site defect and impacted into place, and the final resting position of that osteochondral plug from the capitellum is recessed below the level of the surrounding articular cartilage. After irrigation of the knee, a layered closure is performed, and a sterile bandage applied. Postoperatively, range of motion is restricted from full extension to 90° during the first month after surgery in order to reduce the tensile load on the lateral sided arthrotomy that may be introduced with flexion beyond 90°. The patient may be weight-bearing as tolerated on the lower extremity postoperatively.

39.3.4 Graft Acceptance

Use the metal rod provided in the OATS kit to confirm the depth of the recipient site on the capitellum. Then, carefully study the depth of the donor plug circumferentially while it is in the Donor Site Harvester. The markings on the Donor Site Harvester will assist in determining whether or not the donor plug will need to be inserted while rotated in a particular orientation in order to best match the depth of the recipient site with the length of the donor plug. The harvested donor graft is then aligned at the recipient site on the capitellum for acceptance into the defect (Fig. 39.7). The donor cylindrical plug of osteochondral autograft is gently press fit into the capitellar defect (Fig. 39.8), using an oversized plastic bone tamp and delicately tapping with the mallet until it appears flush with the surrounding capitellar articular surface. When using the bone tamp, care must be taken to use repetitive, low amplitude impactions, rather than a few large amplitude impactions. High forces must be avoided for fear of graft chondrolysis and resultant osteoarthritic changes postoperatively. The elbow is visually inspected and again probed in order to ensure the graft is flush with the surrounding articular cartilage. The range of motion of the elbow is tested to ensure full range of motion without block or crepitus. A layered closure of the capsule and anconeus fascia is performed, followed by subcutaneous tissue then skin. The elbow is then dressed and placed into a hinged brace locked at 75° during the first week. Passive and active-assisted range of motion to tolerance within the postsurgical dressing is started within 1 week of surgery. The hinged brace is unlocked 1 week after surgery and is worn for 4 weeks in total. If a LUCL repair was performed, this bracing period is increased to 6 weeks.

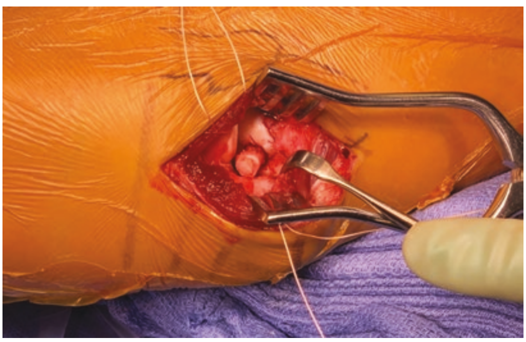

Fig. 39.7 Introduction of the donor graft into the recipient site

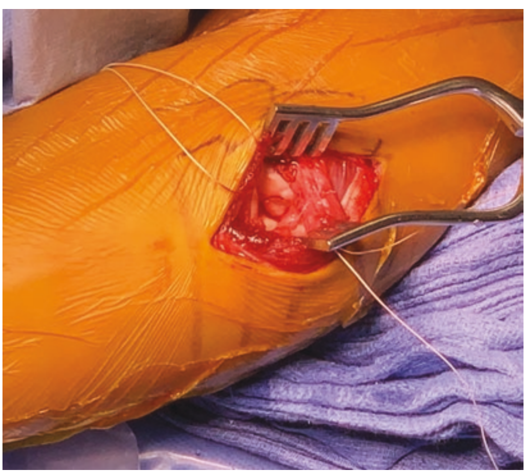

Fig. 39.8 Final press fit of the donor graft into the capitellum

39.3.5 Complications

A recent systematic review on capitellar OATS reports complication rates, reoperation rates, and failure rates ranging from 0% to 11%, 0–26%, and 0–20%, respectively [11]. The most common complication from OATS is donor site morbidity and/or anterior knee pain [15], which has been reported in approximately 7.8% of patients [18].

39.4 Rehabilitation and Return to Sport

Rehabilitation after OATS procedures can begin acutely within the first week of recovery. Goals are to balance protection of the graft with management of pain, swelling, and range of motion. Modalities often consist of early and consistent passive range of motion, active-assisted range of motion, manual therapy, and compression garments. Specific attention is given to the biceps and brachialis muscles to prevent a loss of elbow extension. Grip strengthening exercises are encouraged as tolerated. Progression to move into subsequent phases is dependent on full passive range of motion of the elbow and painless light-load activities of daily living, such as brushing teeth, dressing, and showering. Additional precautions may be necessary for those cases in which the LUCL was peeled off and repaired for additional surgical exposure.

After the first few weeks of rehabilitation, attention is expanded to the surrounding wrist and shoulder joints to regain functional use of the entire upper extremity. Range of motion exercises and light strengthening work are prescribed in addition to the earlier modalities listed. For gymnasts requiring upper extremity weight-bearing, we recommend initiation of a weight-bearing progression at 8 weeks. This recommendation allows for adequate osseointegration of the graft into the capitellum while also promoting positive cartilage adaptations due to healthy load. Although there is basic science research to support this recommendation [19], there are no clinical studies comparing early versus late upper extremity weight-bearing restrictions after capitellar OATS—a clear gap for future research.

Progressive strengthening exercises are then prescribed to regain athletic ability, if applicable. According to a meta-analysis on return to sport following surgical management of capitellar OCD, the cumulative return to sport rate after any surgical management averages at 86% of patients at a mean of 5.6 months [15]. For OATS specifically, this rate increases to 94% [15]; however, lateral lesions treated with OATS had a much lower return to play rate than centralized lesions (25–86%) [20, 21], highlighting the importance of maintaining lateral wall integrity on return to preinjury levels of activity.

39.5 Summary

The OATS procedure is a highly effective treatment for capitellar OCD. OATS reconstruction is correlated with superior outcomes in comparison to other operative treatments—particularly for larger, unstable lesions. Care must be taken to preserve the lateral wall of the capitellum during surgery. Patients typically tolerate this procedure well, with a return to sport rate of approximately 94%.

Questions/Answers

Question 1: What are the relative OCD lesion locations typically observed in gymnasts vs. overhead-throwing athletes, respectively?

(a) Posterior, posterior
(b) Anterior, posterior
(c) Posterior, anterior
(d) Anterior, anterior
(e) None of the above

Answer: c. Posterior, anterior

Question 2: Other than the knee, what are some alternative donor sites that may be used for capitellar OATS?

(a) Radial head
(b) Lateral olecranon tip
(c) Ribs
(d) All of the above
(e) None of the above

Answer: d. All of the above

Question 3: What is the rate of donor site morbidity following capitellar OATS from the knee?

(a) 2.1%
(b) 7.8%
(c) 16.6%
(d) 24.0%
(e) 33.3%

Answer: b. 7.8%

Question 4: What is the approximate return to sport rate following a capitellar OATS procedure?

(a) 25%
(b) 68%
(c) 76%
(d) 86%
(e) 94%

Answer: e. 94%

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40 Triceps Tendon Repair

James B. Carr II, Jonathan Yu, and Answorth A. Allen

40.1 Description

The triceps brachii muscle is comprised of the long, lateral, and medial heads. These three muscle heads form a single tendon that attaches in a dome-shaped pattern directly to the olecranon and indirectly to the lateral fascia of the forearm. The most common mechanisms for a triceps tendon rupture include a fall onto an outstretched arm or sudden failure during weightlifting or athletic activity. These injuries occur most frequently in 30–50 year-old males [1, 2]. Younger patients are prone to acute injuries from athletic participation, while older patients are subject to a degenerative tear pattern [1].

Diagnosis is usually made by physical examination and ultimately confirmed by magnetic resonance imaging (MRI) or ultrasound. Examination often reveals posterior elbow pain with associated ecchymosis, a palpable defect at the triceps insertion site, and weakness or inability to extend the elbow against gravity. Advanced imaging gives definitive radiologic diagnosis and helps assess the degree of injury and amount of tendon retraction.

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40.2 Key Principles

A number of fixation options are available for primary triceps tendon repair, including all-suture transosseous tunnel fixation [3, 4], single row suture anchor fixation [5, 6], double row suture anchor fixation [7–9], and hybrid transosseous tunnel-suture anchor fixation. Achilles tendon allograft augmentation should be considered in the setting of poor tendon quality, significant tendon retraction, inability to perform direct repair, or revision triceps repair.

40.3 Expectations

In cases of acute triceps tendon rupture, a robust, direct repair with the elbow in extension should allow restoration of the extensor mechanism. Ideally, repair should occur within 3 weeks of injury to avoid retraction and excessive scar tissue formation. Appropriate post-operative immobilization and physical therapy can aid in healing and reduce the risk of an extensor lag. Return to non-competitive athletic activity can usually be achieved by 6 months. Competitive athletes may take a full year to achieve maximum extension strength.

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https://doi.org/10.1007/978-3-031-08080-7_40

40.4 Indications

- Complete triceps tendon rupture
- Partial triceps tendon rupture >50% of tendon width
- Failure of conservative management after partial triceps tendon rupture <50% of tendon width, especially in high level athletes

40.5 Contraindications

- Acute infection of the soft tissue or elbow joint
- Major neurologic dysfunction of the triceps muscle
- Significant medical co-morbidities that preclude induction of anesthesia
- Surrounding soft tissue loss or poor quality of the skin (relative)

40.6 Special Considerations

Detailed preoperative assessment of the triceps tendon quality, size of the tear, amount of tendon retraction, and any bony involvement is critical to success. The anticipated quality of the patient's bone density should be considered when planning the fixation construct. If there is any doubt about the feasibility of a direct repair to the olecranon, then the surgeon should be prepared to perform Achilles tendon allograft augmentation. This should be anticipated prior to the day of surgery to ensure that an appropriate fresh frozen allograft is available.

40.7 Special Instructions, Positioning, and Anesthesia

- Regional anesthesia with sedation
- Lateral decubitus position with a lateral arm holder. Prone and supine positioning have also been described. We prefer lateral decubitus positioning because of ease of positioning while maintaining normal orientation of the anatomy.
- Non-sterile arm-high tourniquet above anticipated incision site

40.8 Tips, Pearls, and Lessons Learned

- Protection of the Ulnar Nerve: Depending on the desired surgical exposure, the ulnar nerve may be identified within the cubital tunnel and protected with a vessel loop prior to performing triceps tendon mobilization, especially in the setting of revision surgery. Do not hang a clamp from the vessel loop in order to avoid undue traction on the nerve during the case.
- Preparation of the Olecranon: Any residual tendon or fibrotic tissue should be removed from the olecranon insertion site. Bleeding subcortical bone should be achieved prior to fixation of the triceps tendon. Do not remove too much subcortical bone, especially in older individuals, because the underlying cancellous bone is weaker and less ideal for the fixation construct.
- Transosseous Tunnel Placement: If a transosseous tunnel configuration is chosen, then a 2.4 mm drill bit can be used to create crossing bone tunnels. Maximum spread along the width of the olecranon should be achieved to increase the surface area of the repair.
- Suture Anchor Placement: If a suture anchor construct is desired, then anchors should be pre-drilled prior to insertion to avoid iatrogenic fracture of the ulna, especially in younger patients with dense bone. Care should be taken to direct anchors away from the joint surface to avoid iatrogenic intra-articular penetration.
- Suture Management: Large, non-absorbable suture placed in a running, locking fashion should be used for the repair. Use great care to avoid piercing previously placed suture with the suture needle as this can destabilize the construct. Any knots should be buried to

avoid prominence and soft tissue irritation post-operatively.

40.9 Difficulties Encountered

In the setting of a chronic tear or a revision repair, extensive proximal release of the triceps tendon from scar tissue may be required to achieve direct repair. When doing so, the surgeon must be careful to avoid the radial nerve as it exits the spiral groove and courses laterally through the intermuscular septum. Depending on the patient age and the chronicity of the tear, the quality of the distal tendon may be poor. Any obviously non-viable areas of the distal tendon should be removed to facilitate approximation of healthy tendon back to the olecranon. Delamination of the tendon can also be present. These areas should be identified and incorporated into the repair in order to maximize the quality and thickness of the repaired tendon.

