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REVIEW ARTICLE

Imaging of the post-operative medial elbow in the overhead thrower: common and abnormal findings after ulnar collateral ligament reconstruction and ulnar nerve transposition

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Abstract
Ulnar collateral ligament (UCL) reconstruction is now being performed more commonly and on younger patients than in prior decades. As a result, radiologists will increasingly be asked to evaluate elbow imaging of patients presenting with pain who have had UCL reconstruction. It is essential for radiologists to understand the normal and abnormal imaging appearances after UCL reconstruction and ulnar nerve transposition, which is also commonly performed in overhead-throwing athletes. Doing so will allow radiologists to provide accurate interpretations that appropriately guide patient management.

Keywords Ulnar collateral ligament reconstruction · Medial collateral ligament reconstruction · Throwing athlete · Ulnar nerve transposition · Ulnar neuritis · Baseball · Magnetic resonance imaging · Ultrasound

Introduction

The overhead-throwing motion generates tremendous stress on ligaments, tendons, and bones about the elbow predisposing throwing athletes to arm pain and injury [1–3]. Specifically, the high valgus load across the elbow during the late cocking and acceleration phases of overhead throwing places the medial elbow structures at risk [4]. Injuries to the medial elbow, including the ulnar collateral ligament (UCL), affect throwing athletes of all ages and abilities and have become the focus of recent injury prevention programs in baseball [5–7]. Despite a greater focus on injury prevention, the rate of UCL reconstruction (Tommy John surgery) performed in the United States is increasing and the surgery is becoming more common among younger athletes [6, 8–12]. Recent data show that about 25% of Major League Baseball pitchers and 15% of Minor League Baseball pitchers have undergone UCL reconstruction [13]. As expected with more surgeries performed on younger athletes, the number of revision surgeries has also increased [14–17].

As more and younger patients are undergoing UCL reconstruction and returning to overhead throwing, many will present with elbow pain and require imaging. It is important that radiologists understand the typical post-operative anatomy and recognize signs of re-injury or new pathology in these patients. Therefore, this article will briefly review the anatomy of the medial elbow and focus on the typical and abnormal imaging appearance after UCL reconstruction. As ulnar nerve transposition is often performed concurrently

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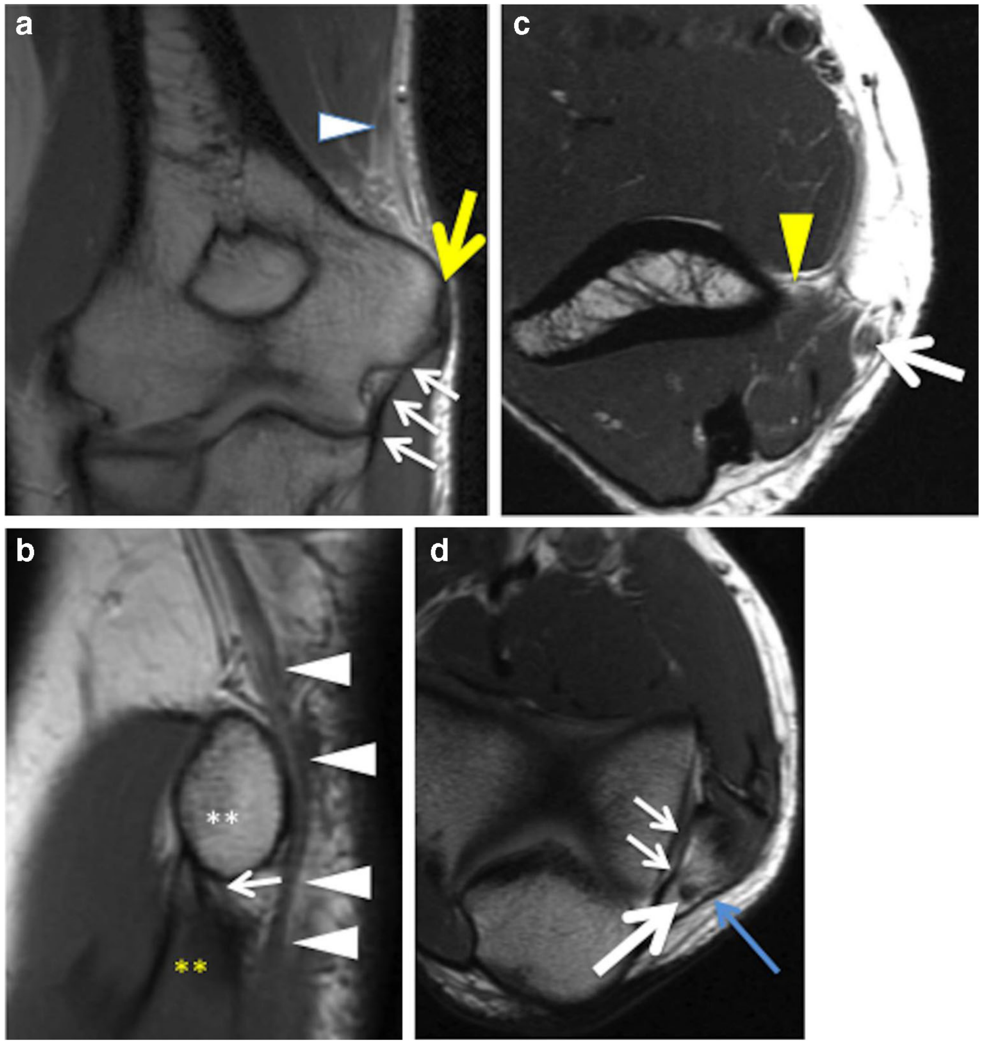

Fig. 1 Normal anatomy of the medial elbow: 28-year-old non-thrower who developed pain after a blood draw. **a** Coronal PD MR image demonstrates the common flexor tendon origin, (*yellow arrow*), just medial to the UCL anterior bundle (*white arrows*). The ulnar nerve is partially imaged (*white arrowhead*). **b** Sagittal PD image demonstrates the proximal UCL (*white arrow*) coursing from its medial epicondylar origin (*white asterisks*), just deep to the flexor digitorum superficialis (*yellow asterisks*). The ulnar nerve (*white arrowheads*) travels just posterior to the medial epicondyle. **c**, **d** Axial PD images demonstrate the ulnar nerve (*large white arrow*) coursing posterior to the intermuscular septum in the arm (*yellow arrowhead*) and within the cubital tunnel (**d**). The ligament of Osborne (*blue arrow*) forms the roof of the cubital tunnel and the posterior bundle of the UCL (*small white arrows*) forms the floor

with UCL reconstruction, this article will briefly discuss the typical imaging appearance after that procedure as well [18].

Normal elbow anatomy and common injuries

Structures placed at risk for injury during the overhead-throwing motion include the UCL, ulnar nerve, common flexor tendon and flexor-pronator muscle mass, and the posterior ulnotrochlear articulation. The UCL is composed of three distinct bundles: anterior, posterior, and transverse. The anterior bundle, which is functionally and anatomically divided into anterior and posterior bands, is the primary restraint to valgus stress in both flexion and extension, and courses from the undersurface of the medial epicondyle to the sublime tubercle of the coronoid process of the ulna (Fig. 1) [19, 20]. Recent studies have shown that in some asymptomatic patients, the anterior bundle of the UCL inserts a few millimeters distal to the articular surface of the sublime tubercle, suggesting that this "T-sign" is not always indicative of a partial tear [21, 22]. The posterior bundle, which originates just posterior to the anterior bundle and inserts broadly on the semilunar notch of the ulna, provides secondary valgus stability when the elbow is in flexion [23]. The transverse bundle does not cross the ulnotrochlear joint and does not have a defined role in providing valgus stability to the elbow. UCL injuries can occur proximally, in the mid-substance, or distally; with distal injuries more often failing non-operative treatment [24].

The ulnar nerve is a terminal branch of the medial cord of the brachial plexus and travels in the medial arm posterior to the intermuscular septum (Fig. 1). Just proximal to the elbow joint, the ulnar nerve travels posterior to the medial epicondyle, in the retrocondylar sulcus, to enter the cubital tunnel. The roof of the cubital tunnel is formed by the ligament of Osborne (Osborne's fascia, cubital tunnel retinaculum) and the floor is formed by the posterior bundle of the UCL (Fig. 1).

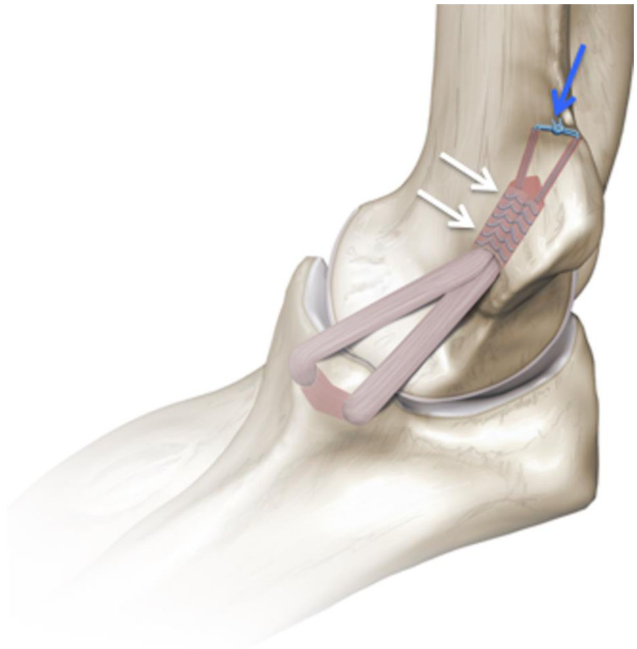

Fig. 2 The docking technique: anatomical diagram demonstrates graft placement in the docking technique of UCL reconstruction. The graft is docked in the humeral tunnel (*white arrows*), graft suture is brought through connecting drill holes, and the graft suture (*blue arrow*) is tied over a bone bridge. (Image provided courtesy of Arthrex®, Naples, FL, USA 2019)

The ulnar nerve then travels through the two heads of the flexor carpi ulnaris muscle and enters the forearm where it proceeds distally to provide motor innervation to the ulnar portion of the forearm and sensory and motor innervation to the hand. Ulnar nerve symptoms are common in overhead throwers, predominantly those with valgus instability, and may be secondary to impingement by osteophytes, flexor muscle hypertrophy, or excessive subluxation [25, 26].

