State of the art review

Treatment of elbow instability: state of the art

Alessandro Marinelli 1, Benjamin R Graves 2, Gregory Ian Bain 3, Luigi Pederzini4

ABSTRACT

The elbow is a congruent joint with a high degree of inherent stability, provided by osseous and soft-tissue constraints; however, when substantial lesions of these stabilising structures happen, instability of the elbow occurs. Significant improvements in surgical elbow instability diagnosis and treatment have been recently introduced both for acute and chronic cases. Specific stress tests, recently introduced in the clinical practice, and different imaging techniques, both static and dynamic, allow assessment of the elbow stabilisers and detection of the instability direction and mechanism even in subtle forms. Many surgical techniques have been standardised and surgical instruments and devices, specifically dedicated to elbow instability treatment, have been developed. Specific rehabilitation protocols have been designed to protect the healing of the elbow stabilisers while minimising elbow stiffness. However, despite the progress, surgical treatments can be challenging even for expert surgeons and the rate of persistent instability, post-traumatic arthritis, stiffness and pain can be still high especially in most demanding cases. The biology of the soft-tissue healing remains one of the most important aspects for future investigation. If future research will help to understand, correct or modulate the biological response of soft-tissue healing, our confidence in elbow instability management and the reproducibility of our treatment will tremendously improve. In this paper, the state of the art of the current knowledge of elbow instability is presented, specifically focusing on modern surgical techniques used to solve instability, with repair or reconstruction of the damaged elbow stabilisers.

INTRODUCTION

The elbow is a congruent joint with a high degree of inherent stability, provided by the osseous and soft-tissue constraints.1–3 When substantial lesions of these stabilising structures occur, the joint becomes unstable. Elbow instability is more common than previously thought and even mildly symptomatic elbows can hide subtle forms of instability. Treatment of elbow instability presents a challenge to balance the opposing risks: persistent instability and progressive stiffness. Especially in severe forms, the treatment strategy requires an extensive anatomical and biomechanical knowledge to understand the complex interactions between the different stabilisers that are injured.

APPLIED ANATOMY OF THE ELBOW STABILITY

The elbow has both static (bone, ligament and capsular) and dynamic (muscle) constraints.1–2 (table 1).

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There are three primary stabilisers: ulno-humeral joint, lateral collateral ligament (LCL) and medial collateral ligament (MCL) (figure 1). The LCL consists of three parts: the lateral ulnar collateral ligament (LuCL), radial collateral ligament (RCL) and annular ligament.6 7 The LuCL is the most effective part of the ligament and spans from the lateral epicondyle to the supinator crista on the ulna (figure 2). The MCL is composed of three parts: anterior bundle, posterior bundle and transverse ligament. The anterior bundle is the most effective part of the ligament and spans from the antero-inferior edge of the medial epicondyle to the sublime tubercle (figure 3).8–10

Primary stabilisers are the static constrainters that provide the main joint stability. If a substantial lesion occurs in a primary stabiliser, elbow instability can occur, even if all other constraints are intact. The secondary stabilisers, both static or dynamic, are constraints that support the primary stabilisers to prevent instability. Even if they are seriously injured, instability does not occur if the primary stabilisers are intact. Primary and secondary constraints work in synchrony to resist the various patterns of instability: posterolateral rotatory instability (PLRI) (an external rotatory dislocation of the radioulnar joint in relation to the humerus, causing a posterolateral subluxation or dislocation of the forearm complex), posterolateral and posteromedial rotatory instability (PMRI) (an internal rotatory dislocation of the radioulnar joint in relation to the humerus, causing a posteromedial subluxation of the forearm complex), varus or valgus stress, direct axial load.

For the prognosis and treatment, it is important to understand how these restraints interact among the specific patterns of instability (table 2).

IMAGING

The combination of history, physical examination and imaging is important to diagnose elbow instability. Standard anteroposterior and lateral radiographic views are the mainstay initial diagnostic tool. If necessary, a CT scan with 3D reconstruction is generally the second-level examination. CT scan demonstrates the presence of joint incongruency and the different involvement of the bony stabilisers. X-Rays and CT scan do not detail the soft-tissue lesions, but these can often be inferred. In appropriate cases, MRI can provide valuable information regarding soft-tissue injuries including ligament, capsular and tendon lesions. MRI is also useful to show the presence of subtle osteochondral injuries, bone bruises and oedema.

Radiography, CT and MRI are static examinations and therefore cannot identify dynamic or recurrent instabilities.11 Static stress radiographs and dynamic fluoroscopy can be useful to confirm the diagnosis of recurrent elbow instability.12 However, they can
be uncomfortable and can expose the patient and operator to radiation. Evaluation under anaesthesia is a method that certainly allows improved diagnostic accuracy in subtle cases (table 3). Additional tools for diagnosing elbow instability are ultrasound examination and arthroscopy. The former is operator dependent and requires training and experience, while the latter should be performed only in cases where a subsequent surgical treatment is indicated. For this reason, the choice and the evaluation of the diagnostic techniques should be considered in the light of the history and examination and resources available.

**New diagnostic tools: 4D CT scan**

The 4D CT scan is a new dynamic diagnostic tool that can be used to assess a joint throughout the range of motion. Therefore, this technique can unmask subtle instabilities at the extremes of motion. Provocation tests of the joint can also be performed. We expect that dynamic diagnostic modalities (4D CT scan, dynamic MRI and position-sensing technologies for movement analysis) will be more widely used to assess subtle joint instabilities in the future.