40.10 Key Procedural Steps for Preferred Technique (Double Row Suture Anchor)

The patient is positioned in the lateral position with a lateral arm holder or large stack of surgical drapes to support the operative arm. The extremity is then prepped and draped in the standard surgical fashion. Prior to incision, exsanguination of the arm with an esmarch bandage and elevation of the tourniquet to 250 mmHg will help with visualization. A 10-cm longitudinal incision should be centered on the posterior arm and curved laterally. This allows for a wide surgical exposure, protection of the ulnar nerve, and avoidance of an incision directly over the olecranon process (Fig. 40.1). The ulnar nerve does not need to be exposed or transposed with this approach. Full thickness subcutaneous flaps are elevated medially and laterally. Hematoma from the injury is often encountered and evacuated, followed by identification of the triceps tendon tear.

Fig. 40.1 Approach for a right distal triceps tendon repair. The patient is positioned in the right side up lateral decubitus position with a lateral arm holder to support the upper arm. A sterile tourniquet allows for maximum proximal exposure if needed

The distal triceps tendon is identified and non-viable regions are sharply excised. Special attention should be paid to identify any delamination within the tendon. A surgical clamp or traction suture can be used to identify the superficial and deeper layer if delamination is present. It is critical to incorporate the entire tendon into the repair construct. Any scar tissue adhesions are released to help mobilize the tendon back to the olecranon. The distal triceps tendon is prepared meticulously by removing all devitalized and degenerative tissue from the tendon stump. Next, fibrotic tissue and residual tendon are removed from the olecranon insertion site using a combination of #15 blade scalpel, curettes, and rongeurs until a bleeding bone bed is obtained (Fig. 40.2). Care is taken to obtain a bleeding bone bed without penetration of the cancellous bone. This is paramount for maintaining the cortical and subcortical surface for anchor fixation.

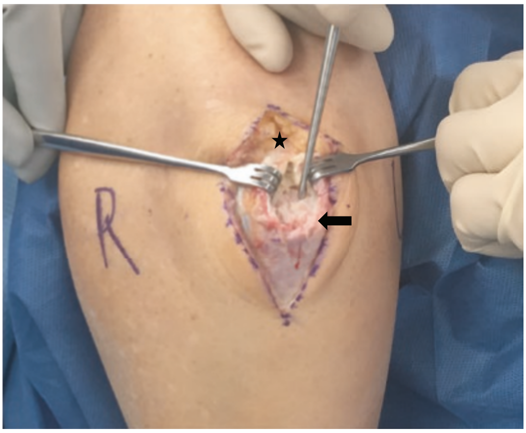

Fig. 40.2 Preparation of right triceps tendon repair site to the olecranon. The triceps tendon (star) has been fully removed from the olecranon process (arrow). The olecranon process has been prepared for reinsertion of the tendon by removal of all fibrous debris until a bleeding bone bed of subcortical bone is achieved

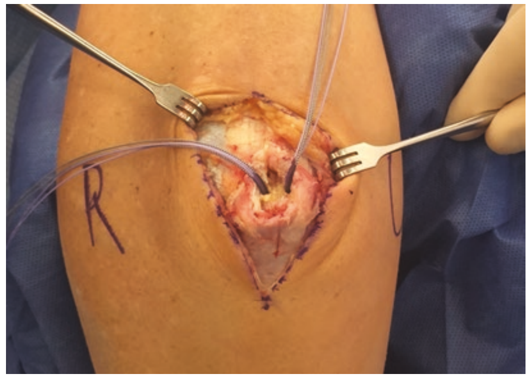

Fig. 40.3 Insertion of two double loaded suture anchors along the radial and ulnar aspects of the olecranon process. The double loaded suture anchors allow for one set to be used in a running Krakow fashion and the second set of sutures to be used in a Mason-Allen "rip-stop" configuration, if desired

We prefer a suture anchor double row, transosseous equivalent construct. In larger individuals, we attempt to achieve two proximal and two distal anchors for the fixation construct, whereas smaller individuals often can only accommodate one proximal and one distal anchor depending on the size of the triceps tendon footprint. The proximal row of anchors is placed first at both the radial and ulnar aspect of the olecranon process in order to achieve full coverage of the triceps tendon footprint (Fig. 40.3). An awl is used to mark the planned insertion point for each anchor, followed by creation of the insertion socket with a drill and then tap. The anchors are then placed sequentially. It is critical to be mindful of the angle for each anchor placement. We recommend placing the anchors about 1–2 cm distal to the olecranon tip and angled downward into the olecranon, slightly away from the elbow joint. Each anchor should have a total of two heavy-duty, braided suture and one thick suture tape.

After insertion of both anchors, the braided suture is passed sequentially in a horizontal mattress fashion using a large free needle. Care is taken to ensure a large bite into the tendon with inclusion of the entire tendon. Next, each pair of thick suture tape is passed proximal to the previously passed braided suture. This creates a "rip-stop" configuration with the heavier suture tape. Next, each set of horizontal mattress suture is tied with the elbow in extension to allow for provisional fixation of the tendon back to the footprint. The suture tape is left untied.

Once the proximal row is secured, attention is turned to distal row fixation. The insertion sites are marked with an awl, followed by drilling and tap insertion. The braided suture and Fiber tape are then passed into the two distal row anchors in a crossed, transosseous-equivalent configuration (Fig. 40.4). This is accomplished by passing the more medial sutures into the lateral distal row and vice-versa, which allows for additional compression across the fixation site. After insertion of the distal row, the free suture ends are cut.

The elbow is then placed through a gentle range of motion to help determine appropriate post-operative range of motion protocol. Copious irrigation and hemostasis are then performed, followed by layered deep closure and running subcuticular skin closure. The arm is immobilized at about 20° of extension with a posterior long arm plaster splint.

The patient remains in the splint for the first 2 weeks with allowance of passive wrist supination and pronation. At the 2-week follow-up visit, the splint is removed and a hinged elbow brace is

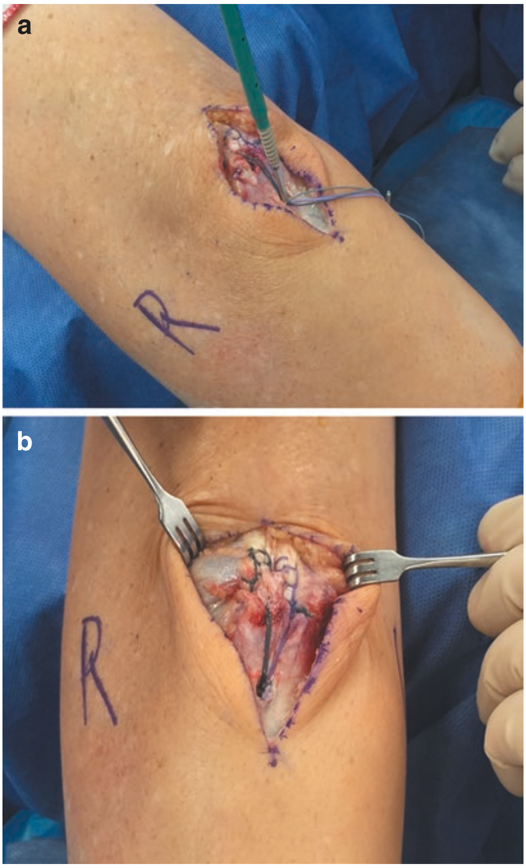

Fig. 40.4 (**a**) After placing all proximal row sutures through the triceps tendon and tying the Krakow sutures to the proximal row anchors, a knotless anchor is placed along the distal olecranon to complete the double row construct. (**b**) Final double row suture anchor repair of a right triceps tendon tear. Note the low profile nature of the repair construct, which minimizes irritation from the sutures and knots

placed. The patient starts active extension and passive flexion with a goal of increase in range of motion by 15° each week to a 90° arc of motion by 6 weeks. Weeks 6–12 focus on removal of the hinged brace and regaining of full range of motion. Isokinetic strengthening exercises are initiated at 12 weeks with gradual strengthening to progress as tolerated beyond this point. The goal is for a return to vigorous labor or physical activity by 6 months post-operative. Strengthening will often be required for the first full year following surgical repair.

40.11 Bailout, Rescue, and Salvage Procedures

If transosseous bone tunnels become incompetent when securing the tendon to the olecranon, then the fixation construct can be converted to suture anchors. Larger suture anchors can also be used if smaller suture anchors fail to obtain appropriate fixation within the olecranon due to poor bone quality. Any gapping at the repair site during 0–30° of elbow flexion should be addressed with additional suture or allograft augmentation. If the tendon quality is poor, then Achilles tendon allograft should be used to augment the repair. This is best achieved by suturing the broad end of the graft to the triceps tendon, followed by securing the distal end of the graft to the ulna with multiple suture anchors with the arm in extension. If a bone plug is present, this should be removed from the allograft prior to distal fixation. If the tendon cannot be reapproximated to the olecranon, then an Achilles tendon allograft can be used as a bridging graft. This is best achieved by first securing the allograft distally to the olecranon with suture anchors and then securing the allograft through the triceps tendon proximally in a Pulvertaft repair technique with the elbow in extension. Any residual allograft can be laid back over the repair site for further reinforcement.

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41 Endoscopic Distal Triceps Repair

Donovan Johnson, Michael Esantsi,
Michael O'Brien, and Felix Savoie

41.1 Description

Endoscopic distal triceps tendon repair is a reliable and reproducible technique to address both degenerative and traumatic triceps tendon injuries. The most preferred technique for repairing a distal triceps tendon tear is through an open posterior approach about the elbow. The open technique can be associated with wound healing problems and increased surgical site morbidity. Using an all-arthroscopic technique does give the treating surgeon the ability to fully assess the injury, debride the damage tissue, and anatomically repair the distal triceps tendon to its normal attachment footprint on the olecranon. Endoscopic repair allows for less wound complications, better cosmesis, and shortened postoperative recovery. Concomitant elbow pathology and injuries can be identified and addressed during the arthroscopic procedure. Patients should be braced to prevent full flexion initially during the postoperative period with gradual pain free motion increased until full range of motion is obtained, usually by 4 weeks. Strengthening should be initiated in a limited basis by 4 weeks post-operatively in the brace and expanded out of the brace 6–8 weeks. Early results are promising.

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41.2 Key Principles

1. Endoscopic repair works as well, if not better than open repair for triceps tendon injuries.
2. Wound complications are much less common in the arthroscopic technique.
3. A double row, bridging suture anchor repair most accurately replicates the normal attachment of the triceps tendon to the olecranon.

41.3 Introduction/Expectations

Injuries that involve the triceps tendon are uncommon [1, 2]. Complete rupture of the distal tendon accounts for less than 1% of tendon injuries involving the upper extremity [3–5]. The mechanism of injury classically reported was a fall on an outstretched arm or through direct trauma to the site of tendon insertion [6, 7]. Waterman et al. recently reported the mechanism of injury was direct elbow trauma (44.9%), extension/lifting exercises (20.3%), overuse (17.4%), and hyper-flexion or hyperextension (17.4%). In addition, 26.1% of their patients were identified with pre-existing symptomatic enthesopathy, and 73.9% of tears were caused by an acute injury [8]. Presentation of this injury usually demonstrates a loss of extension strength to the affected extremity, tenderness to palpation about the triceps insertion, swelling and ecchymosis to this location, and pain with resisted extension. In the

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event of a complete tear there may be a palpable defect and an inability to extend against gravity. While partial tears can sometimes be treated non-operatively, complete tears of the triceps tendon must be repaired to provide active extension at the elbow [1]. Cases of distal triceps tendon repair reported in the literature typically involve an open repair. This repair technique usually involves a 10 cm longitudinal incision over the posterior aspect of the elbow [1]. The open technique can be associated with wound healing complications and increased morbidity related to the open approach. Repair methods of the tendon itself included transosseous repair, suture anchor repair, and primary repair with sutures [8, 9]. While there are reports of partial arthroscopic repairs of the triceps tendon published, evidence of successful complete repairs performed arthroscopically are limited [10–12]. The senior author previously described a technique in 2016 discussion an all-arthroscopic technique for repairing degenerative and complete tears of the distal triceps tendon [13]. The all-arthroscopic technique still allows the treating surgeon to fully assess the injury pattern of the distal triceps tendon, allows for a meticulous debridement and release of contractures or adhesions, and is one method to achieve an anatomic repair to the olecranon. A few benefits using this technique allows include less wound complications, better cosmesis, and a shortened postoperative recovery period as compared to the open technique. Last, concomitant elbow pathology including extra and intra-articular injuries can also be identified and addressed during the arthroscopic procedure.