The flexor muscle bellies overlie the UCL and the flexor-pronator muscle mass helps provide dynamic valgus stability to the medial elbow [2, 26, 27]. The common flexor tendon originates just medial to the UCL (Fig. 1) and both the common flexor tendon and the flexor-pronator muscle mass are potential sites of injury in overhead throwers [28, 29]. Soft tissue stabilizers of the medial elbow, namely the UCL and flexor-pronator mass, allow for normal tracking at the ulnotrochlear joint as it shifts between flexion and extension in the normal throwing motion [30]. Repetitive excessive valgus stress across the elbow can lead to weakened medial soft tissue stabilizers and allows for abutment of the medial olecranon tip with the olecranon fossa when the elbow reaches full extension [31, 32]. This abnormal contact ultimately leads to olecranon osteophyte production, olecranon stress injury, chondral loss over the posterior ulnotrochlear joint, synovitis from

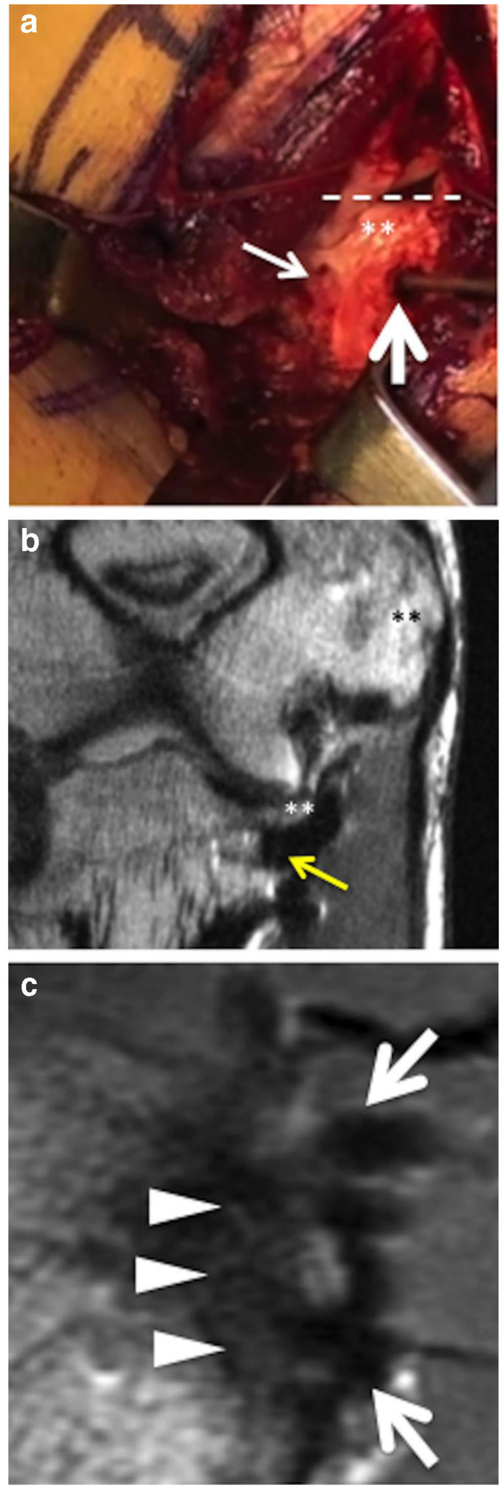

Fig. 3 UCL reconstruction, ulnar side: intraoperative photograph of a 22-year-old professional pitcher undergoing UCL reconstruction (**a**) and MR images of a 21-year-old pitcher with elbow pain 16 months after UCL reconstruction (**b–c**). **a** Note the ulnar drill holes anterior (*small white arrow*) and posterior (*large white arrow*) to the sublime tubercle (*white asterisks*) about 7–10 mm distal to the ulnohumeral joint line (*dashed white line*). **b** Coronal PD image demonstrates the graft (*yellow arrow*) inserting on the ulna just distal to the sublime tubercle (*white asterisk*). **c** Magnified axial PD image demonstrates the graft both entering and exiting (*white arrows*) and within the ulnar tunnel (*white arrowheads*)

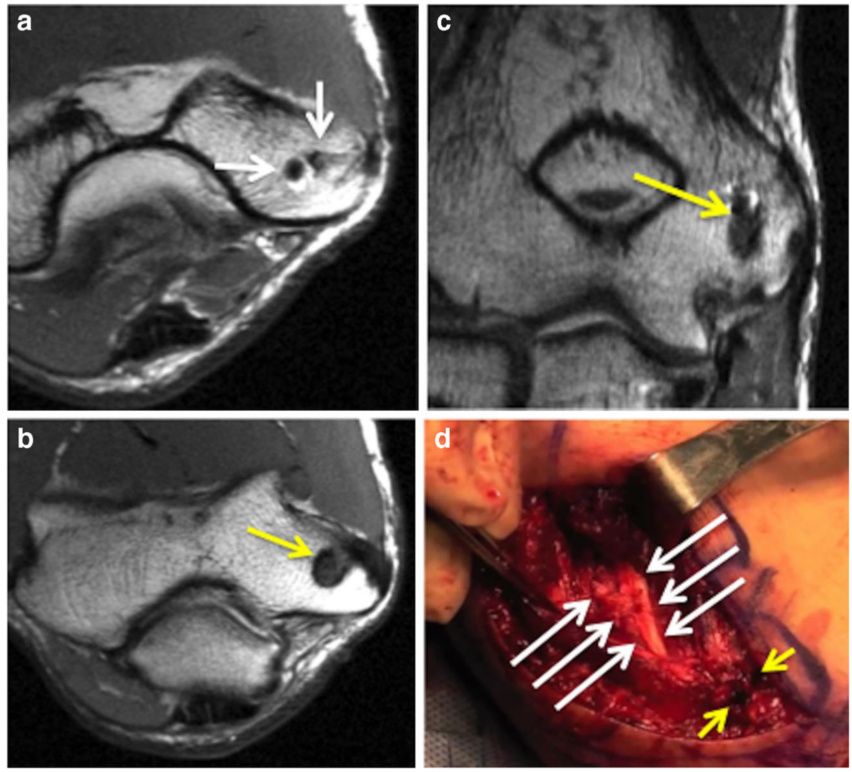

Fig. 4 UCL reconstruction, humeral side: MR images of the patient in Fig. 3b and c (**a**–**c**) and an intraoperative image of the patient in Fig. 3a (**d**). **a**–**c** PD images demonstrate graft suture within the connecting holes placed in the medial epicondyle (*small white arrows* in **a**) and the graft docked within the 4.5-mm socket distally (*yellow arrows* in **b** and **c**). **d** Intraoperative image demonstrates the completed reconstruction graft (*white arrows*) and graft sutures tied over the medial epicondyle bone bridge (*yellow arrows*)

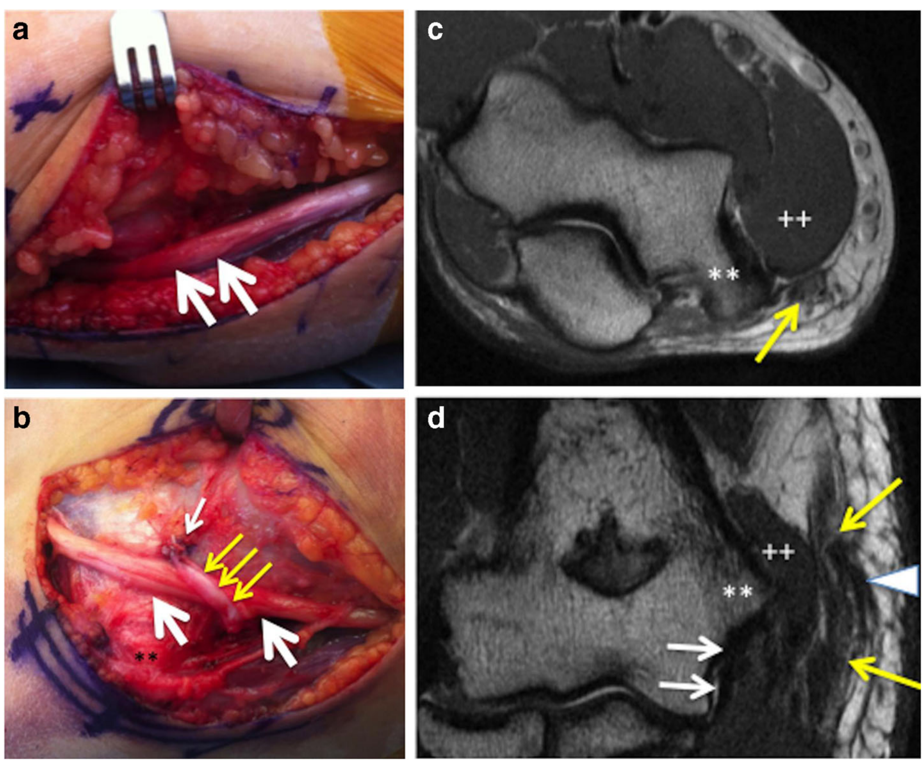

Fig. 5 Subcutaneous ulnar nerve transposition: 21-year-old right-handed pitcher undergoing subcutaneous ulnar nerve transposition (**a**–**b**) and 17-year-old right-handed pitcher who underwent subcutaneous ulnar nerve transposition for pain and paresthesias while pitching (**c**–**d**). **a** and **b** Intraoperative photos show an inflamed, hyperemic ulnar nerve (*white arrows*) before (**a**) and after (**b**) ulnar nerve transposition. The transposed ulnar nerve in **b** is placed anterior to the medial epicondyle (*black asterisks*) and secured in place with a fascial sling (*yellow arrows*), which is sutured to the flexor-pronator fascia (*small white arrow*). **c** and **d** Axial (**c**) and coronal (**d**) PD images show the transposed ulnar nerve (*yellow arrow*) anterior to the medial epicondyle (*white asterisks*) and superficial to the humeral head of the pronator teres (*white plus signs*). On the coronal image (**d**), the fascial sling (*white arrowhead*) and the normal low signal UCL (*white arrows*) can be seen