**ARTHROSCOPIC ASSESSMENT OF INSTABILITY**

In some acute or chronic instability cases, arthroscopic assessment can be indicated. Arthroscopically, the joint space can be appreciated, so that capsular or ligament tears or possible intra-articular lesions can be detected and treated. If there is joint laxity or a capsular/ligamentous tear, then the joint space will open wider, especially with provocation manoeuvre (figure 4).

It is important to point out that the anterior joint space will open medially with valgus force and laterally with varus. The posterior joint space is more influenced by rotatory manoeuvre and, in case of instability, it will open medially with pronation due to laxity of the posterior bundle of MCL and laterally with supination due to laxity of LuCL.

A positive drive-through sign may be due to MCL insufficiency or a PLRI pattern. With PLRI, the ‘drive through sign’ is performed by placing the arthroscope into the posterolateral gutter and moving it straight across the ulno-humeral articulation into the medial gutter: if this manoeuvre is possible, this is a sign of evident laxity or instability. In more severe cases, the PLRI dislocation can be directly observed from inside the joint with the scope introduced through the posterior portal. With the elbow flexed at 30°, producing a compression, valgus and supination manoeuvre, the lateral olecranon will lift off the olecranon fossa, and the ulno-humeral joint will open, to expose the tear of the lateral ligament complex adjacent to the lateral epicondyle. With a little more supination, without major force, the bare area of the trochlear groove can be seen. If even the medial joint space will open, that demonstrates that this is not just a PLRI, but it is a combined lateral and medial instability.

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**Table 1** Based on anatomy and mechanism of action, the elbow stabilisers can be divided into static (bone, capsular and ligament) and dynamic (muscle) constraints. Based on their effectiveness in preserving joint stability, the elbow stabilisers can be divided into primary and secondary constrainers.

<table>
<thead>
<tr>
<th>Static Stabilisers</th>
<th>Function</th>
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<tbody>
<tr>
<td><strong>Primary</strong></td>
<td></td>
</tr>
<tr>
<td>► Ulno-humeral joint: coronoid, olecranon and trochlea</td>
<td>Provides stability in all planes, mostly &lt;20° or &gt;120° flexion</td>
</tr>
<tr>
<td>► MCL (anterior bundle)</td>
<td>Resists valgus stress and PMRI</td>
</tr>
<tr>
<td>► LuCL</td>
<td>Resists PLRI</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
</tr>
<tr>
<td>► Radio-humeral Joint: radial head, capitellum</td>
<td>Resists PLRI and varus stress</td>
</tr>
<tr>
<td>► Capsule</td>
<td>Provides stability in all planes, mostly &lt;20° or &gt;120° flexion</td>
</tr>
<tr>
<td>► Common flexor origin</td>
<td>Resists valgus stress and PMRI</td>
</tr>
<tr>
<td>► Common extensor origin</td>
<td>Resists varus stress and PLRI</td>
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LuCL, lateral ulnar collateral ligament; MCL, medial collateral ligament; PLRI, posterolateral rotatory instability; PMRI, posteromedial rotatory instability.
and this would be an indication for a bilateral ligament repair or reconstruction.

Another typical arthroscopic suggestive of PLRI is the presence of laxity of the annular ligament (figure 3): with the scope in the antero-medial portal, the annular ligament droops down to the radial neck with gapping between the ligament and radial head. Tightening of the annular ligament following repair is one sign of an adequate repair.20

In minor instability cases, the arthroscopic signs can be even more subtle: anterior or anteromedial synovitis, chondropathy of the radial head and/or of the lateral aspect of the capitellum, antero-lateral capsule insufficiency or tears are possible findings, which can be identified both with wet or dry arthroscopy.21 Some dynamic arthroscopic tests, currently under investigation, have been recently described to be associated to subtle instability causing lateral-sided elbow pain: the ‘annular drive-through’ and the ‘R-LCL pull-up sign’.17

CLASSIFICATION

Elbow instability is not a single entity. Rather, it includes a wide spectrum of different presentations.22 For an accurate characterisation of elbow instability, we need to consider six parameters:

1. Timing: (a) acute forms: fractures or fracture-dislocations; (b) chronic recurrent forms: dynamic forms. The elbow, basically reduced, depending on the applied stress, can have a partial or complete dislocation; (c) chronic persistent forms: static forms. The elbow is statically dislocated and it is not possible to reduce it without an extensive surgical release.

2. Involved stabilisers: ‘simple’ forms if only soft tissues are involved; ‘complex’ if bony structures are also involved.

3. Aetiology: instability can be caused by traumatic, overuse or congenital, inflammatory, iatrogenic, post-infective disorders.

4. Involved joint: dislocation can occur at the ulno-humeral joint or at the radio-humeral joint.

5. Severity of the instability: the dislocation can be partial or complete.

6. Direction: specific post-traumatic conditions can result from PLRI, PMRI, direct axial load, or valgus or varus stress.

