Skeletal Radiology (2019) 48:1541–1554
https://doi.org/10.1007/s00256-019-03203-2

REVIEW ARTICLE

MR imaging of the postsurgical cubital tunnel: an imaging review of the cubital tunnel, cubital tunnel syndrome, and associated surgical techniques

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Received: 29 October 2018 / Revised: 15 January 2019 / Accepted: 5 March 2019 / Published online: 28 March 2019

Abstract

Ulnar nerve compression at the elbow, specifically the cubital tunnel, is the second most common upper extremity compression neuropathy. Many patients presenting with compression symptoms will subsequently undergo surgical intervention. We review the open surgical treatment of cubital tunnel syndrome and review the expected postoperative imaging appearance of those treatments on magnetic resonance imaging (MR), including: simple or in situ decompression, medial epicondylectomy, and anterior transposition, including subcutaneous, intramuscular, and submuscular variants. We discuss the relevant anatomy of the presurgical cubital tunnel and common sites and causes of ulnar nerve compression at and about the cubital tunnel. The imaging appearance of the preoperative and postoperative ulnar nerve and postoperative complications are reviewed.

Keywords Cubital tunnel syndrome · Ulnar nerve decompression · Anterior transposition · Intramuscular transposition · Subcutaneous transposition · Submuscular transposition · Nerve entrapment · Medial epicondylectomy · Nerve impingement · Elbow

Introduction

Cubital tunnel syndrome is a compression neuropathy of the ulnar nerve at or near the level of the elbow. It is the second most commonly treated compression neuropathy of the upper extremity [1]. The ulnar nerve can be compressed by more than one structure at the level of the elbow, thereby complicating surgical management. Most patients will improve with conservative treatment, though many will subsequently undergo surgical interventional. Historically, there have been a number of surgeries used to treat this disorder, including simple or in situ decompression, medial epicondylectomy, and anterior transposition of the nerve, including subcutaneous, intramuscular, and submuscular variants. Many surgeons utilize a single technique for all patients, while others advocate an operation tailored to the individual patient's anatomy and presenting symptoms.

Any given surgical technique may fail to address the antecedent nerve abnormality and may provoke secondary complications to the nerve after surgery. As such, it is important that the radiologist and surgeon be familiar with the pre and postoperative MR appearance, both to aid in the initial treatment plan and to identify pathology in the setting of persistent symptoms. Persistent or recurrent symptoms following cubital tunnel surgery have been noted in up to 20–35% of patients [2]. Follow-up imaging is therefore common, and the musculoskeletal radiologist will see these postoperative changes not infrequently. In our experience, many musculoskeletal radiologists are not familiar with these changes. Even incidentally, the radiologist often sees the elbow in its post-operative state and should be accustomed with the appearance of the nerve after surgical intervention.

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Anatomy and physiology

Anatomy

The ulnar nerve is made up of fibers from the C8 and T1 nerves, and represents a terminal branch of the medial cord of the brachial plexus. As the nerve passes distally, common sites of ulnar nerve compression are known (Fig. 1). The proximal nerve lies at the medial aspect of the arm, within the anterior compartment, passing superficially, between the medial head triceps muscle and the more anterior coracobrachialis muscle. In the mid arm, the nerve passes through the medial intermuscular septum into the posterior compartment. More distally in the arm, the ulnar nerve is covered superficially by an aponeurotic extension from the medial head of the triceps that extends in continuity with the intermuscular septum and internal brachial ligaments to form a site of possible compression, especially after surgical rerouting of the ulnar nerve [3]. This is present approximately 8 cm proximal to the medial humeral epicondyle, and is termed the arcade of Struthers, though the terminology of this structure is debated [4–6]. Of note, the ligament of Struthers is a separate structure that extends from the supracondylar spur to the junction of the medial epicondylar ridge and medial epicondyle, within the anterior compartment. This structure may compress the median nerve, which passes beneath it. After passing the arcade of Struthers, the ulnar nerve continues distally, deep to the investing fascia of the medial head of the triceps, passing posterior to the medial epicondyle of the humerus.

At the level of the elbow, the nerve may be compressed at the cubital tunnel (Fig. 2). The tunnel extends from the medial humeral epicondyle to the olecranon and forms a site of passage for the ulnar nerve, which is surrounded by fat in the tunnel. The floor of the cubital tunnel is formed by the olecranon, the medial collateral ligament, and the joint capsule. A shallow groove may allow for subluxation of the nerve onto the epicondyle, exposing it to trauma. The roof of the cubital tunnel is formed by a fibrous structure made up of the aponeurotic attachments of the two flexor carpi ulnaris heads (ulnar and humeral), coursing from the medial epicondyle to the medial olecranon. Proximally, this structure is known as the cubital tunnel retinaculum or the ligament of Osbourne, and is present in 77 to 91% of people [7, 8]. Distally, the contribution from the flexor carpi ulnaris muscles may be referred to as the arcuate ligament. The cubital tunnel retinaculum becomes taut with the elbow in flexion [8], with point of constriction at the cubital tunnel, several centimeters distal to the epicondyle. The anconeus epitrochlearis is an anomalous muscle paralleling the course of the retinaculum that may narrow the cubital tunnel. This is present in approximately 20% of the population [9].