Table 1 MRI protocol in patients after ulnar collateral ligament reconstruction (16-channel flexible wrap coil)

	COR IR	COR MPGR	COR PD	AX PD	SAG PD
TE/TR(ms)	17/5000 TI = 150	20/500	24/5000	24 /5000	24/5000
FOV (Cm)	13	13	16	14	16
Slice thickness (mm) (no gap)	3.0	1.7	1.6	3-3.5	3-3.5
Matrix (frequency × phase)	256 × 224	512 × 224	512 × 384	512 × 320	512 × 320
Bandwidth (kHz)	31.25	15	100	82	100
Excitations (NEX)/echo train length (ETL)	2/9-12	2	4/16	4/16	4/16
Imaging option	2D, FSE-XL, NPW. TRF	2D, GRE, NPW	2D, FSE-XL, NPW	2D, FSE-XL, NPW	2D, FSE-XL, NPW

IR inversion recovery, *MPGR* multiplanar gradient recalled, *PD* proton density, *FOV* field of view, *FSE* fast spin echo, *NPW* no phase wrap

posteromedial impingement, and posteromedial elbow pain [32, 33]. In many cases, posterior elbow pain from this process, termed valgus extension overload, can be treated arthroscopically with debridement, olecranon osteophyte excision, or loose body removal [34, 35].

UCL reconstruction and ulnar nerve transposition

Jobe initially described UCL reconstruction in 1986 following the success of pitcher Tommy John after he

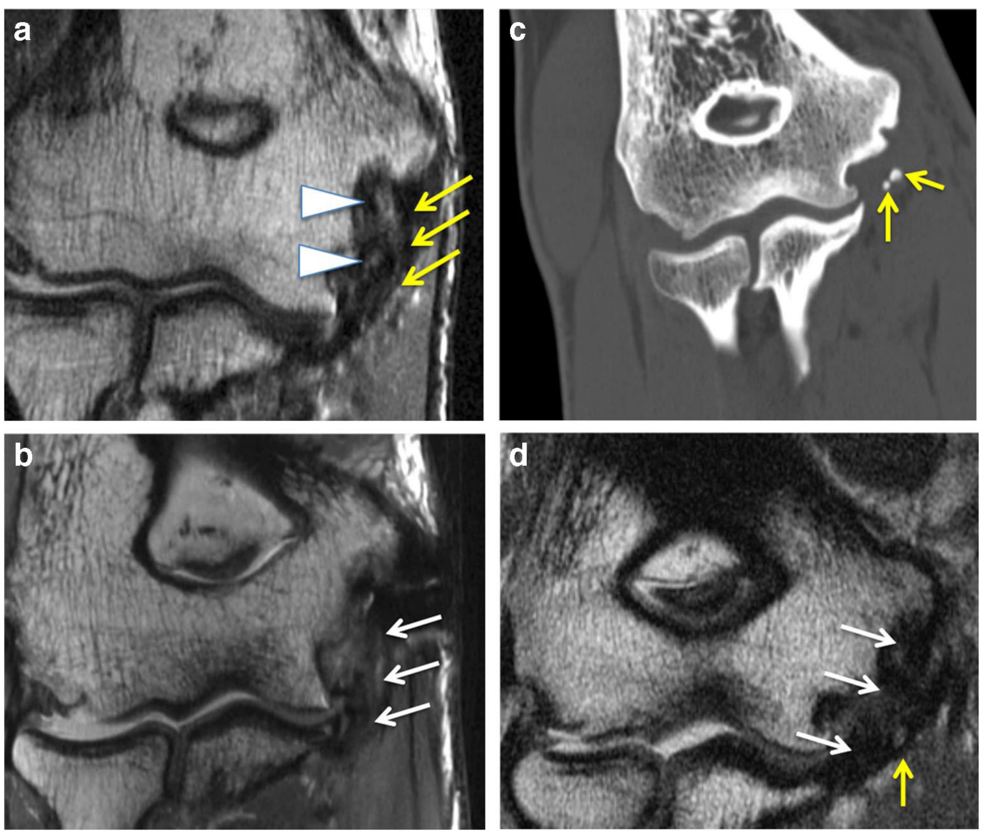

Fig. 6 Typical appearances of UCL reconstruction grafts: imaging in three different patients demonstrating the variety of appearances of UCL reconstruction grafts. **a** Coronal PD image in a 21-year-old right-handed pitcher 16 months after UCL reconstruction shows an intact, predominantly low signal intensity graft (*yellow arrows*). Areas of heterogeneous signal intensity (*white arrowheads*) are likely due to suture passage through the repaired native ligament subjacent to the graft. **b** Coronal PD image in a 22-year-old right-handed pitcher imaged 3 months after UCL reconstruction as part of a research study shows a predominantly high signal intensity, intact graft (*white arrows*). **c**, **d** Coronal CT image (**c**) in a 33-year-old pitcher with medial elbow pain 8 years after UCL reconstruction shows small foci of ossification (*yellow arrows*) along the course of the graft. Coronal PD image (**d**) from an MRI performed shortly before the CT shows a focus of high signal (*yellow arrow*) corresponding to the ossification on the CT as well as an intact graft (*white arrows*). The patient's pain resolved and he returned to pitching soon after the CT was performed

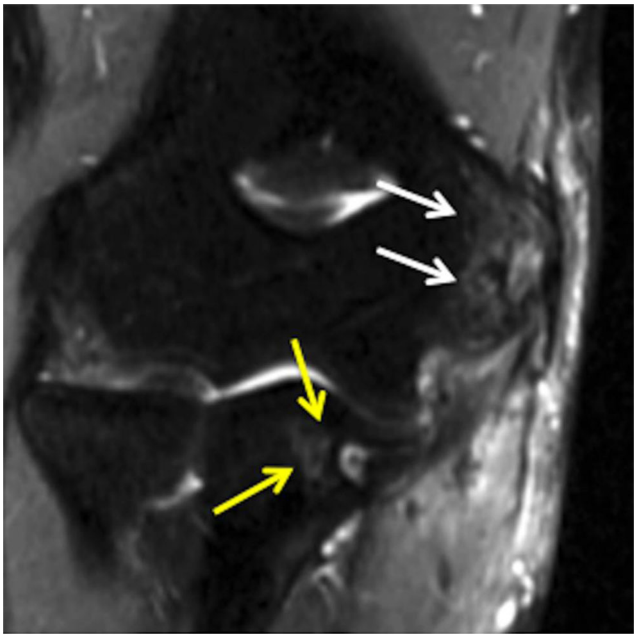

Fig. 7 Typical post-surgical marrow edema pattern: coronal inversion recovery (IR) MR image in an 18-year-old right-handed pitcher without pain imaged 4 months after UCL reconstruction as part of a research study demonstrates expected, mild marrow edema pattern around the humeral (*white arrows*) and ulnar (*yellow arrows*) tunnels, likely reflecting bony remodeling

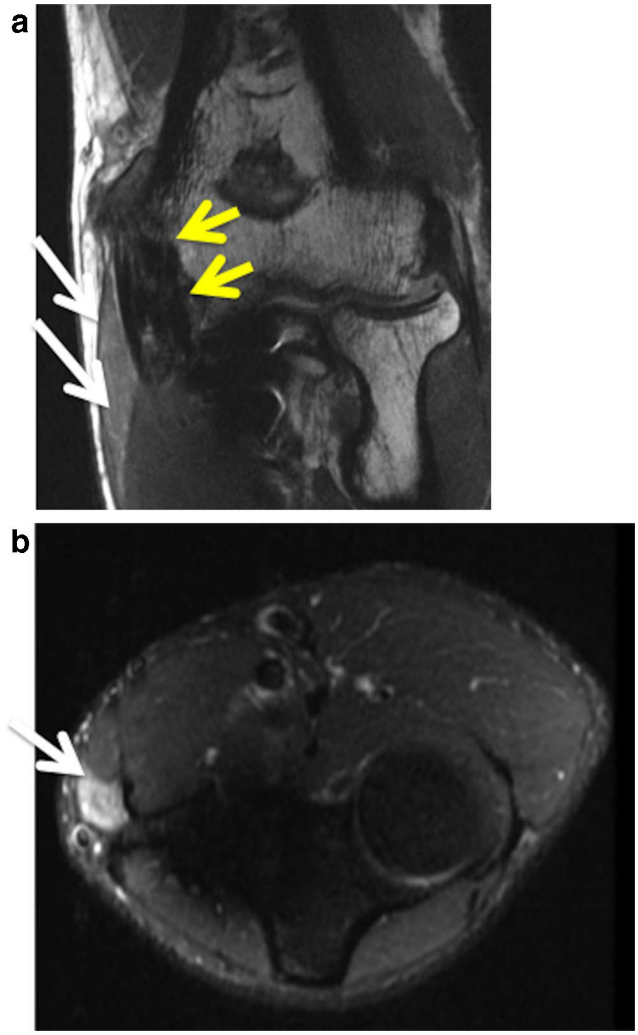

Fig. 8 Typical appearance after palmaris longus graft harvest: 24-year-old left-handed pitcher with medial elbow pain 2 years after UCL reconstruction. Coronal PD (**a**) and axial IR (**b**) MR images demonstrate diffuse high signal intensity of the palmaris longus muscle (*white arrows*), which is an expected finding after more distal tendon harvest. The UCL graft is intact and low in signal (*yellow arrows*, **a**)

underwent the first procedure in 1974 [36]. While primary repair, biologic injection, and conservative treatment are indicated in a subset of patients, UCL reconstruction remains the gold standard for treating ligament injury and several techniques have been described [37–42]. At our institution, surgeons use the docking technique (Fig. 2), which has shown a higher return to sport and lower complication rate than the modified Jobe procedure [18]. The modified Jobe procedure, however, is preferred by many surgeons and remains a suitable option to achieve excellent results [43]. The ulnar nerve is typically transposed only in patients with motor symptoms or persistent sensory symptoms; as evidence suggests that transposition leads to a greater number of post-operative ulnar nerve complications than leaving the nerve in place [44–46].