Considering the first two parameters, which involved stabilisers and timing, it is possible to classify the instability forms into six patterns: simple acute, simple recurrent, simple persistent, complex acute, complex recurrent and complex persistent. Since 2015, this classification has been followed by the Italian Shoulder and Elbow Surgeon Society (SICSeG).23

SIMPLE ACUTE: SOFT TISSUE–ACUTE FORMS

This group includes simple elbow instability cases including acute and traumatic dislocation or subluxation caused by an isolated soft-tissue lesion. In most cases, only capsule and collateral ligaments are involved; in more severe cases, a detachment of the epicondylar tendons (lateral and/or medial) can also occur. Simple forms can be classified as posterior, anterior and divergent. Most common in adults, the direction is nearly always posterior. The most known dislocation mechanism is the PLRI24 25: by falling on the hand with the elbow extended, axial force, combined with valgus and supination stress, produces a circular lesion of the stabilisers: the lesion starts in the LCL, progressively involves the anterior and posterior capsule, until it involves the MCL (Horii circle).3 22

Stage 1: LucL lesion with a temporary subluxation.

Stage 2: Lesion of the anterior and posterior capsule adds to the LCL injury. The joint is dislocated with the trochlea perched on the coronoid process.

Stage 3: The previous ligament and capsular lesions are combined sequentially with a progressive injury of the MCL. The joint is completely dislocated. Based on increasing severity of MCL involvement, stage 3 is further divided:

► Stage 3a: only the posterior portion of MCL is involved. Thanks to the integrity of the anterior band of the MCL, after reduction manoeuvre, it is possible to maintain the joint reduced and centred across the full range of motion, keeping the forearm in pronation.

► Stage 3b: the lesion involves the posterior and anterior band of the MCL, resulting in postero-lateral, and also varus-valgus, instability. In these cases, it is possible to maintain the elbow reduced by avoiding the last 30–45° of extension.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Based on the different dislocation mechanism, the same stabiliser can be differently involved to prevent elbow instability. In all cases, the final result of the trauma will depend on amount of the energy and on specific interactions among stabilisers differently involved.</th>
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<tbody>
<tr>
<td>Stabilisers</td>
<td>Resisting against PLRI PMRI Varus Valgus Direct posterior</td>
</tr>
<tr>
<td>U-H joint</td>
<td>✓</td>
</tr>
<tr>
<td>LCL</td>
<td>✓</td>
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<tr>
<td>MCL</td>
<td>✓</td>
</tr>
<tr>
<td>Radio-humeral joint</td>
<td>✓</td>
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<tr>
<td>Capsule</td>
<td>✓</td>
</tr>
<tr>
<td>Flexo-pronator muscle</td>
<td>✓</td>
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<tr>
<td>Extensor muscles</td>
<td>✓</td>
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</tbody>
</table>

LCL, lateral collateral ligament; MCL, medial collateral ligament; PLRI, posterolateral rotatory instability; PMRI, posteromedial rotatory instability.
Stage 3c: the tendon insertions of the medial and lateral epicondyle add to the MCL lesion. Complete stripping of all soft tissues (ligaments, capsule and tendons) from the distal humerus produces an uncontrollable instability that is hard to control through forearm rotation or using a cast or a brace (figure 6).

More recently, as has been described in the past, several authors have postulated that in some cases the posterior dislocation mechanism might occur in the opposite direction, from medial to lateral, by axial compression and valgus stress.

After reviewing MRI scans, Robinson and Watts described his belief that the medial side it is more likely to be the site of origin of the ligament tears (figure 7).

In a recent paper, it is argued that in simple elbow dislocations associated with an extremely severe soft-tissue injury, it is often possible to recognise a posteromedial mechanism with a severe damage to the lateral complex, often requiring surgical treatment.

Regardless of the mechanism by which it occurs, however, the treatment of a simple elbow dislocation is the same: after reduction, most of the cases (about 90%) can be treated conservatively, and the most severe cases (about 10%) are usually treated surgically.

### Conservative treatment

Since the most common complication after an acute simple dislocation is elbow stiffness and not instability, there is a strong attitude to treat these lesions conservatively, without surgical repair of the injured ligaments and capsule. In the emergency department, a closed reduction is performed after a neurovascular assessment and a radiographic examination. The manoeuvre is usually carried out under sedation, especially if the dislocation is complete and/or lasting several hours. With the patient in the supine or prone position (if awake), placing the arm in extension and supination, a gentle pressure is applied on the tip of the olecranon so that the proximal ulna can move distally and then anteriorly to embrace the trochlea, obtaining the sensation, tactile, audible and visual, of joint reduction.

After the reduction manoeuvre, the stability of the elbow should be assessed through a full range of motion, evaluating if joint stability is influenced by forearm rotation. The correct immobilisation and rehabilitation programme are guided by the amount of residual instability after the joint reduction, evaluated clinically and radiographically.

A radiographic examination permits to confirm that joint congruency has been achieved and to rule out articular fractures. Especially in most severe cases, clinical examination and

| Table 3 Diagnostic provocation tests for elbow instability |
|----------------|----------------|----------------|----------------|
| Instability | Lesion | Test | Sensitivity |
| PLRI | LCL | Posterolateral rotatory drawer | Most |
| | | Lateral pivot-shift | Good |
| | | Supinated push-up tests: | High |
| | | ► Table top relocation | Good |
| | | ► Prone-push-up | Good |
| | | ► Chair push-up | |
| Valgus | MCL | Valgus stress | Fair |
| | | Milking manoeuvre | Good |
| | | Modified milking manoeuvre | Good |
| | | Moving valgus stress | High |
| PMRI | Antero-medial coronoid and LCL | Gravity-assisted varus grind | High |

LCL, lateral collateral ligament; MCL, medial collateral ligament; PLRI, posterolateral rotatory instability.