41.4 Indications

Operative repair of the distal triceps tendon is indicated for complete and symptomatic partial ruptures. Those individuals who are poor operative candidates can be treated non-operatively. Partial tendon tears and avulsions continue to be a controversial indication for operative management. Non-operative treatment can be considered initially for partial tears but the literature does advocate for surgical repairs for tendons with 50% involvement [14]. The decision for operative intervention of partial tears must be patient specific and the overall health, activity level, and comorbidities of these patients need to be considered. Another important consideration is the time from initial injury to presentation. Ideally, primary repair is performed within 2 weeks from injury. van Riet reported primary repair was only possible in 6 of 15 patients when the repair was greater than 25 days [11]. Waterman et al. reported patients with complications underwent surgery at a median of 60 days after injury in their cohort, while the patients without complication underwent surgery on average 35 days after injury. However, their statistical significance was not substantial in their study but the surgeon must consider multiple factors to determine if operative intervention is recommended [8]. It is our opinion that early surgery is preferable but have found that with adequate arthroscopic release of the muscle and tendon off the posterior humerus arthroscopically allows adequate repair in almost every case.

41.5 Contraindications

Contraindications include open wounds, active infections, and significant gouty tophi within the olecranon bursa.

41.6 Preoperative Considerations

41.6.1 Physical Exam

The physical exam for a suspected distal triceps tendon injury usually begins with inspection of the injured and non-injured upper extremity. Swelling and ecchymosis may be appreciated in the acute setting. Palpation of the tendon insertion is usually painful and a palpable defect at the insertion of the triceps tendon is present in both complete and partial tears. Weakness of active extension against resistance may be seen with partial or complete tears but this is not diagnostic

[12]. However, the triceps stress test can be useful tool assisting the treating physician with diagnosing subtle tendon tears. This is done by having the patient fully flex the elbow and then try to extend the elbow against resistance. Pain in the area of detachment can be considered pathognomonic of a significant tear requiring surgery. The surgeon should document a complete neurovascular exam and a complete range of motion exam should be done comparing bilateral upper extremities. A modified Thompson test may also be utilized. The examiner supports the injured arm parallel to the ground. The elbow is allowed to hang and flex to 90°. The triceps muscle belly is gently squeezed. No motion at the elbow is seen in complete tendon ruptures. This maneuver is not as specific for partial tears as compared to complete tendon tears.

41.6.2 Imaging

41.6.2.1 X-Rays

Lateral radiographic views of the elbow may demonstrate a flake of bone avulsed from the olecranon, traction spurs, and olecranon and/or tendon enthesopathy (Fig. 41.1) [12].

Fig. 41.1 X-ray of the elbow demonstrating osseous changes at triceps insertion on the olecranon

Fig. 41.2 Magnetic Resonance Imaging demonstrating chronic tendinopathic changes to the distal triceps

41.6.2.2 Ultrasound

Ultrasound can be used to correlate tendon injury with clinical examination and has been shown to differentiate among complete tendon rupture, partial tendon rupture, and tendinosis [15–17].

41.6.2.3 Magnetic Resonance Imaging (MRI)

MRI closely correlates with examination and other imaging modalities and is useful for surgical planning by identifying calcifications, bursitis, and chronic tendinopathy (Fig. 41.2).

41.7 Procedure Technique

41.7.1 Equipment

A standard 4 mm 30-degree arthroscope and regular arthroscopic instruments are utilized. Suture anchors and suture passing devices are needed for this procedure. The senior author of this chapter prefers a retrograde 30-degree Ideal suture grasper as a retrograde suture retriever (DePuyMitek, Raynham, MA).

41.7.2 Positioning

After induction of anesthesia the patient is placed either in the lateral decubitus or prone position (the author prefers prone). All bony prominences are well padded and a non-sterile tourniquet is applied to the upper arm. An arm board is placed parallel to the operative bed and a non-sterile bolster is used to elevate the humerus to a position parallel to the body. The glenohumeral joint is abducted 90° to the ground and the elbow is allowed to flex 90°.

41.7.3 Surgical Procedure

The patient is then sterilely prepped and draped according to the surgeon's preference (Fig. 41.3). The ulnar nerve is marked prior to placing the portals, the limb exsanguinated, and a quick diagnostic arthroscopy is performed of the anterior compartment using a proximal anteromedial portal. Once completed, a proximal posterior central portal is placed through the defect in the tendon to complete the intra-articular diagnostic arthroscopy. In partial tears we use a proximal posterior lateral portal if we cannot define the extent of the tear. Once the tear is visualized via the posterolateral portal the posterior central portal can be made and a shaver is introduced to debride the tear edges and the olecranon bursa (Fig. 41.4). The arthroscope is then moved to a proximal bursal viewing portal, located 3–4 cm proximal to the tip of the olecranon, and the tear and tendon debrided at this time (Fig. 41.5). The ulnar insertion of the triceps tendon is identified. The footprint is debrided and the olecranon is prepared for acceptance of tendon (Fig. 41.6). The scope is then moved to a distal bursal viewing portal, located 3–4 cm distal to the tip of the olecranon, and the standard central posterior portal is used to place a double loaded suture anchor at the proximal footprint angling away from the joint parallel to the posterior ulnar border to prevent penetra-

Fig. 41.3 Patient positioning for endoscopic distal triceps tendon repair

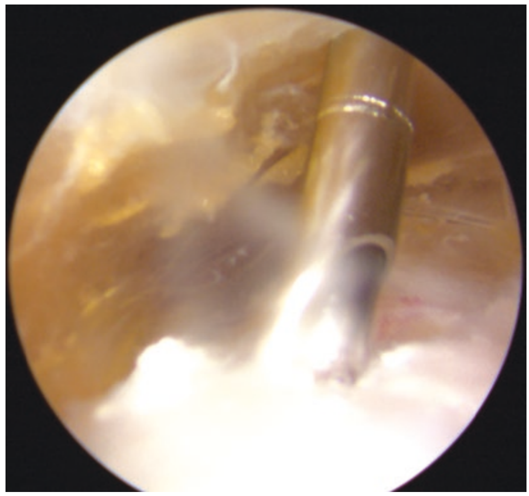

Fig. 41.4 Arthroscopic view of the triceps tendon tear

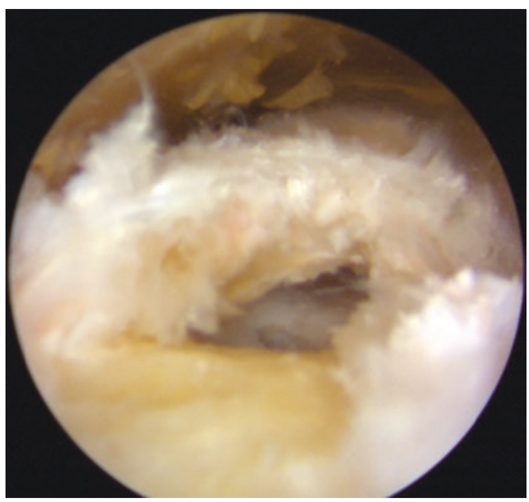

Fig. 41.5 View from proximal bursal viewing portal

tion of the ulno-humeral joint (Fig. 41.7). A retrograde suture passer is used percutaneously to pass all four strands through the tendon, with broad separation, with one strand each medially and laterally and two more central. The suture is retrieved percutaneously, and a sliding knot is tied. The second set of sutures is retrieved and tied in mattress fashion as well. Two of the strands are then "double passed" through the more distal tendon to create four different paths for the sutures and thereby four compression

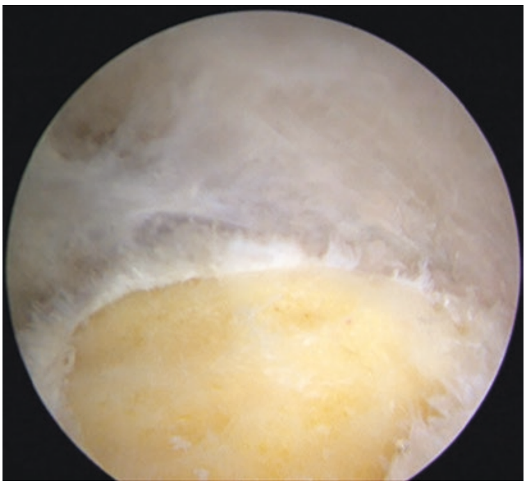

Fig. 41.6 Preparation of the triceps footprint on the olecranon prior to repair

points as they track to the second anchor. The arthroscope is placed in the proximal olecranon bursa portal, and the distal bursal portal is used for a cannula into the olecranon bursa. The sutures from the proximal anchor are retrieved into this cannula and placed into a second anchor which can be inserted into the more distal ulna olecranon to create a suture bridge repair. Alternatively, a second anchor may be placed in the distal ulna. These sutures are passed through the distal tendon and tied in simple fashion. The repair is complete. The arthroscope is placed in both the proximal and distal bursal portals to evaluate the repair (Fig. 41.8). The elbow is ranged through flexion and extension and a stable repair is completed. The fluid is extravasated out of the bursa. A hemovac suction drain is placed via existing portals and removed just prior to patient departure from the hospital or surgery center. All portals are closed, a compression dressing and posterior splint with the elbow in full extension.

41.7.4 Post-procedure Protocol

The extremity is placed in anterior and posterior splints with the elbow in near full extension. At the first postoperative visit, 7–10 days following surgery, the patient is placed in a hinged elbow

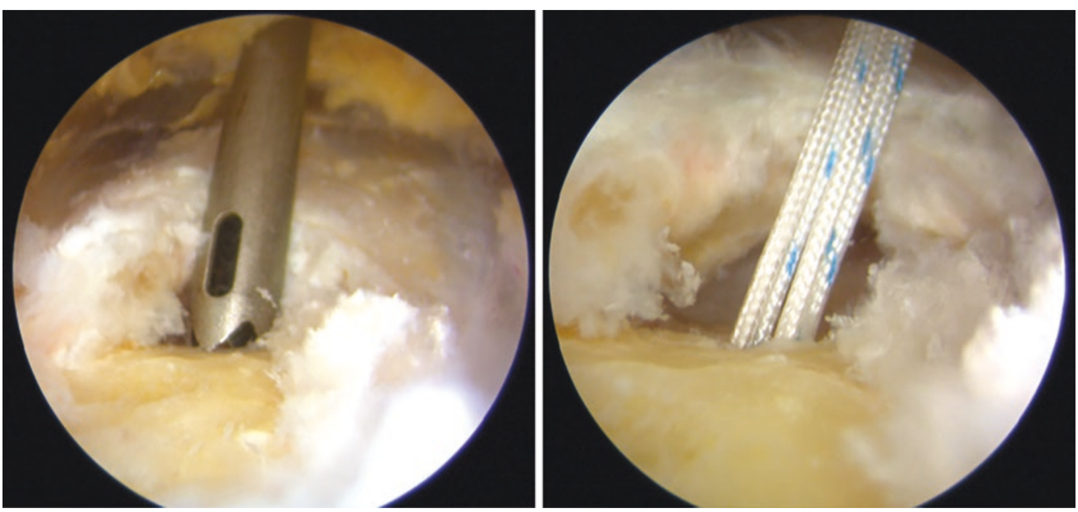

Fig. 41.7 Anchor placed in the olecranon

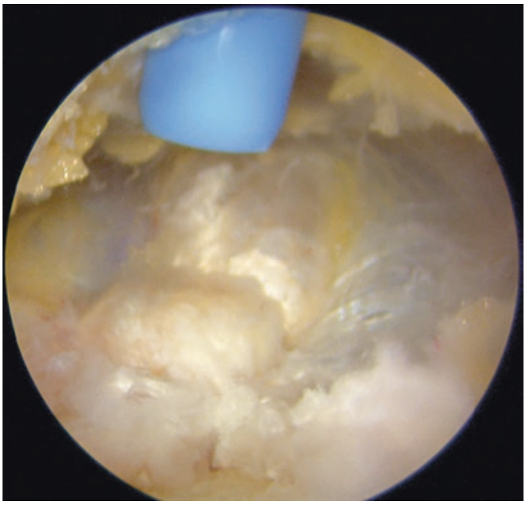

Fig. 41.8 Final arthroscopic view of the repair

brace allowing motion of 0–30°. Weekly advances of 10° of motion are allowed until 6–8 weeks postoperatively. The brace is discontinued at 8 weeks, and a strengthening program is initiated.