In the docking technique, the graft is initially harvested and prepared for reconstruction with suture tied to one end. An incision is then made along the medial elbow and the soft tissues are dissected down to the flexor-pronator mass. The flexor-pronator mass is split along its fibers at about its posterior third and the UCL is longitudinally split to expose the proximal ulna. Converging holes are then drilled into the ulna anterior and posterior to the sublime tubercle approximately 7-10 mm distal to the ulnohumeral joint line (Fig. 3). Next, a 4.5-mm socket is made on the undersurface of the medial epicondyle at the origin of the native ligament. An aiming guide is used to create two connecting holes proximal to this socket on the medial epicondyle. The graft is passed through the ulnar tunnel and cut to appropriate length with suture tied to the new free edge. The native UCL is then suture repaired. The graft ends are docked in the 4.5-mm socket at the medial epicondyle and the graft sutures are pulled through the connecting holes and tied over a bone bridge (Fig. 4). In the modified Jobe procedure, two converging drill holes are made in the medial epicondyle, each end of the graft is placed through one

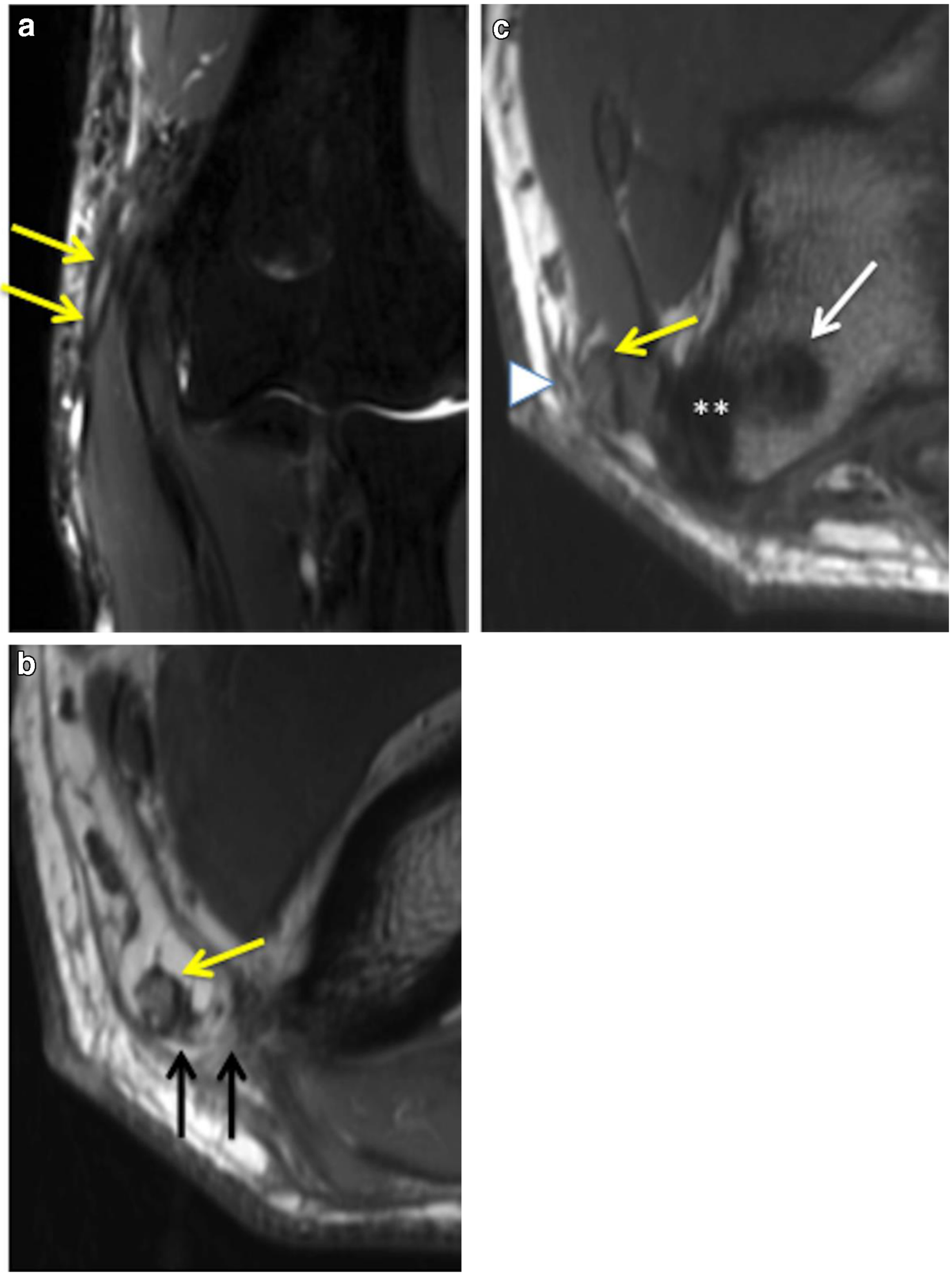

Fig. 9 Typical MRI appearance after subcutaneous ulnar nerve transposition: 21-year-old pitcher who underwent ulnar nerve transposition and UCL reconstruction 5 months prior, now with non-focal elbow pain. **a** Coronal IR MR image shows a mildly enlarged, hyperintense, ulnar nerve, of uniform caliber and without significant perineural scar. **b** Axial PD image shows a mildly enlarged, hyperintense, transposed ulnar nerve (*yellow arrow*) anterior to the intermuscular septum (*black arrows*). **c** Axial PD image just distal to **b** shows the hyperintense, transposed ulnar nerve (*yellow arrow*) deep to the fascial sling (*white arrowhead*) and anterior to the medial epicondyle (*white asterisks*). The humeral tunnel from UCL reconstruction can also be appreciated (*white arrow*)

of the drill holes, and the graft is sutured to itself to create a figure-of-eight appearance [47].

When indicated, the ulnar nerve is transposed at the time of UCL reconstruction. In the throwing athlete, the subcutaneous ulnar nerve transposition is preferred over the submuscular transposition or a simple decompression of the cubital tunnel [44]. The subcutaneous transposition involves dissecting out the nerve about 10 cm proximal and 10 cm distal to the elbow joint. The nerve is then positioned anterior to the medial epicondyle and inspected for sites of compression. Once free of compression, the nerve can be secured in place using a variety of techniques. At our institution, a strip of fascia is excised from the intermuscular septum about 8 cm proximal to the medial epicondyle with the distal portion left attached. The fascial strip is then sutured to the flexor-pronator fascia in

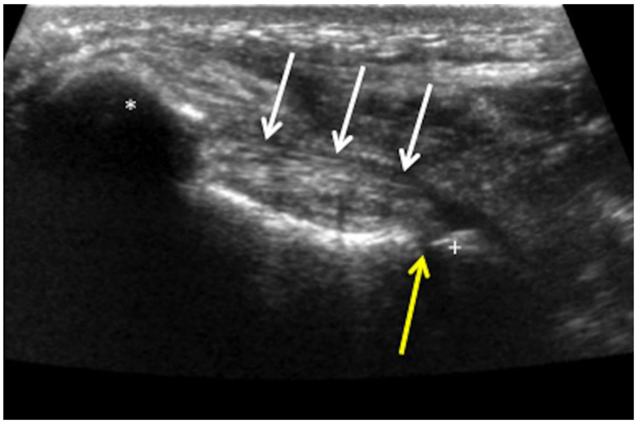

Fig. 10 Ultrasound of the reconstructed UCL: coronal ultrasound image in an 18-year-old pitcher who presented with medial elbow pain 13 months after UCL reconstruction demonstrates an intact, hyperechoic palmaris longus graft (*white arrows*) coursing from the medial epicondyle (*white asterisk*) to the sublime tubercle (*white plus sign*). With valgus stress applied, there is no widening of the ulnohumeral joint space (*yellow arrow*) to suggest graft tear or laxity

an inverted V-shape to serve as a "fascial sling" and prevent the nerve from moving behind the epicondyle (Fig. 5) [44, 48]. Ulnar nerve transposition is also performed as a standalone procedure in throwing athletes presenting with ulnar nerve symptoms without UCL deficiency [49–51].