Figure 4 Elbow arthroscopy of the anterior compartment in a cadaveric model with different instability scenarios. (A) Normally, the medial joint space opens only 1 mm with a valgus stress. (B) If the anterior bundle of the medial collateral ligament (MCL) is divided, the joint space will open 4 mm. (C) If the posterior bundle is also divided, then the medial joint space will open 10 mm and the scope can be easily advanced between the ulna and humerus. The ‘drive through sign’. (Copyright Dr Gregory Bain and Max Crespi)

Figure 5 Arthroscopic view, in a right elbow, of the radio-capitellar joint in the anterior compartment from a proximal anteromedial viewing portal. The laxity of the annular ligament is evident. (Copyright and courtesy of Dr Felix “Buddy” Savoie)
radiographs should be repeated at 1 week after reduction to rule out the rare, but possible, cases of re-dislocation.

CT scan is useful to guide the treatment, for example, in case of associated fractures or in case of a persistent drop sign, which is a radiographic warning sign of elbow instability, represented by an increase in distance between the trochlea and olecranon occurring after joint reduction. The role of MRI is still controversial and not routinely indicated in simple elbow dislocations. It is very useful to appreciate ligament and tendon involvement, but it exposes to the risk of overestimating the severity of soft-tissue lesions and, therefore, of over-treating patients.

After reduction, the elbow is usually protected in a cast or in an articulated brace, generally kept locked at 90° of flexion-extension. Depending on the severity of the damaged structures, a protected active or gravity-assisted overhead motion can be generally allowed after 5–15 days.

Forearm rotation affects joint stability in case of lesion of the collateral ligament. Pronation increases stability in case of disruption of the LCL complex with intact medial structures and supination increases stability in case of disruption of the MCL complex, with intact lateral structures (figure 8). In case of complete disruption of lateral and medial side, forearm rotation does not affect stability and the suggested forearm position is neutral.

The use of the brace is usually discontinued at rest after 3–4 weeks and during activities after 4–8 weeks. Shoulder abduction, without a cast or brace, should be avoided for at least 3 weeks to prevent dangerous varus stress on the lateral collateral ligament. An accelerated rehabilitation programme, which includes wearing a simple sling just for a few days, can be considered in less severe dislocations (usually stage 2), in motivated and compliant patients, that can be carefully followed for the first weeks.

With conservative treatment, good long-term outcomes have been generally reported. The surgical treatment is mandatory only in the following two clinical settings: unreducible dislocation of the joint (1% of cases or less) or inability to maintain the elbow sufficiently reduced (10% of cases). However, with a conservative treatment, we are aware that a small rate of patients (<10%) have a poor outcome. With better early detection of the most severe cases, including evaluation under anaesthetic, X-ray evaluations, CT scan or MRI when in doubt, it is probable that surgical indication for acute cases will increase in the future.

Figure 6 Simple elbow dislocation. (A) The joint dislocation is suggestive of a complete stripping of all soft tissues (ligaments, capsule and tendons) from the distal humerus: stage 3C. (B) An apparent good reduction has been obtained in emergency department and a 90°-locked brace was applied. (C) X-Ray performed few days later shows the failure of the conservative treatment, with a new complete dislocation despite wearing a brace.

Figure 7 MRI of a posterolateral dislocation after reduction showing a lower level (A) injury with isolated medial side disruption and high-grade (B) injury with disruption of all medial (large black arrow common flexor origin and small black arrow medial collateral ligament) and lateral (white arrow) structures. Note the soft-tissue injury is more extensive on the medial side of the elbow. (Copyright and courtesy of Dr Adam Watts)

Figure 8 Fonzie’s thumb rule is useful to remind the ligament-specific rehabilitation protocol. In case of a collateral ligament lesion, the thumb must point in the direction of the strongest ligament. (Copyright Dr Alessandro Marinelli). LCL, lateral collateral ligament. MCL, medial collateral ligament.

Figure 9 Lateral repair. Lateral view of the elbow demonstrating the grasping sutures placed in the lateral ulnar collateral ligament and advanced through drill holes in the centre of rotation through to the posterior lateral condyle. (Copyright Dr Gregory Bain and Max Crespi)
LATERAL LIGAMENT REPAIR

Anatomical repair of the lateral ligament complex is usually performed in traumatic and acute patterns (simple or complex elbow instabilities) or, less frequently, in not severe PLRI cases, when imbrication and/or reattachment of the soft tissues provide structural stability. In those cases, a trans-osseous repair can be performed with number 1 or 2 braided non-absorbable sutures (figure 9) or suture anchors. More subtle PLRI cases can be treated with arthroscopic plication of the LCL complex.19 38 39

LATERAL LIGAMENT RECONSTRUCTION

Reconstruction of the lateral ulnar collateral ligament is the primary treatment for recurrent PLRI. Reconstruction is indicated rather than repair when chronic attenuation or a significant deficiency of the LCL complex exists,40–42 especially in sportsmen and heavy manual workers. First, Savoie et al41 and