41.8 Author's Tips/Tricks/Pearls

The senior author has been using this technique with slight modifications for the past 15 years and this has become his preferred technique for repairing partial and complete distal triceps tendon tears.

41.8.1 Tip 1

The surgeon should mark out the ulnar nerve and remember its location along the medial triceps throughout the case. If there is any concern as to its location it should be located either arthroscopically or open and protected.

41.8.2 Tip 2

Release the triceps off the humerus to ensure enough tendon is available for an anatomic repair.

41.8.3 Tip 3

The olecranon is a very dense bone and anchor fractures can occur. Oversizing the anchor pilot hole, using an expansion anchor and/or using the tap deeper can assist with passage of the anchor.

41.8.4 Tip 4

Although a single anchor may be sufficient for partial tears, the use of two anchors provides a biomechanically sound repair in complete tears.

41.8.5 Tip 5

Remember the olecranon is curved and penetration of the joint by drills, taps, or anchors can happen inadvertently. The surgeon should be careful with depth of penetration of any anchor; we favor absorbable anchors in the elbow.

41.8.6 Tip 6

If the anatomy seems grossly abnormal and the case does not seem to be going as expected the arthroscopic procedure should be abandoned and the elbow opened and the ulnar nerve identified and protected before proceeding with surgery.

41.9 Potential Complications

In the acute setting, swelling may obscure the anatomy and it is imperative to identify the course of the ulnar nerve and protect it through the case. The bone of the olecranon may be extremely hard. To prevent breaking of anchors during insertion, the surgeon can oversize the pilot hole and tap deeper into the bone. An expansion anchor may also be used. Fluid extravasation may interfere with satisfactory repair. Given these potential complications the surgeon must be prepared to abandon arthroscopic technique for open repair.

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42

Open Excision of Posteromedial Olecranon Osteophyte in Throwing Athletes

E. Lyle Cain Jr. and Travis Roth

42.1 Description

Posteromedial olecranon osteophyte excision for valgus extension overload (VEO) can be performed arthroscopically or open. In general, the arthroscopic approach is utilized for isolated VEO in the presence of posteromedial osteophytes, whereas the open approach is performed in conjunction with ulnar collateral ligament (UCL) reconstruction.

42.2 Key Principles

The open approach is preferred for excision of posteromedial osteophytes in throwing athletes with UCL insufficiency [1–4]. While arthroscopic excision of posteromedial osteophytes prior to open UCL reconstruction is possible, it may lead to disrupted tissue planes due to fluid extravasation. Therefore, if this procedure is to be performed in conjunction with UCL reconstruction, the preference is to perform it via open approach.

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42.3 Expectations

Open excision of posteromedial osteophytes is an adjunct procedure to UCL reconstruction in overhead athletes that demonstrate VEO with posteromedial osteophytes. With the approach described, posteromedial osteophytes are easily accessible and completely resected. The open procedure leads to resolution of VEO symptoms and does not significantly alter recovery from UCL reconstruction.

42.4 Indications

Overhead athletes with VEO and presence of posteromedial osteophytes as demonstrated on plain films or advanced imaging, typically in the setting of UCL insufficiency requiring UCL reconstruction.

42.5 Contraindications

Isolated posteromedial osteophytes without UCL insufficiency do not require an open approach and can be managed arthroscopically.

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42.6 Special Considerations

Detailed preoperative physical examination consistent with VEO and identification of posteromedial osteophytes on imaging studies is critical to success. MRI evaluation often allows complete understanding of the number and size of osteophytes. Recognition of osteophytes and open excision during UCL reconstruction leads to the best possible outcome without residual pain during throwing in the athlete's recovery.

42.7 Special Instructions, Positioning, and Anesthesia

- General anesthesia
- Supine with a hand table
- Tourniquet applied to upper arm
- Bump placed under elbow

42.8 Tips, Pearls, and Lessons Learned

42.8.1 Exposure

Access to the posterior capsule and subsequent posteromedial osteophytes is easily accomplished with our approach to the medial elbow. We utilize a medial incision over the medial epicondyle. The cubital tunnel is exposed and wide ulnar neurolysis is performed to allow anterior retraction of the nerve over the medial epicondyle. This provides excellent ability to perform a posterior capsulotomy and gain access to posteromedial osteophytes.

42.8.2 Equipment and Tools

Right angle retractors are utilized for ulnar nerve retraction as well as for the capsulotomy. A baby Homan retractor is also key to exposing the osteophytes. Instruments utilized for osteophyte removal include a small osteotome, rongeur, and motorized micro-burr.

42.9 Difficulties Encountered

Inadequate mobilization and retraction of the ulnar nerve limits exposure required. While the nerve is typically mobilized and retracted posteriorly during the duration of the UCL reconstruction procedure, anterior retraction over the epicondyle is needed for posteromedial osteophyte excision. Hemostasis is also critical for visualization. This is accomplished with use of a tourniquet inflated to 300 mmHg and meticulous hemostasis performed during ulnar nerve mobilization.

42.10 Key Procedural Steps

A medial elbow incision is created, centered over the medial epicondyle, extending approximately 3 cm proximal and 6 cm distal to the epicondyle (Fig. 42.1). Careful dissection is carried out to protect the medial antebrachial cutaneous nerve. Its location is variable and it may have branches, but is often encountered in the distal third of the incision. Once protected, full-thickness flaps are created to expose the medial epicondyle, flexor-pronator mass, and the cubital tunnel. The cubital tunnel is opened with a No. 15 blade or tenotomy scissors to identify the ulnar nerve. A vessel loop is placed around the nerve to provide gentle retraction during this portion of the procedure.

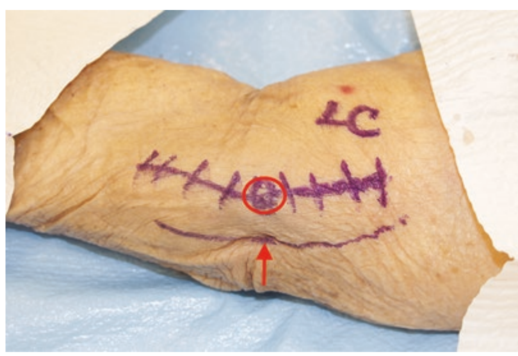

Fig. 42.1 Skin incision for right medial elbow centered over the medial epicondyle (red circle). For orientation, the hand is to the left, shoulder to the right. The course of the ulnar nerve is marked (red arrow)

The nerve is then completely released from as far proximally as possible, through the arcade of Struthers, as well as distally between the two heads of the flexor carpi ulnaris (FCU) muscle. Fascia of the FCU must be split sharply, followed by blunt dissection of the muscle, to completely release the nerve in this area. Care must be taken to protect the first motor branch to the FCU found in this area. Once mobilized, the ulnar nerve can be safely retracted anteriorly over the medial epicondyle using a right angle retractor or rubber vessel loop.

With the ulnar nerve retracted anteriorly over the medial epicondyle, the posterior bundle of the UCL and posterior capsule are visualized. A vertically oriented incision into the posterior capsule is made with a No. 15 blade, just posterior to the posterior bundle of the UCL (Fig. 42.2). The capsulotomy is retracted with right angle retractors. A baby Homan retractor is placed posteriorly under the posteromedial olecranon tip. The posteromedial osteophytes are now visible and can be resected (Fig. 42.3). This is typically accomplished using a combination of a small osteotome, small rongeur, and a 4.0 mm motorized micro-burr (Fig. 42.4). Osteophyte resection is often noted to be complete when the baby Homan retractor is less stable or falls off of the olecranon due to the now absent osteophytes (Fig. 42.5). The capsulotomy is irrigated to remove bony fragments and then closed side-to-side with interrupted 0-Vicryl suture (Fig. 42.6). The ulnar nerve can then be retracted posterior to the medial epicondyle and the remaining portions of the UCL reconstruction procedure are completed. At the conclusion of UCL reconstruction, the ulnar

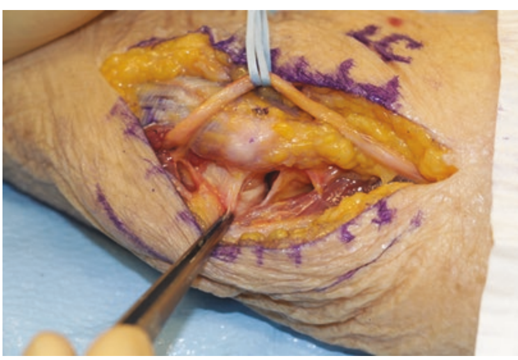

Fig. 42.2 A vertically oriented incision into the posterior capsule is made just posterior to the posterior bundle of the UCL (in forceps). The ulnar nerve is held anterior to the medial epicondyle during the procedure (in blue loop)

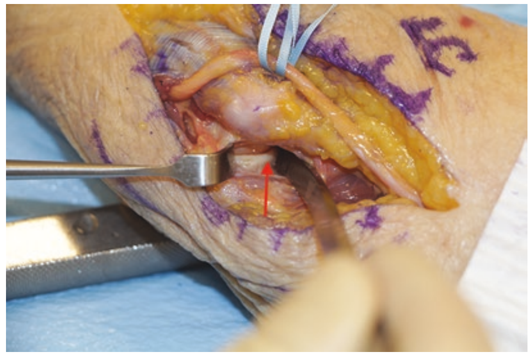

Fig. 42.3 The posteromedial olecranon osteophyte is now visible (red arrow)

Fig. 42.4 Olecranon osteophyte excision (red arrow) is accomplished using a combination of a small osteotome (pictured), small rongeur, and a 4.0 mm motorized micro-burr to contour a smooth edge

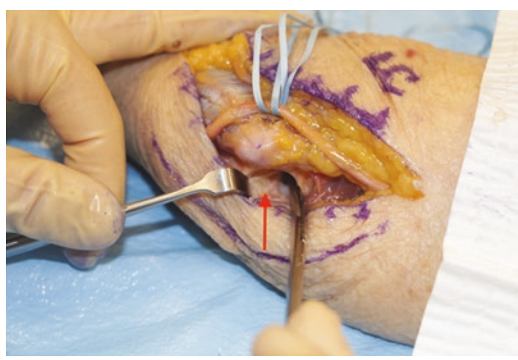

Fig. 42.5 Final olecranon resection with smooth, contoured posterior edge (red arrow)

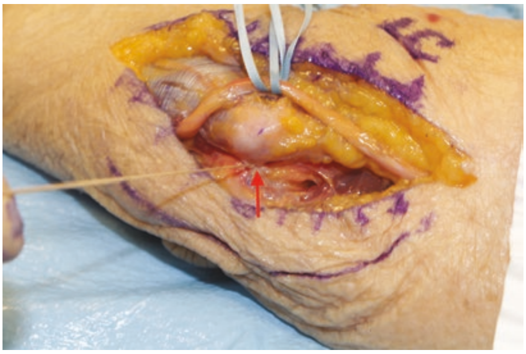

Fig. 42.6 The capsulotomy is irrigated to remove bony fragments and then closed side-to-side with interrupted absorbable suture (red arrow)

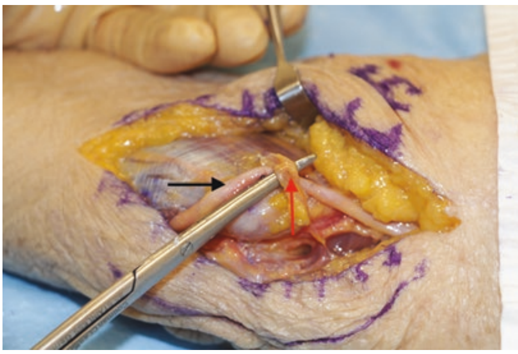

Fig. 42.7 At the conclusion of UCL reconstruction, the ulnar nerve (black arrow) is transposed anterior to the medial epicondyle and held loosely in place with a strip of the medial intermuscular septum (red arrow)

nerve is transposed anterior to the medial epicondyle and held loosely in place with a strip of the medial intermuscular septum (Fig. 42.7).