Fig. 11 Typical ultrasound appearance after subcutaneous ulnar nerve transposition: short-axis ultrasound image in a 24-year-old male with medial elbow pain 3 months after ulnar nerve transposition demonstrates the transposed ulnar nerve (*white oval*) anterior to the medial epicondyle (*white asterisk*). The nerve fascicles (*black arrows*) are mildly thickened and the fascicular architecture is preserved

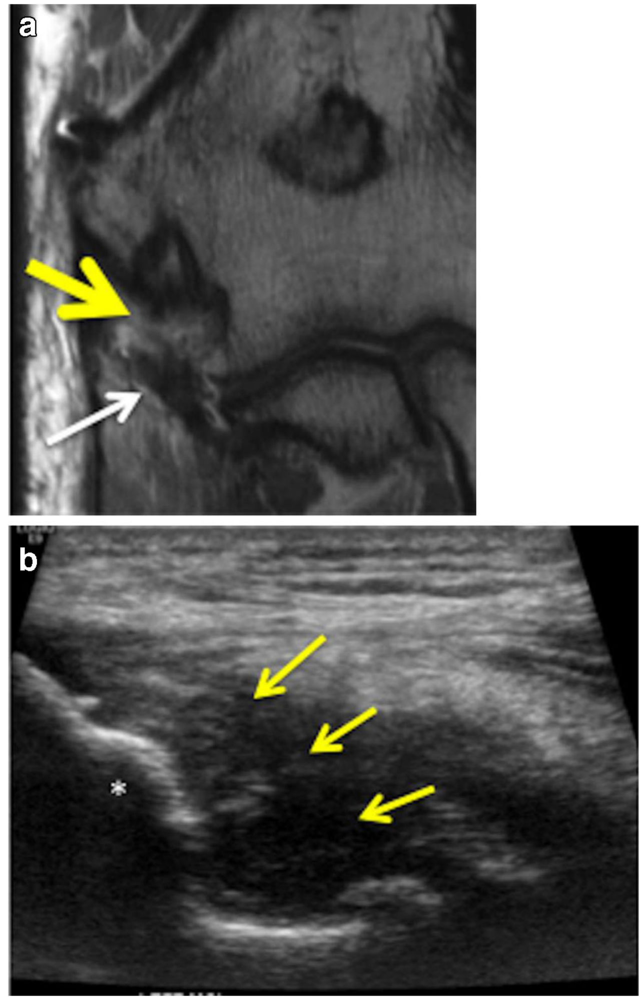

Fig. 12 Complete UCL graft tear: 22-year-old left-handed pitcher who presented with acute medial elbow pain while throwing 15 months after UCL reconstruction. **a** Coronal PD MR image demonstrates a complete tear of the proximal graft (*yellow arrow*). The remnant graft is slightly retracted distally (*white arrow*). **b** Ultrasound image of the same patient at the time of PRP injection shows a full-thickness defect (*small yellow arrows*) just distal to the medial epicondyle (white asterisk)

Post-operative imaging technique and common findings

MRI is the study of choice for evaluating the status of a UCL reconstruction and has been shown to be accurate in identifying surgically proven, torn, or degenerated reconstruction grafts [52]. Our elbow MRI protocol is optimized to specifically evaluate the UCL reconstruction (Table 1). A gradient echo sequence is not always acquired, as with the native elbow, to mitigate potential paramagnetic susceptibility effect from ferrous material around the construct. Additionally, the coronal proton density sequence is acquired with higher through-plane resolution (1.5 mm)

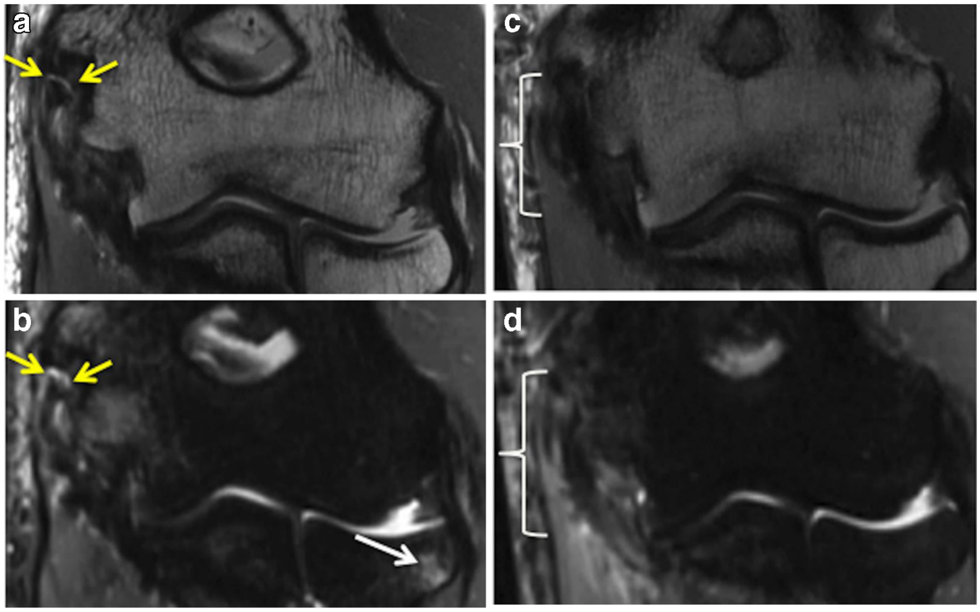

Fig. 13 Partial UCL graft tear: 21-year-old collegiate pitcher with medial elbow pain 13 months after UCL reconstruction. Coronal PD (**a**) and IR (**b**) MR images demonstrate linear fluid signal in the reconstruction graft (*yellow arrows*), which does not traverse the entire graft width, as well as marrow edema pattern in the radial head consistent with stress reaction. The findings are new when compared with coronal PD (**c**) and IR (**d**) images from an MRI done 7 months prior which showed no linear fluid signal in the graft (*white brackets*)

as compared to our routine elbow MRI (2.0 mm). Proton density sequences are performed with higher receiver bandwidth to reduce potential susceptibility effect with concomitant higher field of view and number of acquisitions to maintain the signal-to-noise ratio. Notably, our studies are performed without intra-articular contrast and we prefer a 1.5-T magnet in the post-operative setting to reduce susceptibility artifact. This is unlike a previously published protocol at another institution [52].

There are very little published data on the expected MRI findings after UCL reconstruction. A 2011 paper by Wear et al. analyzed the signal of UCL reconstruction grafts and found that while most normal grafts demonstrate low T1 and T2 signal, almost 20% of normal, uninjured grafts demonstrate intermediate or high T2 signal [52]. As with other ligament reconstruction procedures, the signal arising from the graft is probably dependent on the time since implantation, intrinsic graft properties, degree of remodeling, and surgical materials used (Fig. 6) [53–55]. Importantly, the graft should be thicker than the native ligament and appear taut without redundancy or sharp outward bowing with the elbow imaged in extension. Foci of ossification can develop within and around the graft over time and are usually of little clinical significance unless extensive (Fig. 6) [52, 56]. Mild, geographic bone marrow edema pattern surrounding both the humeral and ulnar tunnels is an expected finding in the early post-operative period though it is unknown for how long this persists (Fig. 7). If the ipsilateral palmaris longus tendon is used as a graft, the muscle belly may demonstrate increased T2 signal and/or be atrophic, which are expected findings and should not be mistaken for denervation due to injury to the median nerve (Fig. 8). However, there are reports of inadvertent median nerve, rather than palmaris longus tendon, harvesting [57]. In patients who have undergone ulnar nerve transposition, the nerve often appears prominent and mildly hyperintense to muscle on T2-weighted imaging though should be without focal abnormality or caliber change (Fig. 9) [58, 59].

While MRI is the study of choice for evaluating the post-operative medial elbow, susceptibility artifact can make assessment of the reconstruction graft and transposed ulnar nerve difficult in some cases. Ultrasound has emerged as a valuable imaging alternative that provides the advantages of dynamic assessment, comparison with the contralateral side, and the ability to perform sonopalpation to target specific regions that may be causing pain [60].

Ultrasound of the UCL graft is performed with a technique identical to the evaluation of the native ligament [61]. The transducer is oriented in the coronal plane with the proximal end over the medial epicondyle and the graft is assessed for structural integrity. With the elbow held in 30 degrees of flexion, a valgus stress is applied and the ulnohumeral joint space is measured (Fig. 10). We consider a joint space widening with valgus stress of greater than 1.0 mm compared to the contralateral side as an indicator of graft tear or graft insufficiency, although there are little published data on the expected ultrasound appearance of the UCL graft [61, 62]. If ultrasound is requested to evaluate the transposed ulnar nerve, we

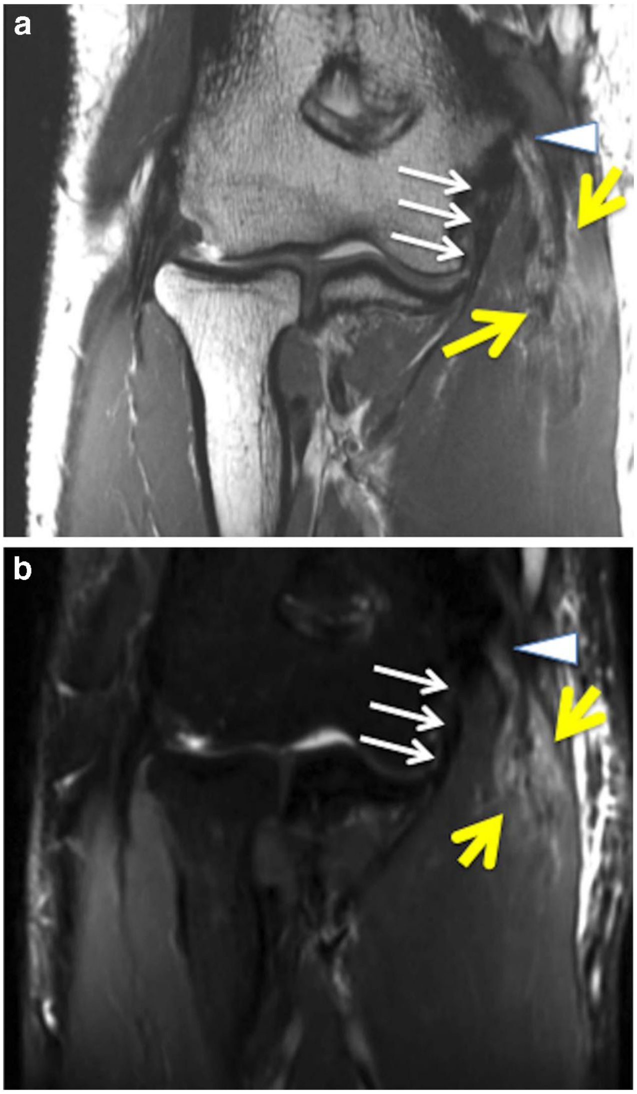

Fig. 14 Flexor-pronator muscle injury: a 26-year-old professional pitcher who underwent UCL reconstruction 5 years prior and developed sudden onset medial elbow pain while pitching. Coronal PD (**a**) and IR (**b**) MR images demonstrate partial tear at the flexor muscle-tendon junction with adjacent intramuscular edema (*yellow arrows*). The flexor tendon is high in signal though intact (*white arrowhead*). The UCL graft appears normal (*white arrows*)

evaluate the nerve in both short and long axes to assess for integrity of fascicular architecture and perineural fat, total cross-sectional area, and areas of caliber change and extrinsic compression. We routinely compare with the contralateral side to assess for subtle asymmetries. The transposed nerve may be enlarged and demonstrate fascicular thickening in asymptomatic patients (Fig. 11) [63]. Importantly, as on MRI, there should be no areas of abrupt caliber change or extensive perineural scarring and the fascicular architecture of the nerve should be maintained. The nerve should also maintain a stable position anterior to the medial epicondyle when the elbow is put through range of motion.