Figure 10  Treatment algorithm for lateral instability. Lateral ulnar collateral ligament (LuCL) reconstruction with grafts is indicated in patients with an evident and recurrent posterolateral rotatory instability (PLRI) instability; in less symptomatic patients, ligament repair seems to be the best choice. It can be performed with open technique, using bone tunnels or bone anchors, or arthroscopically with imbrication/plication of the lateral collateral ligament (LCL). In acute cases, when it is needed, direct ligament repair is preferred. (Copyright Dr Gregory Bain and Alessandro Marinelli)

Figure 11  (A) Isometric test performed pulling the free ends of the passing suture from the ulnar tunnel to the lateral epicondyle during flexion-extension arc of motion. (B) Passage of the graft through the bone tunnel. (C) The graft is tensioned and dynamic test for stability are performed. (D) The strands of the graft are sutured on to themselves. (Copyright Dr Luigi Pederzini)

Figure 12  MRI (T2, coronal sequence) demonstrating acute humeral avulsion of the medial ulnar collateral ligament. (Copyright Dr Benjamin Graves)

Figure 13  MCL repair with Internal Brace augmentation: (A) flexor pronator split, medial collateral ligament (MCL) dissected out; (B) MCL is split longitudinally (blue dashed line), humeral and ulnar tunnels are drilled. An extra #2 suture is thread through the humeral implant for repair of avulsed humeral MCL origin. (C) Ulnar implant is placed, FiberTape non-absorbable suture spans the two tunnels. (D) Native MCL is repaired over FiberTape suture. (Copyright Dr Benjamin Graves)
then van Riet et al\textsuperscript{43} have proposed an algorithm for lateral instability (figure 10).

In the last 15 years, many techniques have been described for LCL reconstruction, different graft types, number of strands, bone tunnel configurations and graft fixation. The graft can be either autologous (eg, palmaris longus, triceps or gracilis) or allograft (eg, extensor hallucis longus, Achilles tendon) or synthetic. The ligament reconstruction can be single or doubled strand. The bone tunnel configuration at the ulnar or humeral level can be performed using direct pass-through hole, or convergent half tunnels, or half tunnels with two smaller holes to dock the ligament. The graft can be secured with sutures back onto itself, suture anchors, interference screws or cortical buttons. There is no difference reported between the described techniques. The overall results after reconstruction for PLRI are good to excellent in about 85% of patients.\textsuperscript{40,42}

The authors prefer to use autogenous semitendinosus graft or extensor hallucis longus allograft if it is available.

**Surgical technique**

Via a Kocker approach, between the anconeus and flexor carpi ulnaris (FCU) muscle, the tubercle of the supinator crest is exposed. At this level, two convergent drill holes (3.2 to 4.5 mm based on graft size) are performed, spaced 1.5 cm apart, to be then connected. On the lateral epicondyle, the isometric point of the origin of the LuCL complex is identified (figure 11A). At this level, two diverging tunnels are created (figure 11B). Some authors prefer to dock the tendon over the supracondylar ridge, connecting two small holes to the half humeral tunnel. The graft is passed through the tunnels and the capsule is closed to ensure the graft remains extra-articular (figure 11C). Performing a flexion-extension arc of movement, the graft is accurately tensioned and then fixed. The graft is stabilised with either strands sutured together (figure 11D), sutures tied over a bone bridge, interference screws or cortical buttons.

After surgery, the arm is placed in a splint. After 3 weeks, a removable splint or a dynamic elbow brace is applied and the physiotherapy is commenced, with over-head exercise, to avoid the varus stress. At 3 months, strengthening exercises are performed. At 6 months, unrestricted activity and return to sport are permitted.

**MEDIAL LIGAMENT REPAIR AND RECONSTRUCTION**

**Primary repair of MCL**

Most MCL injuries can be treated successfully without surgery; however, when non-operative treatment is unsuccessful, or when...
a more rapid return to sport is desired, isolated medial ligamentous avulsion injuries of the MCL (figure 12) can be repaired primarily. Initially abandoned due to poor outcomes, Savoie et al showed that primary repair with suture anchors can produce good results with less than 6-month return to sport. Using a 6–8 cm curvilinear incision centred over the medial epicondyle, the flexor-pronator origin is dissected to expose the humeral bony footprint, or distally at the sublime tubercle. The bony footprint is debrided and prepared for repair. A 3.5–4.5 mm suture anchor with #2 non-absorbable suture is placed into the footprint, and the torn ligament is repaired.

Augmentation of the repair with high-strength non-absorbable suture has become increasingly popular. The Internal Brace (Arthrex, Naples, FL, USA) consists of a collagen-dipped FiberTape that spans between two 3.5 mm SwiveLock anchors that are placed at the humeral and ulnar insertions of the anterior band of MCL (figure 13 A–D).

Collateral ligament repairs augmented with this construct have been shown in a cadaver model to have similar load to failure strength and may be more resistant to gapping at time-zero than reconstruction. Dugas et al also reported the results of a clinical series of 128 throwing athletes followed for 1–2 years. Internal Brace augmentation allowed for quicker return to sport than ligament reconstruction (average 6.7 months compared with 11.6 months following modified Jobe reconstruction). However, long-term data are lacking.