42.11 Bailout, Rescue, and Salvage Procedures

It is critical to utilize preoperative history and physical examination for VEO and imaging studies to confirm the presence of posteromedial osteophytes. In athletes with UCL injuries requiring surgery, the optimal timing for resection of osteophytes is during UCL reconstruction. Arthroscopic resection of posteromedial osteophytes at a later date is also possible. Arthroscopic posterior elbow portal placement for osteophyte removal may be made safely after anterior ulnar nerve transposition has been performed; however, anteromedial portal placement may require open nerve exposure and protection. If it is unclear whether or not an ulnar nerve transposition was performed, arthroscopy may be contraindicated. In that case, an open approach may be considered.

Pitfalls

- It is critical to not overlook VEO and presence of posteromedial osteophytes at preoperative examination of UCL injuries.
- Wide mobilization of the ulnar nerve is required for anterior retraction during the procedure.
- A vertically oriented capsulotomy provides exposure needed for osteophyte excision.
- Right angle retractors and a baby Homan provide necessary visualization.
- Small instruments are needed for osteophyte excision: small osteotome, rongeur, and micro-burr.

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43 Flexor Pronator Repair

Joshua Wright-Chisem and Joshua S. Dines

43.1 Description

The purpose of this chapter is to outline the salient techniques, surgical pearls, and preventable complications associated with surgical debridement and repair of the flexor pronator mass.

43.2 Key Principles

The goal of flexor pronator mass repair is to restore elbow flexion and pronation. This is achieved by recreating the anatomic footprint of the tendon and by establishing appropriate length and tension of all repaired structures.

43.3 Expectations

In cases of medial epicondylitis recalcitrant to non-operative treatment, or in acute injuries, the flexor pronator mass origin may be acutely torn or degenerative destructed. Open debridement and repair of the flexor pronator mass and the common flexor tendon onto the medial epicondyle help restore normal elbow and forearm function and strength.

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43.4 Indications

Medial epicondylitis is less common than its lateral alternative, with population studies showing the prevalence of these two conditions at 0.4% and 1.3%, respectively [1]. The first line treatment for medial epicondylitis is non-operative treatment, initiating with periods of rest, focused on symptom alleviation [2]. Patients who fail non-operative treatment after four to 6 months and high level athletes with magnetic resonance imaging (MRI) proven tendon disruption may be candidates for flexor pronator mass repair (Fig. 43.1).

43.5 Contraindications

- Flexor pronator mass tear in the setting of high energy trauma with severely comminuted medial epicondyle fracture
- Irreparable soft tissue
- Low demand patient with medical comorbidities

43.6 Special Considerations

If a patient has failed conservative treatment for medial epicondylitis or flexor pronator strain, or if there is concern for complete disruption of one of the associated tendons, it is important to obtain advanced imaging. Non-contrast MRI may demonstrate edema, high signal intensity, or disruption

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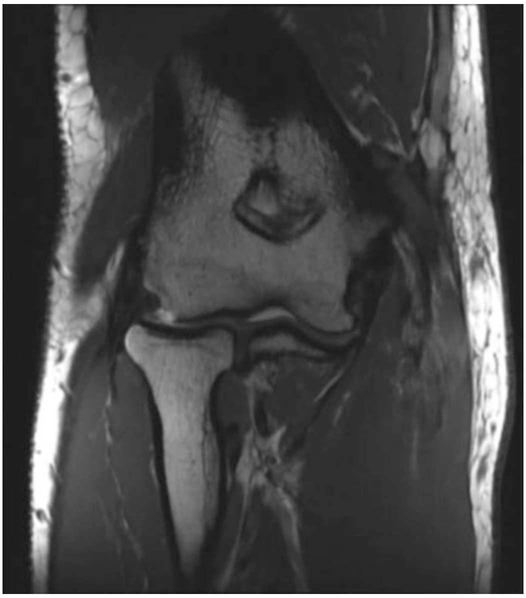

Fig. 43.1 Coronal MRI demonstrating tear of origin of flexor pronator mass

of tendon integrity in the case of a rupture, on T2-weighted imaging [3]. It is imperative to consider additional pathology in these patients, as Descatha et al. showed that over 80% of patients who sustained medial epicondylitis in an occupational setting may present with accompanying injuries, including carpal tunnel syndrome, lateral epicondylitis, or ulnar neuritis [4].

43.7 Special Instructions, Positioning, and Anesthesia

- Consider peripheral nerve blocks, including supra, or infraclavicular blocks.
- Consider short acting block for post-operative ulnar nerve assessment. Some surgeons may elect to avoid any block.
- Patient supine on hand table with arm abducted and externally rotated.
- Non-sterile tourniquet placed on proximal arm.

43.8 Tips, Pearls, and Lessons Learned

Anatomic restoration of the origin of the common flexor tendon is key. After thorough debridement of the tendinotic tissue, it is imperative to create a bony environment that may allow adequate healing. This may be done with unicortical drilling of the bony surface with a non-threaded Kirschner wire.

43.9 Difficulties Encountered

The ulnar collateral ligament is found immediately deep to the common flexor tendon origin. When elevating this tissue of the medial epicondyle and during debridement of the medial epicondyle, this structure can be torn iatrogenically.

43.10 Key Procedural Steps

The procedure begins with a roughly 5 cm curvilinear incision, centered over the medial epicondyle. Subcutaneous dissection is carried out with dissecting or tenotomy scissors, with care taken to identify the medial antebrachial cutaneous nerve and its associated branches. At this point, the common flexor tendon should be visualized. If the tendon is partially torn, it is frequently at the junction of the flexor carpi radialis and pronator teres junction (Fig. 43.2). In treating recalcitrant medial epicondylitis, the flexor carpi ulnaris and the pronator teres tendon insertion sites are bluntly separated from the common flexor tendon. The central aspect of the common flexor tendon is then elevated directly off its insertion on the medial epicondyle, revealing the degenerative tissue beneath. Care must be taken to ensure that the ulnar collateral ligament is not injured during this step. The degenerative or diseased tissue is then incised in an elliptical or oval shape. Scratch test with a

Fig. 43.2 Here a tear is seen at the junction of the flexor carpi ulnaris and pronator teres tendons

Fig. 43.3 Demonstrating removal of all pathologic tissue from the torn flexor pronator mass with healthy bone exposed

scalpel is used to confirm resection of all pathologic tissue (Fig. 43.3).

After thorough excision of the pathologic tissue of the common flexor tendon, attention is paid to the medial epicondyle. Using a curette, the epicondyle is debrided gently so as not to deform the normal bony architecture. The goal is to create a fresh bony surface for soft tissue-bone healing.

There are several described techniques to repair the elevated common flexor tendon back to the medial epicondyle. Vinod et al. describe a side-to-side repair of the common flexor tendon with an absorbable suture [5]. This is followed by soft tissue fixation utilizing a suture anchor. In this technique, permanent sutures are exchanged for absorbable sutures in the suture anchor construct and are secured to the medial epicondyle in a horizontal mattress fashion.

Following adequate repair and fixation, the elbow is then ranged fully and tested for stability and deficits of range of motion. Post-operatively, the patient is placed in a well-padded splint for 1–2 weeks, followed by a hinged elbow brace for another 4 weeks. Full range of motion is permitted in the brace, but we find that the brace keeps other people careful around the patient. After 6 weeks, progressive strengthening is initiated. Unrestricted return to full sports occurs at roughly 4–5 months after surgery, which is a slightly longer time course than required for lateral epicondylitis surgery.

43.11 Bailout, Rescue, Salvage Procedures

It is important for surgeons to recognize that in severe cases of flexor pronator tendinosis/degeneration, a big defect may be present after adequate debridement. Occasionally, repair of healthy tendon back to the epicondyle is not feasible. In these cases, our surgical approach is more similar to the Nirschl procedure done on the lateral side of the elbow where the tendon is debrided and the epicondyle is drilled to enhance blood flow to the area without a repair being performed [6].

43.12 Pitfalls

If dissection proceeds too posteriorly, the ulnar nerve is at risk during exposure of the flexor pronator mass. It is also at risk during any transosseous drilling of the medial epicondyle, and it should be identified and protected if transosseous sutures are placed.

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44 Arthroscopic Management of Valgus Extension Overload

Braiden Heaps and Orr Limpisvasti

44.1 Introduction

Valgus extension overload is a condition commonly found in the dominant arm of throwing athletes, particularly pitchers. Repetitive stress of throwing leads to pathology in the posteromedial elbow. When conservative measures fail, surgical intervention is indicated. This chapter will focus on arthroscopic intervention.

44.2 Background

Valgus extension overload is a condition commonly found in the dominant arm of throwing athletes, particularly pitchers. Repetitive stress of throwing leads to pathology in the posteromedial elbow including cartilage injury on the olecranon, osteochondral lesions of the capitellum, osteophyte formation on the posteromedial humerus and olecranon, loose bodies and has been correlated with MCL attenuation and strain. Surgical intervention is often indicated. Elbow arthroscopy has been clearly established as a safe and effective operation and clearly demonstrates utility in treating patients with valgus extension overload.

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44.3 Clinical Evaluation

Careful history taking is the first step in evaluating a patient for valgus extension overload. Important questions to ask throwing athletes include: where do the symptoms occur, when in the course of the throwing motion do the symptoms occur, and was there a sudden or gradual onset of symptoms. Typical symptoms occur mainly on the medial side of the posterior aspect of the elbow, which is in contrast to medial ulnar collateral ligament injuries where patients report pain centered over the medial aspect of the elbow. The timing of pain in the throwing motion is another important element to understand. Patients report valgus extension overload symptoms at ball release, but ulnar collateral ligament pain is more commonly reported during a thrower's lay back. Lastly, onset is another distinguishing factor with valgus extension overload presenting with a gradual onset, and ulnar collateral ligament injuries typically have an acute onset [1].

Physical examination should include inspection, range of motion, strength testing, stability testing, and a thorough neurovascular examination. Once general examination of the symptomatic elbow is complete the examiner should proceed with valgus extension overload specific examination maneuvers. The examiner should place a valgus stress on the elbow at 20 to 30 degrees of flexion while forcing the elbow into terminal extension. If this test elicits symptoms

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the examiner should clarify if these represent the symptoms that the patient presented for. Additionally, the examination should assess for symptoms with repeated forced full elbow extension while keeping in mind that it can be common for throwing athletes to lose some terminal extension. Lastly, the examiner should assess other common sources of medial elbow pain including the medial ulnar collateral ligament, ulnar groove, flexor muscle mass, and medial triceps [1, 2] and assess for instability.

44.4 Diagnostics

After a careful history and examination is performed, imaging is obtained to confirm the suspected diagnosis of valgus extension overload syndrome. Standard 3 view (anteroposterior, lateral, axial) radiographs should be obtained. The reviewer should pay particular attention for the presence of a posteromedial olecranon osteophyte or loose bodies on these studies. If necessary contralateral elbow images may be obtained for reference. Advanced imaging studies may be obtained. Reasons for magnetic resonance imaging include assessment for other concurrent injuries such as medial ulnar collateral ligament or chondral injuries. Reasons for computed tomography include pre-operative planning and careful assessment of any unseen but suspected loose bodies [2, 3].

Another powerful tool in accurate diagnosis is posterior fossa intra-articular injections. Injections of local anesthetic with or without a corticosteroid are particularly helpful to tease out valgus extension overload from other causes of posteromedial elbow pain. The diagnostician's confidence should increase with alleviation of symptoms after injection. An additional benefit of this treatment is it can manage a throwing athletes symptoms so that they can finish their season and surgically address their pathology if necessary during the offseason.