Elbow pain after UCL reconstruction

Outcomes following UCL reconstruction are generally very good with about 85% of athletes returning to their sport after surgery [18, 64]. Specifically, in Major League Baseball, 83% of pitchers undergoing UCL reconstruction return to pitch at the major league level and 97% return to professional baseball, while only 3.9% require a revision reconstruction [65]. Outcomes, however, are heterogeneous depending on the patient population and surgical technique performed [62, 66]. A large series by Cain et al. noted an 83% return to sport rate though a complication rate of 20% [64]. Surgeons using the docking technique have lower reported rates of complications, mostly due to lower rates of post-operative ulnar neurapraxia [66].

As all overhead throwers undergoing UCL reconstruction or ulnar nerve transposition hope to return to their sport, many will present with elbow pain during their rehabilitation or subsequent athletic career. While serious complications are uncommon, imaging is often ordered in these situations to exclude an etiology that would require subsequent intervention and help define a reasonable timeline for return to play.

Graft tear

UCL reconstruction graft tear is estimated to occur in about 2% of cases [67, 68]. Reconstruction construct failure in general was a cause of revision surgery in nine of 743 cases in a large series [64]. These rates, however, may be underestimated as subsequent injuries after primary UCL reconstruction may be career ending for patients unwilling to undergo the long rehabilitation of a revision procedure. Further research may provide insight into the true rates of graft re-tears as younger athletes may be more willing to undergo a revision procedure earlier in their athletic careers [11, 17].

In a retrospective series of 15 patients who underwent UCL revision reconstruction, surgery was performed at a mean time of 36 months after initial reconstruction with a range of 12-76 months [68]. All patients presented with pain, and about half noted an acute event just prior to symptom onset [68]. Complete graft tears on MRI appear as linear fluid signal traversing the graft with no graft fibers extending in continuity from the medial epicondyle to the ulna (Fig. 12a). On ultrasound, a hypoechoic fluid gap can be seen in place of the normal hyperechoic graft fibers (Fig. 12b). Partial graft tears appear on MRI as linear fluid signal within the graft substance

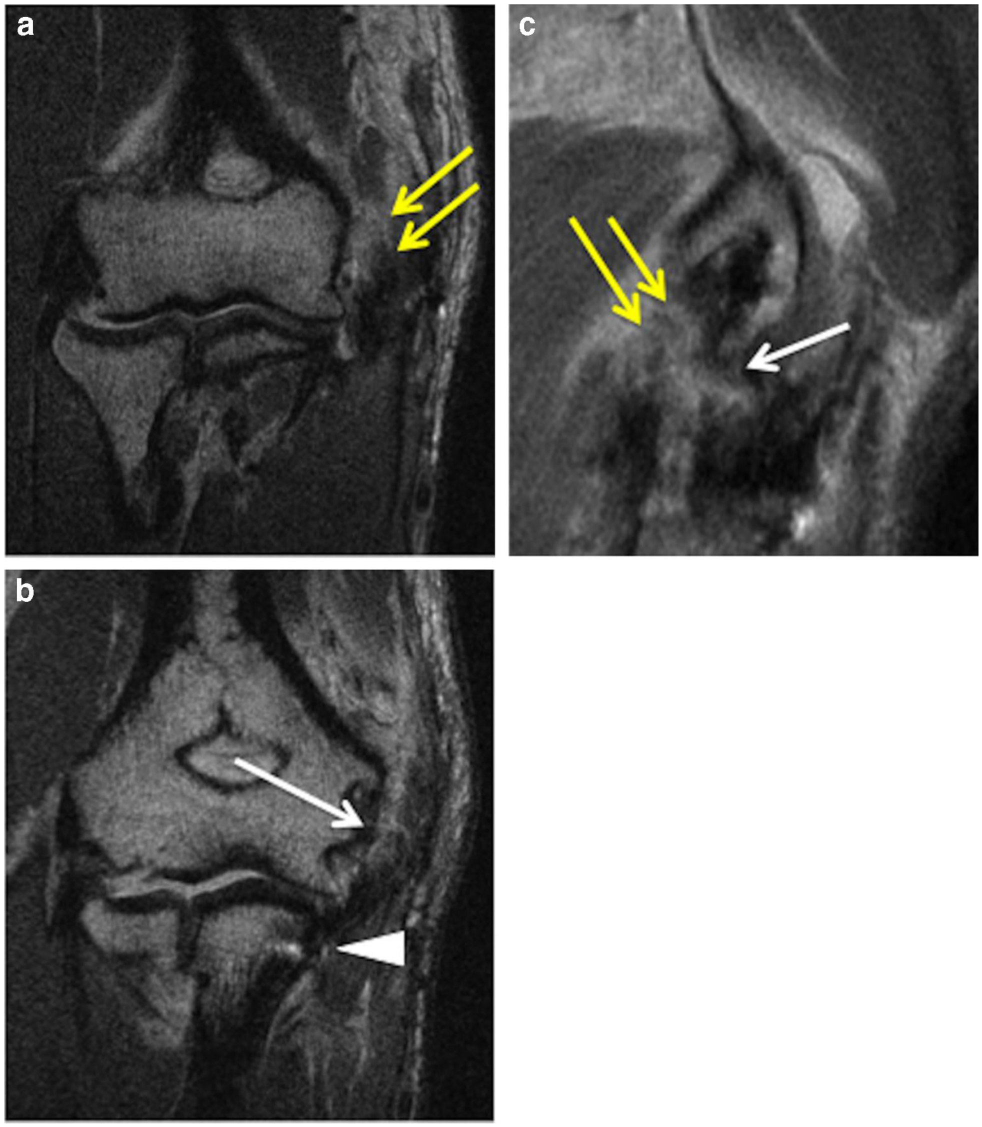

Fig. 15 Complete common flexor tendon and UCL graft tear: 35-year-old major league baseball position player with acute medial elbow pain 11 months after UCL reconstruction, flexor tendon repair, and subcutaneous ulnar nerve transposition. Coronal (**a**, **b**) and sagittal (**c**) PD MR images demonstrate complete tears of the repaired common flexor tendon (*yellow arrows*) and the UCL reconstruction graft (*white arrows*) proximally off the medial epicondyle. The distal portion of the UCL graft remains fixed at the ulnar tunnel (*white arrowhead*, **b**)

that does not traverse the entire graft width. New high signal within the graft when compared with prior imaging is suspicious for an intrasubstance partial tear (Fig. 13). UCL insufficiency caused by interstitial tearing can manifest as redundancy of the graft or outward bowing as the graft courses from the medial epicondyle to the proximal ulna.

Flexor-pronator injury

The common flexor tendon and flexor-pronator muscle mass provide dynamic elbow stabilization during the throwing motion and injury to these structures can present with acute pain, mimicking a graft tear (Fig. 14) [26, 39]. Injuries to the flexor pronator muscle mass commonly occur during the acceleration and follow through phases of throwing and patients often present with tenderness over the medial epicondyle [26]. Higher-grade injuries demonstrate fluid signal undercutting the common flexor tendon origin, indicating a tear. Though most injuries improve with non-operative treatment, refractory partial tendon tears and muscle injuries and complete tears of the common flexor tendon often require surgical intervention to facilitate return to play (Fig. 15) [69].

Valgus extension overload, posteromedial impingement, olecranon stress injury

Valgus extension overload is common in overhead-throwing athletes and can result in posteromedial impingement,