Reconstruction of MCL

In the setting of more chronic medial ligamentous insufficiency, the diagnosis may be more subtle. This is most common in athletes, such as baseball pitchers, that place repetitive valgus strain across the elbow. The first line of treatment remains non-operative, with cessation of throwing, anti-inflammatory medications and physical therapy. When surgical intervention for persistent and/or recurrent medial ligamentous injury is considered, one must consider whether the damaged medial ligamentous structures are amenable for direct repair or if tissue supplementation will be required. In the case of mid-substance ligamentous rupture, or in chronic injuries, especially with multiple corticosteroid injections, tissue supplementation is required for reconstruction of the medial ulnar collateral ligament. Augmentation includes autograft or allograft tendon, typically hamstring or palmaris longus. There are multiple techniques reported for surgical approach and MCL reconstruction, and the ‘docking technique’ is described in the next section.

Authors’ preferred technique

Our preferred tendon graft is palmaris longus tendon (figure 14). If palmaris is absent, autograft or allograft alternatives are used, as toe extensor or hamstring tendon. Depending on the size of the patient and the technique of reconstruction being employed, a graft diameter of 3–4 mm and length of greater than 115 mm are typically required.

Elbow arthroscopy may be performed prior to open reconstruction to confirm valgus instability and to address concurrent pathology such as loose bodies or chondral injuries.

Medial approach to the elbow is made. The decision to dissect out the ulnar nerve is based on surgeon preference and varies with the exposure required on a case-by-case basis. Regardless, it is important to protect the ulnar nerve throughout the case (figure 15A). The MCL’s humeral origin and ulnar insertion are debrided. Two 3.5 mm drill holes are made at the sublime tubercle, the first at the most proximal extent of the metaphyseal tubercle and the second is placed distally creating a stable bony bridge (10–20 mm in length). At the humeral level, a drill hole is performed at the anterior inferior medial epicondyle.
This hole must be sized appropriately (6–8mm) to accept two strands of the graft (figure 15B). Two spaced additional holes are drilled proximally and the tails of the suture are shuttled through them (figure 15C and D). Varus compression is applied across the elbow while the suture tails are tied to each other over a bony bridge. In the case of osteopenia or poor bony quality, the sutures may be tied over a cortical button or a small plate.

Rehabilitation

Rehabilitation after MCL repair or reconstruction is performed under the care of a physical or occupational therapist. Care is taken to avoid valgus stress on the repair during the early stages of healing while maintaining range of motion to help prevent elbow stiffness. A hinged elbow brace is worn immediately following surgery and is locked at 90° of elbow flexion for the first 2 weeks. Passive and active range of motion is gradually progressed thereafter until full flexion and extension are achieved. The hinged brace is discontinued between 4 and 6 weeks for repairs and is discontinued at 8–10 weeks for reconstructions. An interval throwing programme will typically begin at 4 months after surgery, with return to competitive throwing around 6 months for repair, with or without Internal Brace, and 12 months for reconstruction.

Outcomes

The largest published series following modified Jobe medial ulnar collateral ligament reconstruction is Cain et al in 2010, which reported the results of 743 throwing athletes, 95% of which were baseball players, with a minimum of 2-year follow-up after surgery. The authors reported 83% returned to sport at the same or higher level of play with an average return to sport time of 11.6 months. Transient ulnar neuropathy was seen in 16%. Results of the docking technique have been similar, with several smaller series reporting 90%–95% return to sport at previous level, with a lower incidence of ulnar neuropathy (3%). More recent investigation suggests medial ulnar collateral ligament surgery is not the panacea for throwing athletes it was once believed to be. A recent meta-analysis evaluated the quality of published reports for return to sport following surgery and demonstrates that the majority of the literature is from low-quality, retrospective cohort and case series. It appears that...
what we can draw from this literature is that although a high percentage of baseball pitchers are returning to sport at their previous level, they often will not throw as fast or for as many innings as they did before their injury.

**CIRCUMFERENTIAL GRAFT RECONSTRUCTION**

In cases where the medial and lateral stabilising ligaments need reconstruction, a circumferential graft can be considered. This involves using an autologous, homologous or synthetic tendon graft. It is passed through the centre of rotation of the distal humerus. For the ulna, the tendon passes through the sublime tubercle medially, and through the supinator crest laterally, creating a circumferential tendon graft (figures 16–17). Interference screws have been proposed at each corner of the graft to prevent graft slippage (figure 18).

**COMPLEX ACUTE INSTABILITY**

The complex acute instabilities, also known as acute fracture-dislocations, are a heterogeneous group of acute and traumatic lesions characterised by elbow joint dislocation that include an associated fracture in addition to disruption of the soft-tissue stabilisers. Three main groups of fractures make up the so-called ‘Complex elbow instability’ as described by Morrey.