44.5 Treatment

First line treatment for valgus extension overload includes anti-inflammatory medications, throwing rest, activity modification, and steroid injections. Operative indications include failure of conservative measures, symptomatic loose bodies, and loss of range of motion. Once the decision to pursue operative intervention has been made, arthroscopy offers certain advantages over an open surgical approach. These advantages include inspection of the entire joint including articular surfaces, no disruption of the extensor mechanism and the ability to assess and treat other intra-articular pathology including loose bodies, lateral meniscoid lesions, and/or posterolateral plica. Additionally, arthroscopic procedures do not limit future open or arthroscopic procedures from being performed. When indicating patients for surgical treatment of valgus extension overload surgeons must be careful to rule out any concomitant instability. Hassan et al. demonstrated that even partial proximal medial ulnar collateral ligament disruptions alter the contact area and biomechanics of the posteromedial elbow [4]. These alterations can contribute to osteophytic changes and impingement, consistent with the findings in valgus extension overload and demonstrate how valgus extension overload is an advanced finding of elbow instability.

Elbow arthroscopy including positioning and portal placement has been well described. The positioning of the patient should be determined by the operating surgeon and their comfort level and familiarity along with that of the operative team. Many safe portals have been well described and similar to positioning we advocate for surgeons to use a portal combination that is safe and familiar to the surgical team. Once intra-articular access and visualization has been established we advocate for a thorough diagnostic examination. Careful attention must be paid to evaluate for loose bodies, medial ulnar collateral ligament damage, chondral lesions on the medial aspect of the olecranon, and posteromedial humerus. Once the offending lesion has been identified, the surgeon must establish the transition between native non-pathologic olecranon bone and impinging osteophytic bone. Using an arthroscopic shaver or burr, the impinging bone is resected. Close attention must be paid to the quality and architecture of the bone during this resection. Once the bone transitions to normal cancellous architecture, the resection is complete. While leaving remaining impinging bone is suboptimal excessive resection is equally concerning. Kamineni et al. showed that resection of as little as 3 mm of olecranon leads to increased strain in the anterior bundle of the medial ulnar collateral ligament. In their study they also demonstrated that resection of 9 mm of olecranon leads to failure of the medial ulnar collateral ligament in some specimens [5]. The surgeon therefore must exercise careful judgment intraoperatively when performing the resection to allow for enough bone resection that the procedure treats the patient's symptoms, but also not too much that there is iatrogenic increased instability.

44.6 Results

Elbow arthroscopy has been established as a safe and effective intervention. The data on arthroscopic treatment of valgus extension overload and posterior impingement of the elbow has been encouraging. Published data demonstrates significant pain relief, improved elbow motion, and function [6, 7]. Reddy et al. published their experience with 187 patients undergoing elbow arthroscopy. 92% of their patients reported good to excellent outcomes and 47 out of 55 baseball players were able to return to their preinjury level of competition [8]. More recently Koh et al. reported a 97% return to play for patients at their same athletic level including professional athletes [7]. These studies demonstrate that arthroscopic intervention is an effective option that can be utilized to treat patients with valgus extension overload.

44.7 Conclusion

Valgus extension overload commonly ails throwing athletes. Careful attention must be paid to the patient's reported symptoms including duration, location, and timing during the throwing motion for the examiner to correctly diagnose the condition. First line of treatment includes conservative measures, but when these fail surgical intervention is effective. Arthroscopic intervention offers multiple advantages over open surgery. Surgeons must pay close attention while performing the resection to avoid iatrogenic instability while performing adequate resection to alleviate impingement symptoms.

Key Points

- Valgus extension overload develops gradually on the posteromedial aspect of the dominant arm of throwing athletes with pain in the terminal phase of the throwing motion.
- Elbow arthroscopy is a safe and effective treatment method for valgus extension overload.
- The clinician should always suspect and rule out instability as a cause of posteromedial elbow pain.
- Care must be taken intraoperatively to not over-resect any osteophytes as aggressive resection can lead to iatrogenic instability.
- Good clinical and functional results can be expected with arthroscopic management.

Questions

1. Amount of olecranon resection before increased strain is seen in the medial ulnar collateral ligament?
   (a) 1 mm
   (b) 2 mm
   (c) 3 mm
   (d) 4 mm
2. Valgus extension overload leads to pain during which phase of throwing?
   (a) Wind up.
   (b) Cocking
   (c) Acceleration
   (d) Ball release

3. Valgus extension overload is often seen in which type of athlete?
   (a) Rower
   (b) Overhead thrower
   (c) Volleyball player
   (d) Runner

Key

1. c
2. d
3. b

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Part V

Neurologic Conditions of the Elbow

45 Radial Nerve Decompression

Jeevaka E. Amaranath, Richard P. Jamieson, and Gregory A. Hoy

45.1 Goals and Expectations

Radial nerve compression at the elbow can be defined as mainly motor or posterior interosseous nerve (PIN) syndrome, or primarily sensory or radial tunnel syndrome (RTS). The majority of PIN syndromes (with weakness) occur following trauma, but compression by space occupying lesions such as lipomas, schwannomas, hemangiomas, radiocapitellar cysts and ganglia, etc. have also been known causes. Radial tunnel syndrome (RTS) relates to compression of the radial nerve within the radial tunnel and can be associated with lateral epicondylitis. Morrey suggested half of the failures of tennis elbow surgery were due to missed RTS. Because of this we routinely release the PIN with tennis elbow reconstructions.

45.2 Radial Tunnel Anatomy

The radial tunnel exists as a theoretical space between the level of the radiocapitellar joint (RCJ) and the supinator where the PIN passes. It is approximately 5–7 cm in length and curved as the PIN travels within it. Its boundaries consist of the brachioradialis as its roof, biceps and brachialis as its medial border, extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) as its lateral border. Its floor comprises the radiocapitellar joint proximally and extends distally through the two heads of supinator.

There are five primary sites of compression as the radial nerve passes through the tunnel. The first is at the level of the radiocapitellar joint and can be caused by the presence of fibrous bands anterior to the RCJ, osteophytes secondary to osteoarthritis or even thickened synovium. The second site is the leash of Henry, which is an arcade of anastomosing branches of the radial artery at the level of the radial neck. The third point is at the fibrous edge of ECRB at its proximal point. The fourth is at the arcade of Frohse, which marks the proximal edge of the supinator muscle as the PIN enters into the supinator. The final point of potential compression is distal edge of the supinator muscle.

45.3 Indications

Both PIN syndrome and RTS initially present with pain with no sensory disturbance. This pain tends to be worse with activities that consist of supination and wrist extension and is therefore commonly seen in manual labourers. In PIN syndrome the pain will progress to paresis of the

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muscle innervated by the PIN. Subsequently, this leads to the fingers and thumb not being able to extend, with atrophy and muscle wasting present in the extensors forearm if the symptoms persist. Wrist extension is maintained, due to sparing of ECRL (radial nerve proper); however, it becomes unbalanced and leads to radial deviation as extensor carpi ulnaris (ECU) is weak.

In RTS the pain is commonly felt as a dull ache that is located 5 cm distal to the lateral epicondyle. Patients can also report night pain that can eventually affect their sleep. On examination there is pain on palpation over the dorsal-radial forearm (5 cm distal to the lateral epicondyle). Pain with resisted extension over the middle finger is a specific test as it aims to tighten the fascial edge of ECRB, thereby compressing the nerve at one of its sites. Similarly, supination against resistance causes compression of the nerve as it courses in and through the supinator muscle to cause pain.

The primary differential diagnosis of RTS is lateral epicondylitis, along with cervical radiculopathies and other chronic pain conditions. The critical difference is the location of the pain in lateral epicondylitis is over the lateral epicondyle as opposed to radial tunnel syndrome pain which is 5 cm distal to the epicondyle. Other tests such as resisted extension are non-specific as they have cross over of ECRB's effect on the PIN and the tendon insertion. The site of pain reproduced by this manoeuvre as over the lateral epicondyle or proximal dorsal-forearm is more reliable to differentiate between the two.

Plain X-rays can be used to identify any evidence of osteoarthritis or spurs around the RCJ. Magnetic resonance imaging (MRI) is essential to look for space occupying lesions (Fig. 45.1) compressing the nerve leading to RTS or PINS, while increased signal around the extensor insertion may indicate a lateral epicondylitis. Our routine extensor reconstruction for tennis elbow now includes PIN neurolysis.

Electrophysiological examination can be useful in confirming the diagnosis of PINS, but not as much in RTS. In PIN syndrome the electromyogram (EMG) shows muscle denervation with slowing of the conduction velocity, while in RTS there is no consensus of electrophysiological testing results with multiple studies showing variable findings.

Fig. 45.1 Sagittal MRI demonstrates a ganglion anterior to the radiocapitellar joint putting the posterior interosseous nerve at risk

45.4 Contraindications

The missed diagnosis of cervical nerve compression is the primary contra-indication. Inadequate investigation may mean finding a tumour requiring wider excision and compartment protection if found at exploration. Peripheral neuropathies will not be corrected by local nerve release. Infected lesions may require pre-operative medical control before surgery.

45.5 Pre-Operative Preparation and Positioning

We routinely perform this surgery supine with high tourniquet control (250 mm Hg pressure) and the arm prepared and draped on an independent hand table. This allows height adjustments of the patient with respect to the arm table for subtle position changes.

The surgical approach to radial nerve decompression around the elbow is centred around decompression of the PIN at the 5 sites of compression. The anterior or anterolateral approach is extensile, but is a much larger incision than the posterior (or lateral) approach.

The posterior approach is best in conjunction with epicondylar release and common extensor reconstruction (our preferred treatment for tennis elbow). This approach decompresses 4 out of the 5 sites easily by exposing the ECRB insertion and revealing the radial tunnel under the ECRB and ECRL, the leash of Henry, arcade of Frohse, as well as the supinator covering the PIN.

For decompression of a cyst or ganglion (Fig. 45.1), the anterior approach is better, allowing you to gain access to the radio-carpal joint (RCJ) and the proximal aspect of the radial nerve.

45.5.1 Anterior Approach

The patient is supine with the arm out on a table with the tourniquet inflated. Anatomical landmarks to be marked are the cubital fossa skin crease and medial edge of brachioradialis distally. The arm is held in supination and the incision starts longitudinally at the ulna border of brachioradialis approximately 3 cm from the elbow crease. It is then extended proximally and then transversely over the elbow crease. Further exposure can be achieved by extending the skin incision proximally on the medial side of biceps. The fascia overlying the brachioradialis is identified and incised with the underlying lateral cutaneous nerve of the forearm (which lies just lateral to the biceps muscle proximally and at the interval of brachioradialis and pronator distally) protected. The radial nerve is identified in the interval between the brachioradialis and brachialis proximally. It is then traced distally where it divides into superficial radial nerve and PIN (Fig. 45.2). At this point identify the second interval between brachioradialis muscle laterally and pronator teres muscle medially. At this point the recurrent branches of radial artery are identified and ligated. The supinator muscle is also identified and subperiosteally dissected on radius to expose anterior elbow joint capsule to access the RCJ.

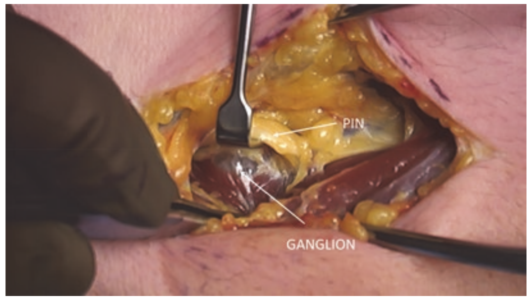

Fig. 45.2 Surgical exposure of the ganglion and posterior interosseous nerve adjacent to the nerve

45.5.2 Posterior Approach

The patient is supine with the arm out on a hand table with the tourniquet inflated. The anatomical landmarks of the lateral epicondyle, radial head and lister's tubercle are marked. A longitudinal incision of approximately 6 cm is made from the lateral epicondyle with the arm in 90 degrees flexion and neutral rotation aiming toward lister's tubercle. The fascial interval between ECRB and EDC is clearly identified. The fascia is incised and the muscle is divided by either sharp or blunt means. This exposes the underlying oblique fibres of supinator muscle (Fig. 45.3). The forearm is supinated to allow easier identification of the PIN. The PIN is located proximal to the leading edge of supinator (arcade of Frohse) and can be identified with a yellow fatty streak surrounding it (Fig. 45.4). A knife is then used to release the arcade of Frohse and supinator along the course of the PIN from proximal to distal (Fig. 45.5). Only if a wider release is required in addition to the tennis elbow (from Nerve Conduction Studies), the leash of Henry (radial recurrent artery) is identified just proximal to the arcade of Frohse and is carefully ligated or diathermied with bipolar diathermy (Fig. 45.6). Care is also taken to avoid injury to the venae comitantes running with the PIN as this can be a source of post-operative haematoma. The tendinous part of ECRB overlying the nerve is then palpated with a finger. If this is deemed to be a source of compression, then a release is performed at this level. The aim is an in situ decompression without mobilisation of the nerve.