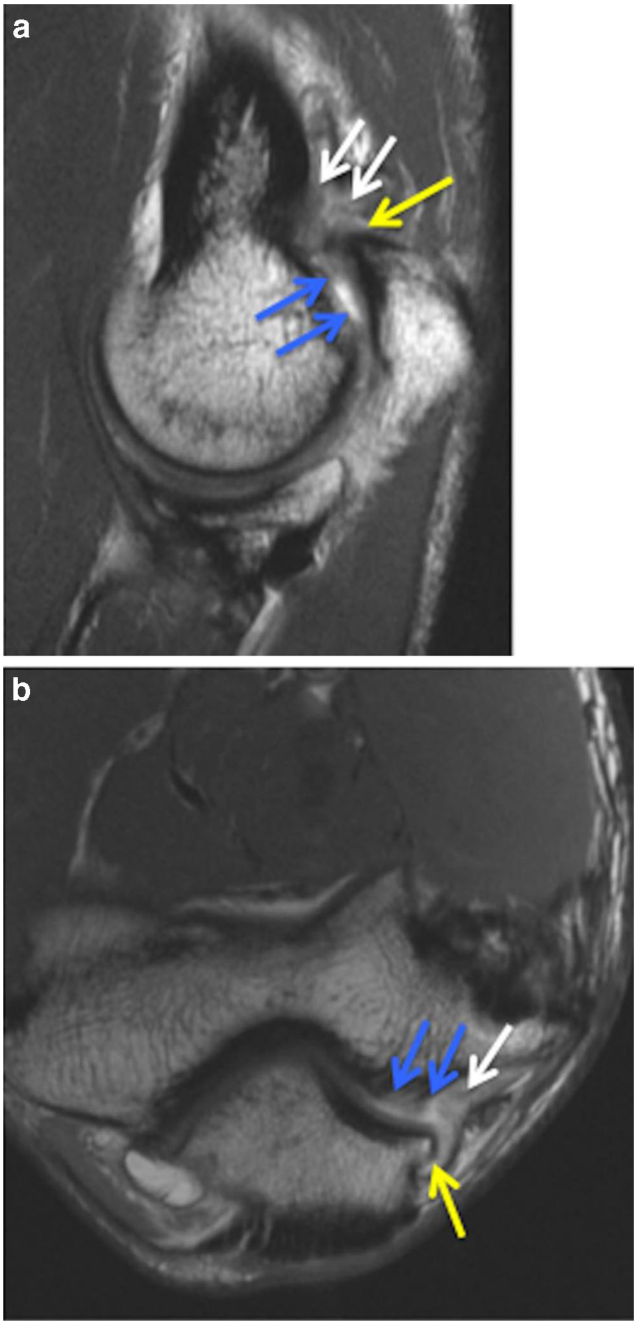

Fig. 16 Posteromedial impingement: 29-year-old pitcher with 2 days of worsening elbow pain with throwing 2 years after UCL reconstruction. Sagittal (**a**) and axial (**b**) PD MR images demonstrate a small posteromedial olecranon osteophyte (*yellow arrows*), posterior trochlear cartilage thinning (*blue arrows*) and subchondral sclerosis, and synovitis (*white arrows*). The patient underwent posteromedial decompression 4 months later

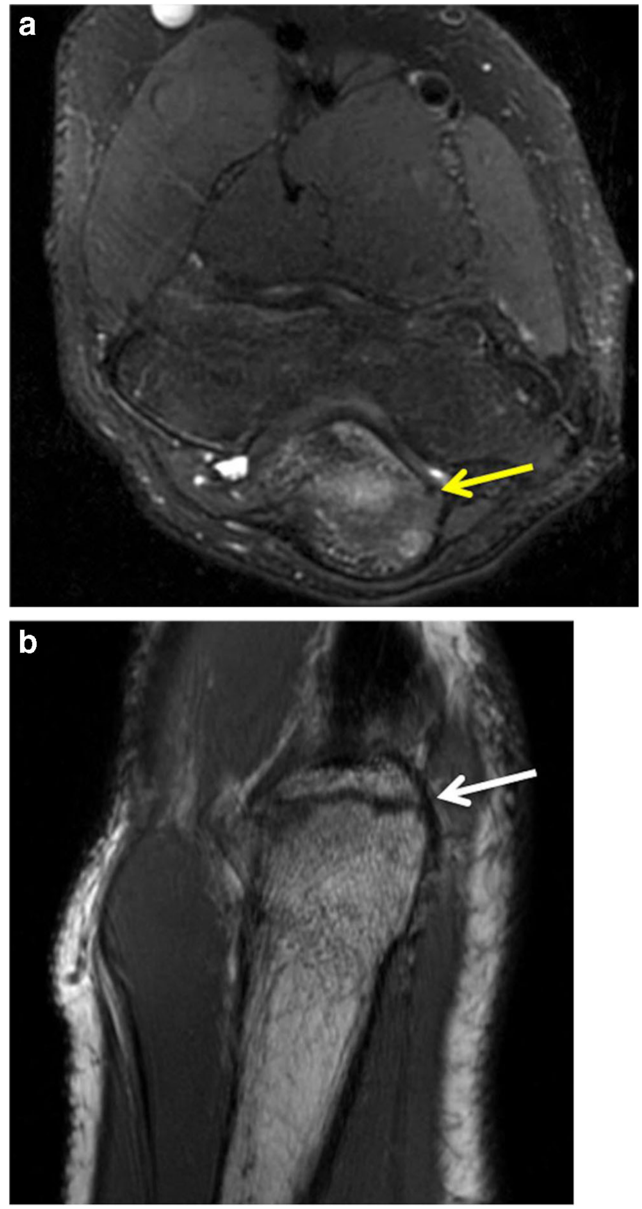

Fig. 17 Olecranon stress injury: 15-year-old pitcher with elbow pain 15 months after UCL reconstruction. **a** Axial IR image demonstrates marrow edema pattern in the olecranon (*yellow arrow*). **b** Coronal PD image demonstrates the physis (*white arrow*) though no fracture line

olecranon stress injury, and olecranon fracture (Fig. 16) [29, 31, 33, 70]. In a large series published by Cain et al., 19% of patients who underwent UCL reconstruction required subsequent surgery to address posteromedial impingement [64]. Many surgeons subsequently advocate for elbow arthroscopy at the time of UCL reconstruction to evaluate for and address intra-articular pathology [64, 71]. In patients with elbow pain after returning to throwing following UCL reconstruction, it is particularly important to evaluate the posterior ulnotrochlear joint and olecranon and assess for interval development of olecranon osteophytes or synovitis, which may require

Fig. 18 Olecranon fracture: a 31-year-old Major League pitcher with sudden severe elbow while pitching 13 months after UCL reconstruction. **a** Lateral radiograph shows a fractured olecranon (*yellow arrow*) and joint effusion. **b** Sagittal PD image demonstrates the complete fracture (*yellow arrow*) and large lipohemarthrosis (*white arrow*). **c** Post-operative radiograph demonstrates the reduced fracture bridged by a cannulated screw

subsequent arthroscopic treatment [34, 35]. Marrow edema pattern within the olecranon is indicative of a stress reaction, which should recover with rest (Fig. 17) [72]. In contrast, the presence of a hypointense line on T1 or PD imaging indicates a stress fracture, which can progress and often requires internal fixation (Fig. 18) [73–75].

Medial epicondyle avulsion

The humeral tunnel placed during UCL reconstruction can act as a stress riser and predispose to avulsions of the medial epicondyle (Fig. 19) [52, 76]. In a small series with this injury type, all patients presented with

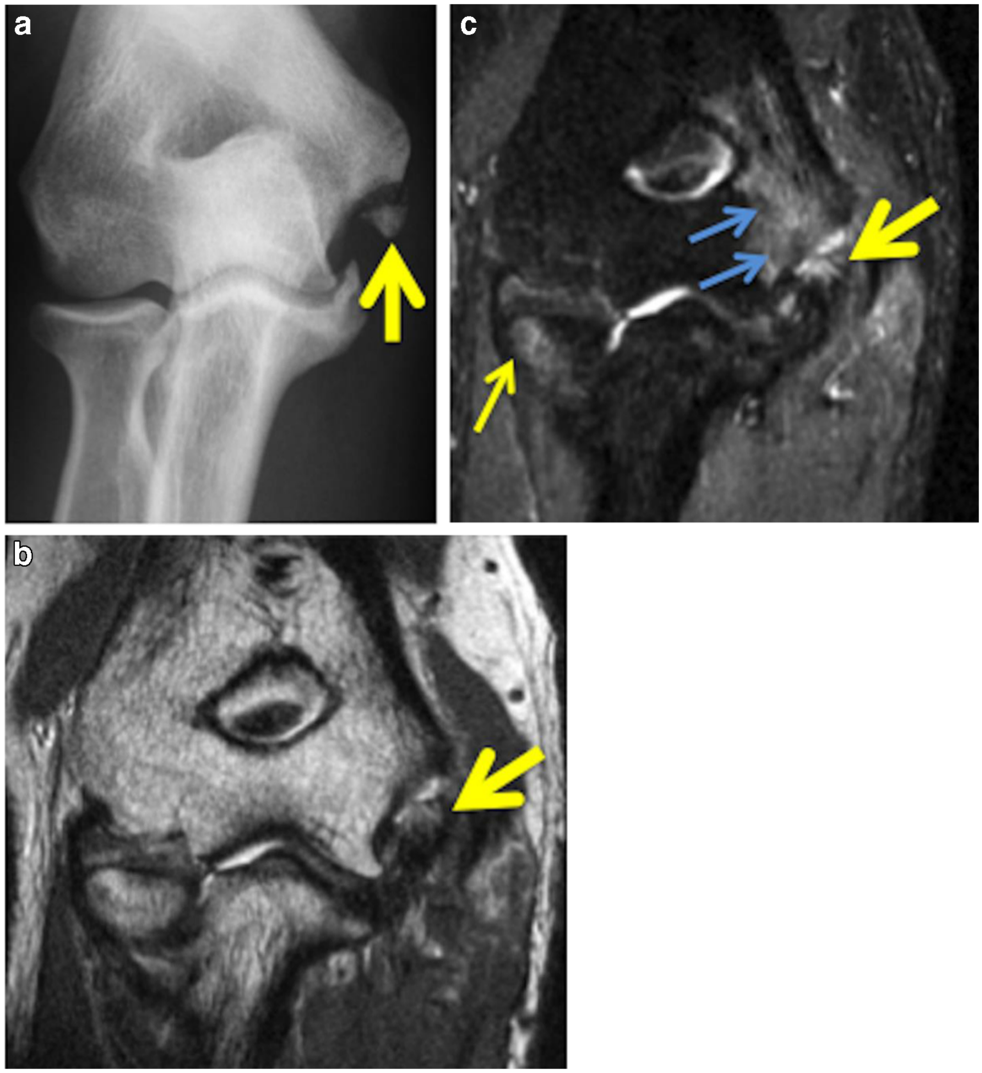

Fig. 19 Medial epicondyle avulsion fracture: a 20-year-old collegiate pitcher with sudden onset medial elbow pain 18 months after UCL reconstruction performed at an outside institution. **a** AP radiograph shows a medial epicondyle avulsion fracture fragment (*yellow arrow*). **b** and **c** Coronal PD (**b**) and IR (**c**) images demonstrate the avulsed fracture fragment with the UCL reconstruction graft attached (*large yellow arrows*), as well as marrow edema pattern at the site of avulsion (*blue arrows*, **c**) and at the radial head (*small yellow arrow*, **c**) due to valgus load

acute, severe medial elbow pain and most presented between 6.5 and 13 months after reconstruction [76]. These cases are most frequently diagnosed with standard radiographs though CT and/or MRI can be helpful in better delineating the degree of displacement. Cain et al. described five cases of medial epicondyle fractures in 743 UCL reconstructions [64]. To minimize risk of this complication, many surgeons have modified their technique to place the humeral tunnel more laterally, allowing for a wider cortical rim [77]. Similarly, the docking technique theoretically decreases risk and to date, no avulsions of the medial epicondyle have been reported in patients after undergoing this procedure. Open reduction and internal fixation is the recommended treatment for this injury [76].