1. Olecranon fracture-dislocations: include fractures of the greater sigmoid notch in which the olecranon (always affected) can be multi-fragmented and the coronoid process (often affected) is usually fractured at its base. The ulno-humeral joint is consistently disrupted, with a dislocation or a fracture-dislocation of the radio-capitellar joint. The proximal radioulnar joint remains intact, which distinguishes the olecranon fracture-dislocations from the Monteggia injuries. Based on the level of comminution of the greater sigmoid notch, of the antero-medial coronoid facet and of proximal ulna metaphysis, olecranon fracture-dislocations can be divided into ‘simple’ and ‘complex’. Based on the position of the radial head dislocation with respect to the capitellum, the trans-olecranon fracture-dislocations are divided into anterior and posterior. Posterior olecranon fracture-dislocations can be considered the most proximal injury type among the spectrum of posterior (Bado type 2) Monteggia lesions because the principle and pitfalls of treatment are similar. Anterior trans-olecranon fracture-dislocations are often associated with larger coronoid fractures and radial head fractures, but collateral ligaments typically remain intact. For this reason, in anterior olecranon fracture-dislocations,
1. Treatment of elbow instability is challenging and always requires the balance of opposing risks: instability and stiffness.
2. In some acute or chronic instability cases, arthroscopic assessment can confirm the diagnosis, allows to evaluate its severity and to perform the treatment. In case of joint laxity or a capsular/ligamentous tear, the joint space will open wider, especially with provocation manoeuvre:
   - A positive drive-through sign may be due to medial collateral ligament (MCL) insufficiency or a posterolateral rotatory instability (PLRI) pattern.
   - The anterior joint space will open medially with valgus force and laterally with varus. The posterior joint space is more influenced by rotatory manoeuvre: it will open medially with pronation due to laxity of the posterior bundle of MCL and laterally with supination due to laxity of lateral ulnar collateral ligament.
3. The arthroscopic treatment of elbow instability includes capsular-ligament plication or ligament reattachment using suture anchors.
4. Since the most common complication after an acute simple dislocation is elbow stiffness and not instability, elbow dislocation is usually treated conservatively. The surgical treatment is mandatory only in case of unreducible dislocation of the joint (less than 1% of cases) or inability to maintain the elbow sufficiently reduced (10% of cases).
5. After an elbow dislocation, rehabilitation should be tailored on the severity of the residual instability, evaluated clinically and radiographically. Pronation increases stability in case the soft-tissue lesion is more extensive in the lateral compartment than in the medial one. Supination increases stability in case the disruption of the medial structures is more severe than the lateral ones.
6. In most severe simple dislocation cases, clinical examination and radiographs should be repeated at 1 week after reduction to rule out a possible re-dislocation. At this stage, if a partial subluxation is suspected, a CT scan is recommended to ensure the joint congruency is maintained.
7. Anatomical repair of the lateral collateral ligament (LCL) complex is performed in traumatic and acute patterns or in not severe recurrent PLRI cases: suture anchors or trans-osseous repair are both viable options. More subtle PLRI cases can be treated with arthroscopic plication of the LCL complex. Reconstruction is indicated when chronic attenuation or a significant deficiency of the LCL complex exists, especially in sportsmen and heavy manual workers.
8. Many techniques have been described for LCL reconstruction, different graft types, number of strands, bone tunnel configurations and graft fixation: we prefer the docking technique using an autogenous semitendinosus graft, or extensor hallucis longus allograft. However, there is no difference reported between the described techniques and the overall results after PLRI reconstruction are good to excellent in about 85% of the cases.
9. Most MCL injuries can be treated successfully without surgery; however, when non-operative treatment is unsuccessful or when a more rapid return to sport is desired, isolated medial ligamentous avulsion injuries of the MCL can be primarily repaired with suture anchors. Recently, augmentation of the repair with high-strength non-absorbable suture has become increasingly popular. In case of chronic insufficiency, the reconstruction of the MCL with tissue supplementation is recommended. Augmentation can include autograft or allograft tendon, typically hamstring or palmaris longus.
10. In cases where both medial and lateral stabilising ligaments need reconstruction, a circumferential graft can be considered.

Once the alignment of the olecranon and coronoid is restored, elbow stability and forearm function are usually recovered. In contrast, in the case of posterior olecranon fracture-dislocations, elbow stability and forearm function are typically affected. Surgical treatment is performed with a posterior midline skin incision, preserving the triceps insertion. In most cases, coronoid exposure can be accomplished through the olecranon fracture or, in case of basal or antero-medial coronoid fractures, through a medial window by elevating the FCU from the medial proximal ulna.

Fixation is usually performed with screws passing through an anatomical olecranon plate or, depending on the size, comminution and location of the fracture, with free screws or K-wires, or rarely with a pre-contoured coronoid plate. The radial head injury can be treated through the fractured olecranon and the injured anconeus muscle; otherwise, a separate lateral approach can be used. A radial head osteotomy is usually contraindicated. When possible, radial head fixation is preferred; otherwise, a radial head replacement is performed. Finally, the greater sigmoid notch can be fixed with a pre-contoured proximal ulna plate: tension-band wiring presents a high failure rate and should be reserved for simple, non-committed transverse or short oblique fractures of the olecranon.

2. Terrible triad: this lesion is characterised by dislocation or subluxation of the elbow which occurs by fracture of the radial head, and of coronoid process and lesion of the lateral collateral ligament. The most common mechanism by which the terrible triad occurs is the PLRI. Terrible triads include a wide spectrum of lesions: although select terrible triad injuries can be managed non-operatively, most injuries are treated with stable surgical repair to allow early elbow motion. In terrible triad lesions, there is agreement (a) to avoid radial head osteotomy considering fixation, when it is possible, or replacement using a lateral or posterior skin approach; (b) to fix with screws all the
significant coronoid fragments, using the window created by the osteotomy of the radial head in preparation of the subsequent replacement, (c) to repair the lateral collateral ligament. It is still under debate the necessity to fix smaller coronoid fragments and the threshold of instability to consider repair of the MCL or to use an external fixator.