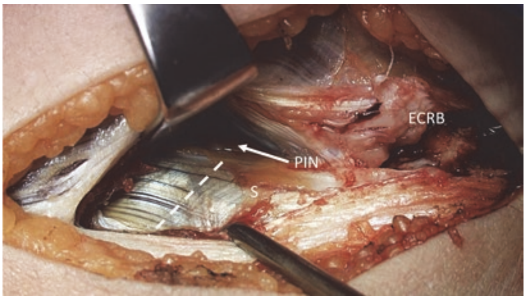

Fig. 45.3 Superficial head of supinator showing the course of the PIN under the arcade of Frohse and the superficial tendon through a split of the ECRB

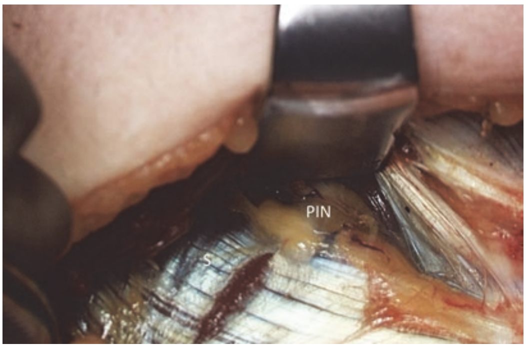

Fig. 45.4 Division of the superficial head of supinator perpendicular to the fibres from the arcade of Frohse

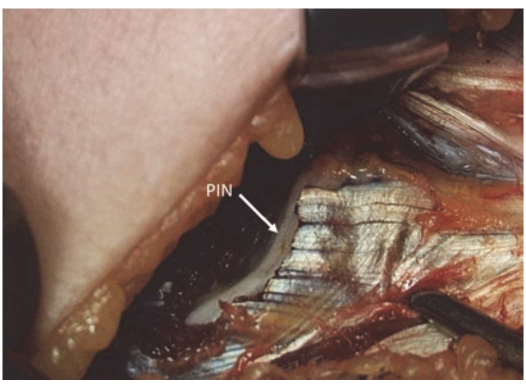

Fig. 45.5 More extensive released nerve deep to superficial head of supinator

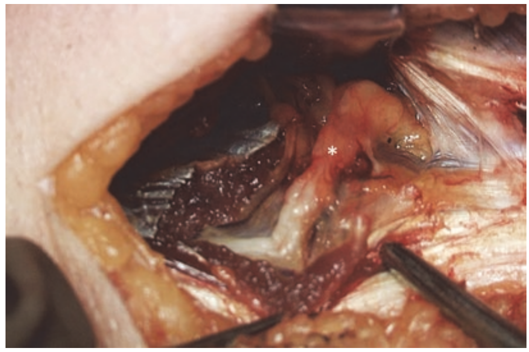

Fig. 45.6 Fully released nerve showing compressive lesion and adjacent swelling

45.6 Tips and Pearls (Posterior Approach)

1. DO NOT release below "the equator" of the epicondyle as this represents the functional LUCL attachment and post-operative (iatrogenic) posterolateral instability is not uncommon.
2. Release ECRB proximally to the level of the muscle (brachioradialis); a full tendinous release prevents one site of compression (the free edge of the ECRB tendon).
3. Find the superficial supinator deep to ECRB carefully; the oblique fibres show the way.
4. Use bipolar diathermy from here on as the nerve branches are susceptible.
5. Use a fresh sharp blade (I use a No. 15 blade) perpendicular to the supinator fibres up to the fat.
6. Dissect the fat with tenotomy scissors to protect the nerve branches.

45.7 What to Avoid

Bleeding: Gain perfect haemostasis BEFORE dissecting the nerve and branches under supinator. There are small veins that bleed easily.

Damage to the nerve is clearly the most important thing to avoid.

45.8 Complications/Bailout/Salvage

This procedure already is the salvage of failed tennis elbow releases (especially arthroscopic release).

If the posterolateral corner is loose at exploration, you must tighten the humeral attachment to prevent poster-lateral elbow instability. If instability is ongoing, an internal brace with anchors at the LUCL anchor points gives early stability.

If the nerve is already damaged, you may need to consider grafting or neural tube repair, and consideration of a Jones transfer in older patients who may not recover.

45.9 Post-operative Care

Neurolysis on its own requires no protection, and a bandage without plaster for a week is all that is necessary. If tennis elbow reconstruction is performed, we protect the elbow with a plaster slab over the elbow for a week, but allow free movement after this. We do not allow resistance work for the tendon repair until 6 weeks post-operatively.

Further Reading

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46 Ulnar Nerve Decompression

David J. Wilson and Mark S. Cohen

46.1 Description

Ulnar neuropathy in the cubital tunnel can be successfully treated through surgical decompression. Anterior transposition can decrease traction during peak elbow flexion and provide stability in cases of ulnar nerve subluxation. Anterior transposition can be performed using subcutaneous, submuscular, and intramuscular techniques.

46.2 Key Principles

Cubital tunnel syndrome (CuTS) involves compression of the ulnar nerve at the level of the elbow. The ulnar nerve is a branch of the lateral cord of the brachial plexus, carrying C8-T1 fibers. The ulnar nerve descends the medial brachium to the elbow, penetrates the medial intermuscular septum (IMS), and courses deep to a fascial arcade of Struthers. The nerve courses posteriorly around the medial epicondyle of the distal humerus and enters the cubital retinaculum (Osborne's ligament). The nerve finally exits the cubital tunnel and enters the forearm between the humeral and ulnar heads of the flexor carpi ulnaris (FCU) muscle. As it does so, it passes beneath a final fascial arcade (of Osborne), which is found deep to the fascia of the FCU. Release of any/all of these offending compressive structures is key to successful surgical decompression (see Fig. 46.1).

46.3 Expectations

In situ decompression of the ulnar nerve can be performed through an open or endoscopic approach. In these cases, the nerve is decompressed starting at the cubital retinaculum, through the leading fascial edge of FCU and between the heads of FCU. In situ ulnar nerve release involves a balance of wide release through a smaller exposure while avoiding subsequent iatrogenic nerve instability. When a wider release is performed, the far proximal and distal sites of compression can be more definitively addressed. A larger resection of the intermuscular septum, definitive visualization and decompression of the *ligament of Struthers*, extensile intramuscular decompression of the ulnar nerve as it traverses the FCU, and the ability to address concomitant pathology are all benefits of a more extensile open approach. A wider release is required to prevent tethering and subsequent "Z deformity" when performing an anterior transposition.

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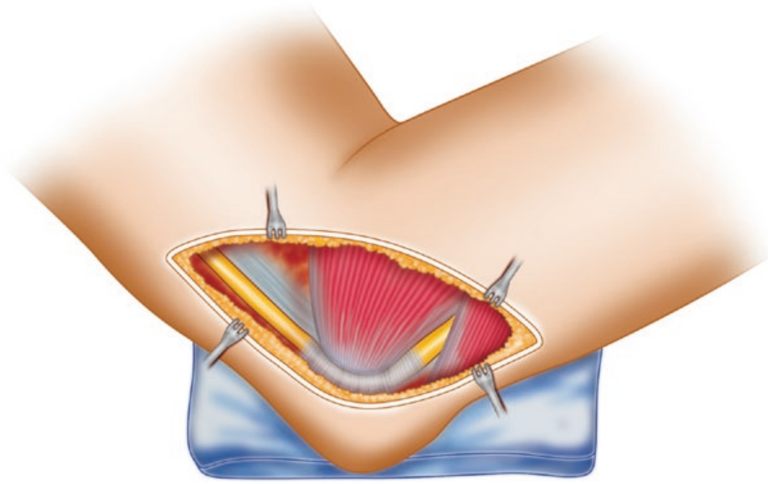

Fig. 46.1 Native position of the ulnar nerve and all sites of compression

46.4 Indications

Symptomatic ulnar neuropathy commonly involves painful paraesthesias with predominant night time and positional exacerbations. The onset is typically idiopathic with no identifiable cause. Less commonly, the condition can be posttraumatic. Symptoms can occur with normal anatomy or in the presence of posttraumatic or congenital bony deformity. Nerve conduction studies (NCS) are commonly abnormal, showing increased latency, decreased amplitudes, with signs of denervation and axonal injury in more severe cases.

46.5 Contraindications

Contraindications to in situ release include symptomatic ulnar nerve instability and in some cases severe motor changes.

46.6 Special Considerations

Alternate and often compounding sites of compression (second crush phenomenon) should be considered in the diagnosis of CuTS. Clinical evidence of ulnar nerve subluxation warrants transposition techniques. Snapping triceps symptoms or other concomitant local pathology should guide additional procedures (e.g. debridement of snapping portion of the medial triceps band). Severe motor atrophy should prompt consideration of techniques to augment axonal regeneration (e.g. anterior interosseous nerve into motor branch of the ulnar nerve, end to side "supercharge" procedure) and/or address additional sites of compression.

46.7 Special Instructions, Positioning, and Anesthesia

Supine positioning on a gurney using a hand table with a high brachial sterile tourniquet is preferred. Regional anesthesia is preferred. The medial elbow is brought into view by abducting the flexed and externally rotated elbow to 90 degrees at the patient's side over a bump of towels. The surgeon sits in the axilla, while an assistant stabilizes the arm and retracts opposite him or her (see Fig. 46.2).

46.8 Tips, Pearls, and Lessons Learned

Optimal visualization through an adequate surgical exposure facilitates definitive neural decompression. Anterior subcutaneous transposition is tolerated well and can be performed efficiently with minimal change to post-operative recovery.

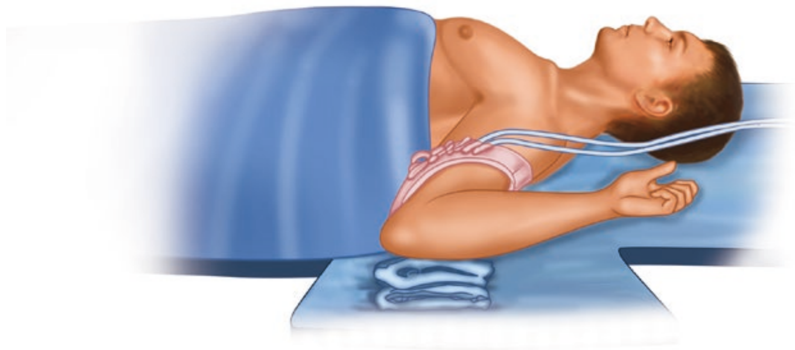

Fig. 46.2 Supine positioning, on a gurney with a hand table, utilizing a sterile tourniquet

46.9 Difficulties Encountered

Meticulous hemostasis prevents complicating hematoma formation. Wide decompression of the proximal course of the ulnar nerve through generous resection of the intermuscular septum minimizes proximal tethering of the nerve following anterior transposition. Meticulous care is required to prevent inadvertent traction injury to the nerve intra-operatively.