Recurrent ulnar neuritis

There are sparse publications correlating imaging findings to recurrent symptoms after ulnar nerve transposition and no data specifically looking at cases of overhead throwers. A 2013 report of two cases demonstrated the ability of MRI to identify surgically confirmed areas of nerve caliber change due to perineural fibrosis (Fig. 20) [78]. Ultrasound has also proven reliable in identifying areas of caliber change that correspond to sites of nerve compression [79]. In cases of recurrent symptoms after surgery for cubital tunnel syndrome, common operative findings include kinking of the nerve either due to pressure from the fascial sling, common flexor aponeurosis, or the arcade of Struthers or distally as the nerve transitions from its transposed course at the elbow joint to its to anatomic

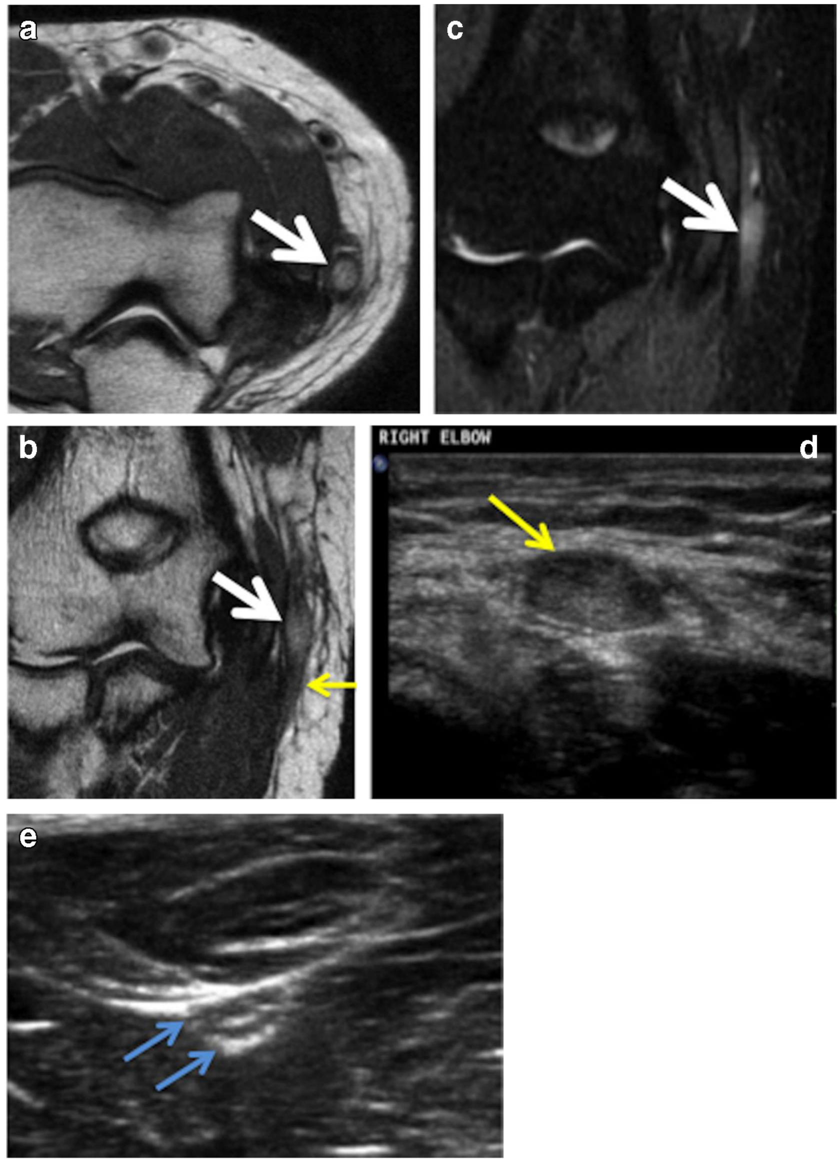

Fig. 20 Recurrent ulnar neuritis: 20-year-old female softball player with recurrent medial elbow pain 2 years after UCL reconstruction and subcutaneous ulnar nerve transposition. Axial (**a**) and coronal (**b**) PD and coronal IR (**c**) MR images demonstrate focal enlargement of a hyperintense, transposed ulnar nerve (*white arrows*) likely due to adjacent scarring (*yellow arrow*, **b**). **d**–**e** Short-axis ultrasound image (**d**) shows a hypoechoic, enlarged, nerve with loss of expected fascicular architecture at the level of the elbow joint. A short-axis image distal to the elbow within the proximal forearm (**e**) demonstrates normal nerve size and fascicular architecture. The patient responded well to subsequent ultrasound-guided anesthetic and steroid injection, underwent revision neurolysis, and was able to return to softball

position in the forearm [80, 81]. A neuroma of the medial antebrachial cutaneous nerve is also a cause of recurrent medial elbow pain in these patients [80].

Symptomatic heterotopic ossification

Heterotopic ossification (HO) may occur about the elbow after surgery or trauma and occasionally occurs within or along UCL grafts [52, 82]. Andrachuk et al. identified eight cases of symptomatic HO from a total of 1420 UCL reconstruction procedures performed over a 10-year period. All eight were baseball players with medial elbow pain and stiffness and had HO at the proximal end of the graft adjacent to the medial epicondyle (Fig. 21). CT is the study of choice for demonstrating the degree of HO though in symptomatic cases, the HO is often apparent on and can be characterized with radiographs. Depending on patient presentation and degree of ossification, symptomatic HO can be treated with open or arthroscopic excision, revision UCL reconstruction, or non-operative management [56].

Conclusions

The rate of UCL reconstruction surgery in the United States is increasing and surgery is now more commonly performed on

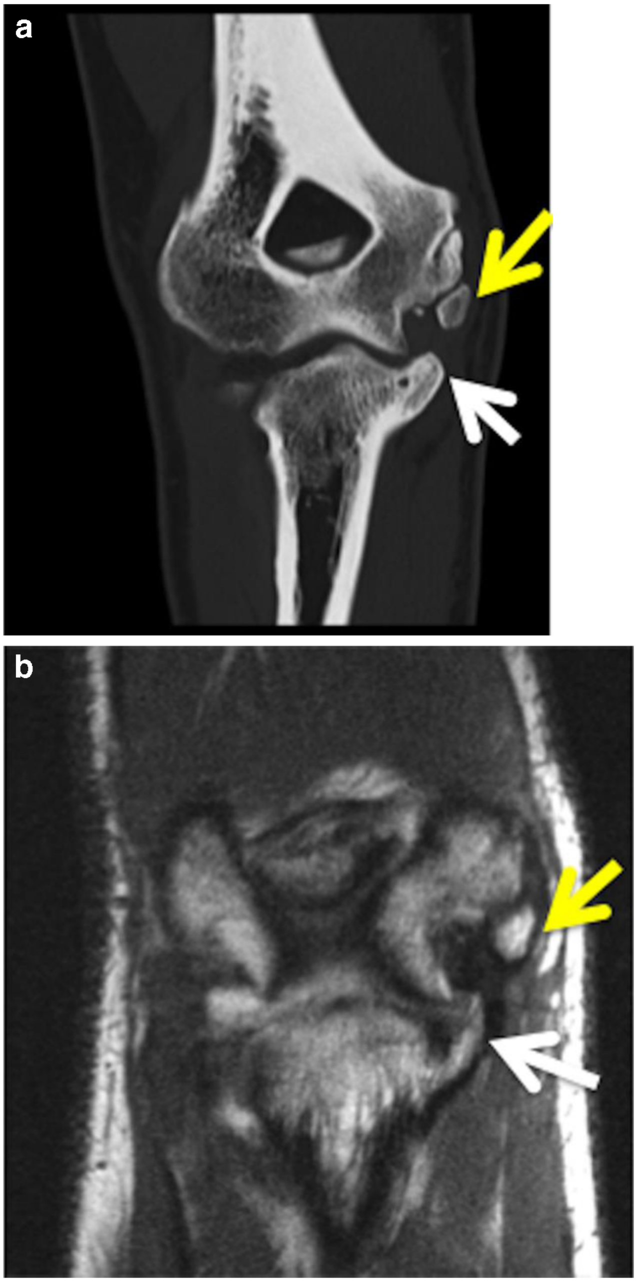

Fig. 21 Symptomatic heterotopic ossification: 26-year-old professional baseball position player with progressive medial elbow pain 5 years after UCL reconstruction. Coronal CT image (**a**) and coronal PD image (**b**) demonstrate prominent heterotopic ossification adjacent to the medial epicondyle (*yellow arrows*) and remodeling of the proximal ulna (*white arrows*)

younger patients than in years past. As many athletes who undergo UCL reconstruction and/or ulnar nerve transposition will return to throwing and present with recurrent elbow pain, it is important for radiologists to understand the normal and abnormal imaging appearance after these procedures to help guide appropriate management. Further research is necessary to identify techniques best suited to image the post-operative elbow and to identify imaging findings which correlate with recurrent symptoms and the need for subsequent surgery.

Compliance with ethical standards

Conflict of interest Dr. Sneag and Dr. Endo disclose that HSS has an institutional research agreement with GE Healthcare.

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