3. Fracture of the anteromedial portion of the coronoid process: fracture-dislocations characterised by fracture of the antero-medial rim of the coronoid process and avulsion fractures of the posterior band of the MCL vary with the severity of the LCL injury. The antero-medial coronoid fractures can be sometimes associated with radial head fractures and may occur by a posteromedial rotatory instability (PMRI) mechanism. They usually cause ulno-humeral incongruity rather than a complete joint dislocation. Anteromedial coronoid fractures may appear benign on X-rays, but if not treated, they can cause an ulno-humeral subluxation during physiological varus stress and result in post-traumatic arthritis. CT scans are helpful to determine if surgery is required based on (a) coronoid fracture pattern (sublime tubercle involvement, fragment size and dislocation), (b) ulno-humeral joint reduction and (c) associated lesions. Often, an evaluation under anaesthesia provides a greater understanding of the true degree of instability compared with that seen during the CT scan, helping to determine if surgery is indicated. Depending on the case, antero-medial coronoid fractures can be fixed with free screws or dedicated plates which require a more extensive medial approach. If a varus instability persists, the LCL repair should be performed.

In complex acute elbow instability, the rehabilitation should be tailored to protect the injured stabilisers for the shortest possible time, allowing as much protected range of motion as possible. However, as a general rule, stability takes priority over motion. In stiff but concentrically reduced elbow, mobility can be subsequently improved with capsular release. Treatment of articular surface damage that results from chronic instability is much more challenging to treat.

CORONOID PROCESS RECONSTRUCTION

Chronic process reconstruction is a salvage procedure that can be considered to treat chronic coronoid deficiency that can occur with coronoid fracture malunion/non-union. Several surgical options have been described to reconstruct the coronoid (figure 19). Few papers, with few case series, report clinical experience of coronoid graft reconstruction. Positive results, without graft resorption, have been reported even at 10 years of follow-up (figure 20).

EXTERNAL FIXATORS

A temporary external fixator can be used when the surgeon is unable to obtain primary stability with internal fixation and ligament repairs. In this case, an external fixator is preferred to trans-articular K-wire. There is a variety of external fixators which are static or hinged. The hinged fixator maintains stability and allows motion, but are more difficult to apply and have major complications (10%) and minor complications (15%). External fixators are usually maintained for 4–6 weeks.

INTERNAL JOINT STABILISER

Internal joint stabiliser is a relatively new option that can provide initial stability of the elbow joint. A peg is placed through the centre of rotation; it is connected to an articulated arm that locks onto a small plate fixed to the proximal ulna (figure 21). The advantage of this system is that it can provide good initial stability to allow active mobilisation, without the need for an external frame. Usually, this device is removed after 3 months. Some initial experiences are good, but the device has yet to be proven in the wider community.

BRIDGE PLATE FIXATION OF THE ELBOW

This is a salvage procedure, used in some complex wrist injuries and recently proposed also for the elbow, when alternative treatments are not available or do not guarantee sufficient stability. The technique consists of a temporary plate bridging the ulno-humeral joint, to maintain the elbow centred and stable, while waiting for the soft tissues to heal. The bridge plate has limited indications; it can be considered in the very unstable elbow in obese and low-demand patients or in highly complex fracture dislocation with severe articular bone loss, needing subsequent surgical reconstruction (figure 22). The plate is removed after 4–8 weeks, and depending on the case, a capsular release and joint mobilisation is performed.

FUTURE PERSPECTIVES

Elbow instability is more common and complex than thought in the past. Its study, started long time ago, only in the last three decades gained renewed interest, making possible the tremendous improvements in the understanding of elbow anatomy and biomechanics that are the fundamental basis for a correct diagnosis and an appropriate treatment.

In the last 30 years, we have understood that elbow stability is provided by three primary (ulno-humeral joint, LCL, MCL) and four secondary stabilisers (radio-humeral joint, capsule, common flexor origin, common extensor origin) that work in synchrony to resist the various patterns of instability. We have learnt to repair or reconstruct each primary stabiliser and that the repair or reconstruction of the secondary stabilisers reinforces the stability, preventing unnecessary long cast immobilisation that in the past was the cause of many elbow contractures.

Anatomical repair of the lateral collateral ligaments is performed with suture anchors or trans-osseous repair in traumatic and acute patterns or in not severe chronic recurrent instability cases. Reconstruction with soft-tissue augmentation is indicated when chronic attenuation or a significant deficiency of the ligaments exists. Arthroscopy plays an ever-increasing role in the treatment of subtler instability cases, especially involving the lateral compartment.

In 3 to 5 years, the surgical techniques to repair or reconstruct the various elements involved in elbow stability will further improve.

The rehabilitation protocols play an essential role in instability management: they should be tailored and started as soon as possible, protecting the healing of the elbow stabilisers while, at the same time, avoiding stiffness occurrence.

The biology of soft-tissue healing remains one of the most important aspects to understand in the future. If future research will help to understand, correct or modulate the biological


Since the Online First publication of this article, author name Benjamin Graves has been corrected to Benjamin R Gr....