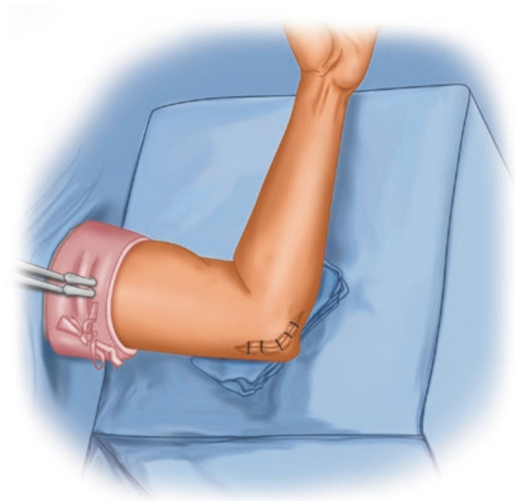

Fig. 46.3 Widely abducted and externally rotated arm with the elbow in a flexed position. From the axilla, the surgeon has clear access to the topical landmarks which guide the incision

46.10 Key Procedural Steps

The medial epicondyle is a prominent landmark for any incision to expose the ulnar nerve. The incision is drawn just posterior to this, extending approximately 6 cm proximal, along the course of the palpable intermuscular septum, and 6 cm distal to the medial epicondyle. The distal extent angles gently posteriorly, toward the subcutaneous border of the ulna (see Fig. 46.3). The incision generally forms a straight line when the elbow is in an extended position. Care is taken during the approach to protect any encountered branches of the medial antebrachial cutaneous nerve (MABC). These are most commonly located crossing distal to the epicondyle. The ulnar nerve is best found proximal to the cubital tunnel as it lies deep and posterior to the IMS. Care is taken during this step to develop a definitive decompression plane that facilitates safe and efficient exposure of the nerve. Once the correct plane is identified, it is developed first superficially and then circumferentially to decompress the ulnar nerve in its entirety. Retraction of the superficial overlying tissue can facilitate visualization and decompression of the high IMS and any proximal fascial arcade (of Struthers). Superficial decompression of the ulnar nerve through Osborne's ligament, around the prominence of the medial epicondyle, can be facilitated by slight elbow extension. Once exposure has descended to between the heads of FCU, care must be taken to decompress the superficial and deep fascial layers. It is at this level that motor branches of the ulnar nerve are encountered and must be dissected free to allow mobilization of the nerve anteriorly when transposition is performed. Once superficial dissection to the desired plane is completed, circumferential decompression is facilitated by gentle retraction

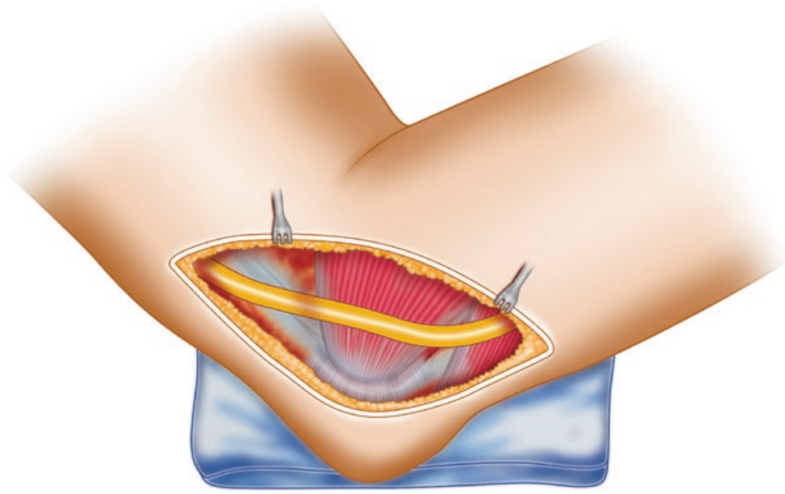

Fig. 46.4 Widely decompressed ulnar nerve, demonstrating un-tensioned anteriorly transposed subcutaneous position

of the nerve. This is best accomplished through non-mechanical pliable manipulation techniques, such as the use of a looped non-weighted Penrose drain. Circumferential decompression should allow un-tensioned anterior transposition of the ulnar nerve without any sharp angle (Z deformity) turns (see Fig. 46.4).

46.11 Bailout, Rescue, and Salvage Procedures

Any clinical evidence of pre-existing or iatrogenic instability resulting from decompression of the ulnar nerve should prompt consideration of anterior transposition. Stable anterior transposition can be performed successfully through various subcutaneous, intramuscular, and submuscular techniques. The type of technique chosen should reflect a patient specific surgical plan and depends heavily on response to prior surgery and concomitant pathology. In the setting of revision surgery, augments to prevent scaring around the nerve can be considered.

47 Anterior Subcutaneous Ulnar Nerve Transposition

Evan W. James, John M. Apostolakos, and Joshua S. Dines

47.1 Background

Entrapment of the ulnar nerve can occur at multiple sites including the arcade of Struthers, intermuscular septum, medial epicondyle, cubital retinaculum, Osborne ligament, anconeus epitrochlearis, and between the two heads of the flexor carpi ulnaris (FCU). Other external sources of compression include osteophytes, gouty tophi, ganglion cysts, fractures, and tumors. Compression of the ulnar nerve may result in pain at the elbow along with numbness and paresthesias in the ring and/or small finger. In some cases, weakness may occur in the ulnar nerve motor distribution. The severity of nerve compression is best quantified using electrodiagnostic studies.

47.2 Expectations

Non-operative management including postural modifications and static night splinting with the elbow in extension are first line treatments for most patients. In cases where non-operative treatment fails, anterior subcutaneous ulnar nerve transposition may be warranted. A number of techniques for subcutaneous ulnar nerve transposition have been described including the subcutaneous pocket [3], subcutaneous fascial tunnel [4], fasciodermal sling [5], fascial sling [6], V-sling [7], and endoscopic release [8].

47.3 Indications

- Nerve conduction velocity of less than 40 meters (m)/second (sec) or nerve conduction velocity of greater than 40 m/sec following failure of 2–4 months of non-operative management.
- Intrinsic muscle atrophy.
- Failure of non-operative measures including activity modification and night splinting to relieve symptoms.

47.4 Contraindications

- Patients with bleeding disorders, including hemophilia, are at risk for intramuscular and perineural bleeding.
- Patients with double crush phenomenon (concurrent C8-T1 radiculopathy, lower trunk brachial plexopathy, thoracic outlet syndrome, or ulnar tunnel syndrome of the wrist with cubital tunnel syndrome) may not experience complete relief of symptoms.

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47.5 Special Considerations

A detailed preoperative physical exam is critical to success. Exam should begin at the cervical spine and proceed distally. In some cases, subluxation of the nerve over the medial epicondyle can be palpated while cycling the elbow through flexion and extension. Sensory testing is performed using Semmes-Weinstein monofilament and two-point discrimination tests. A provocative elbow flexion test with extrinsic compression over the nerve held for 30–60 s may elicit reproduction of symptoms. Other classic signs of ulnar nerve entrapment include the Froment, Wartenberg, Jeanne, and Masse signs. Late findings include clawing of the ring and small finger and atrophy of the first web space and interossei. Imaging is not routinely warranted but radiographs (anteroposterior and lateral views), static ultrasound (to measure ulnar nerve cross sectional area at the cubital tunnel) [1], dynamic ultrasound (to assess for ulnar nerve subluxation), and magnetic resonance imaging of the elbow can be helpful in select cases.

47.6 Special Instructions, Positioning, and Anesthesia

- Supine with a hand table.
- Non-sterile or sterile tourniquet.
- Regional or general anesthesia.
- Some surgeons may elect to use a Bier block with dexmedetomidine hydrochloride and lidocaine.

47.7 Tips, Pearls, and Lessons Learned

47.7.1 Anconeus Epitrochlearis

The anconeus epitrochlearis is an accessory muscle found in approximately 15% of the population that originates at the inferior aspect of the medial epicondyle and inserts on the medial olecranon [2]. When present, it passes over the roof of the cubital tunnel and can cause compression of the ulnar nerve. Care should be taken to release the muscle in addition to other sites of compression.

47.7.2 Ulnar Collateral Ligament Injury

The transverse and posterior bundles of the ulnar collateral ligament (UCL) form the floor of the cubital tunnel. Deep dissection in the floor of the cubital tunnel should be avoided to prevent iatrogenic injury to the UCL and medial elbow instability.

47.8 Difficulties Encountered

Select patient populations may present unique challenges during decompression and transposition. In patients with gout, tophi and tenosynovitis due to uric acid crystal deposits can cause entrapment neuropathy. Similarly, patients with rheumatoid arthritis can develop entrapment neuropathy secondary to proliferative synovium and tenosynovitis adjacent to the cubital tunnel. Extra care should be taken in these cases to ensure adequate decompression.

47.9 Key Procedural Steps

A 10 cm curvilinear incision is made over the medial aspect of the elbow overlying the ulnar nerve. Blunt dissection is carried down to the level of the ulnar nerve. Care should be taken to protect the medial antebrachial cutaneous nerve for the duration of the procedure. Direct palpation is used to identify the intramuscular septum proximally and the nerve can be found just distal to the septum. The nerve should be decompressed proximally from the medial intermuscular septum and arcade of Struthers to the cubital retinaculum, arcade of Osborne, and the two heads

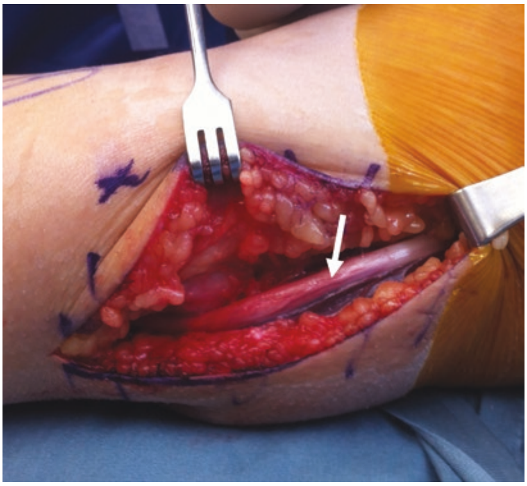

Fig. 47.1 The ulnar nerve (arrow) is decompressed in situ prior to transposition

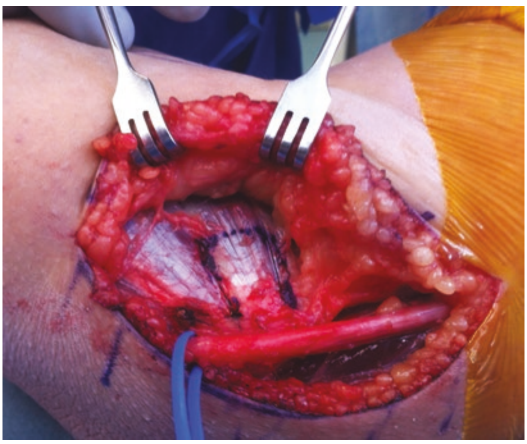

Fig. 47.2 The ulnar nerve is tagged with a vessel loop and mobilized anterior to the medial epicondyle

of the flexor carpi ulnaris muscle distally (Fig. 47.1). Once adequately decompressed, the medial intermuscular septum is divided 3-4 cm proximal to the medial epicondyle and rotated on its insertion. The ulnar nerve is then tagged with a vessel loop (Fig. 47.2) and transposed anteriorly. The fascial sling is passed over the nerve and secured with a suture, taking care to avoid excessive tension on the nerve (Fig. 47.3). Once the fascial sling is secured, the elbow is cycled

Fig. 47.3 The ulnar nerve is transposed anterior to the medial epicondyle and secured with a fascial sling (arrow)

through a full range of motion to ensure that the sling does not produce excessive tension, pressure, or kinking at the extremes of motion.

47.10 Bailout, Rescue, and Salvage Procedures

If the fascial sling is disrupted or found to be insufficient, a subcutaneous pocket technique [3] can be used as an effective bailout procedure. A subcutaneous pocket is developed in the fat anterior to the medial epicondyle. Suture is used to approximate adipose tissue of the anterior subcutaneous flap to the medial epicondyle, creating a tension-free pocket that prevents posterior translation of the nerve.

If a branch of the medial antebrachial cutaneous nerve is inadvertently transected, the distal end of the nerve should be cauterized and mobilized proximally away from the incision.

47.11 Pitfalls

Persistent symptoms may result from inadequate release of the ulnar nerve proximal and distal to the cubital tunnel, perineural scarring, irreversible nerve damage from chronic compression, or other sites of compression (e.g. cervical spine or brachial plexus). In addition, care should be taken that the fascial sling does not cause any kinking of the nerve which could produce a new compression point. Elbow stiffness can result from immobilization for longer than 2–3 days. To avoid stiffness, a hinged elbow brace can be applied locked at 90° flexion to protect the wound for the first 2–3 days postoperatively followed by progressive range of motion exercises. In situ decompression alone should be avoided in throwing athletes. In these patients, ulnar nerve symptoms can be elicited with the throwing motion alone and are often accompanied by medial elbow instability.

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