Distal to the cubital tunnel, the ulnar nerve passes deep to the flexor carpi ulnaris (FCU) muscle to enter the fascial sleeve of the flexor digitorum superficialis (FDS) muscle. The deep flexor-pronator aponeurosis is an intermuscular fascial band, centered 5 cm distal to the medial epicondyle that extends between the FCU and FDS (Fig. 3). This site represents an additional known location of ulnar nerve compression [10, 11]. Beyond this, the nerve passes along the superficial and medial margin of the flexor digitorum profundus, with the FDS and FCU muscles lying more superficial and medial.

Physiology

Ulnar nerve compression at the level of the elbow usually presents with numbness in the dorsal and palmar aspects of the little finger and in half of the ring finger and sensory loss at the dorsoulnar aspect of the hand. Pain, if present, typically presents along the medial

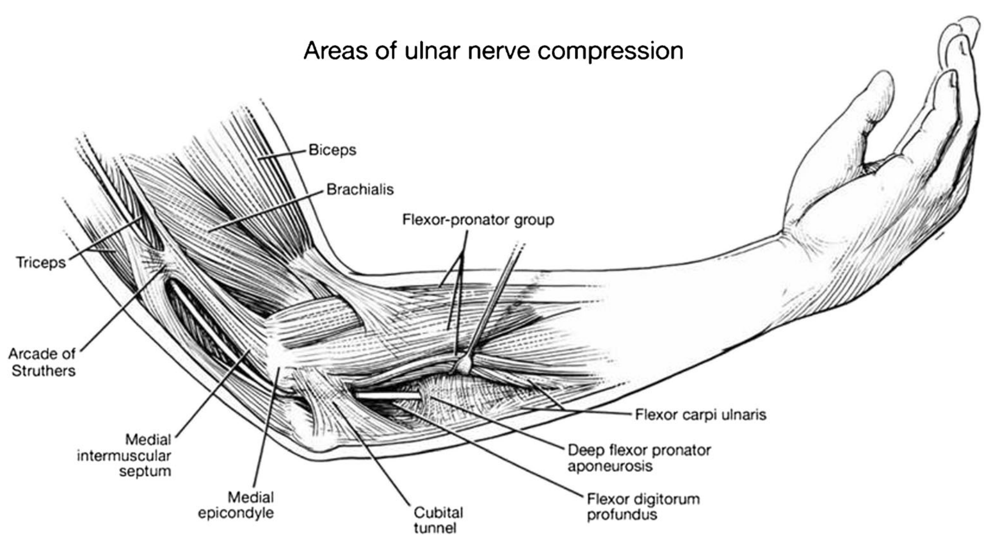


Fig. 1 Normal course of the ulnar nerve and relevant anatomy at the elbow, highlighting common sites of ulnar nerve compression

elbow and commonly worsens with elbow flexion. Paresis or paralysis of the flexor carpi ulnaris, ulnar portion of the flexor digitorum profundus, palmar and dorsal interossei, and adductor pollicis muscles, may be present. Pain to percussion at the ulnar nerve or pain with elbow flexion can help to localize the site of entrapment.

Motion at the elbow can profoundly affect the ulnar nerve. With flexion, the cubital tunnel volume decreases by 55% and pressure increases 7-fold [12]. The normal ulnar nerve undergoes greater than 5 mm of excursion with flexion, subjecting the nerve to significant longitudinal tension and friction [13]. As such, those at risk for ulnar nerve compression include persons undergoing persistent or repetitive elbow flexion: such as truck drivers, cell phone users, baseball pitchers, and those with underlying recurrent anterior dislocation of the ulnar nerve [14] generally due to deficient or absent cubital tunnel retinaculum (Fig. 4). Anterior subluxation of the nerve may present with a snap during flexion, though snapping may also be induced by the medial head of the triceps or by an accessory triceps muscle. This snapping of the triceps may itself be painful or may induce ulnar neuritis [15]. This pathology can often be appreciated clinically, though it can be well confirmed by ultrasound.

Structural anomalies, such as congenital or post-traumatic valgus deformity of the distal humerus, accessory triceps muscle heads, hypertrophy of the medial head of the triceps, accessory triceps muscle heads, osteophytes projecting from the medial humeral epicondyle, anomalous anconeus epitrochlearis muscle (Fig. 5), ganglion cysts along the course of the nerve, loose joint bodies, and synovitis in the epicondylar groove may cause compression of the nerve.

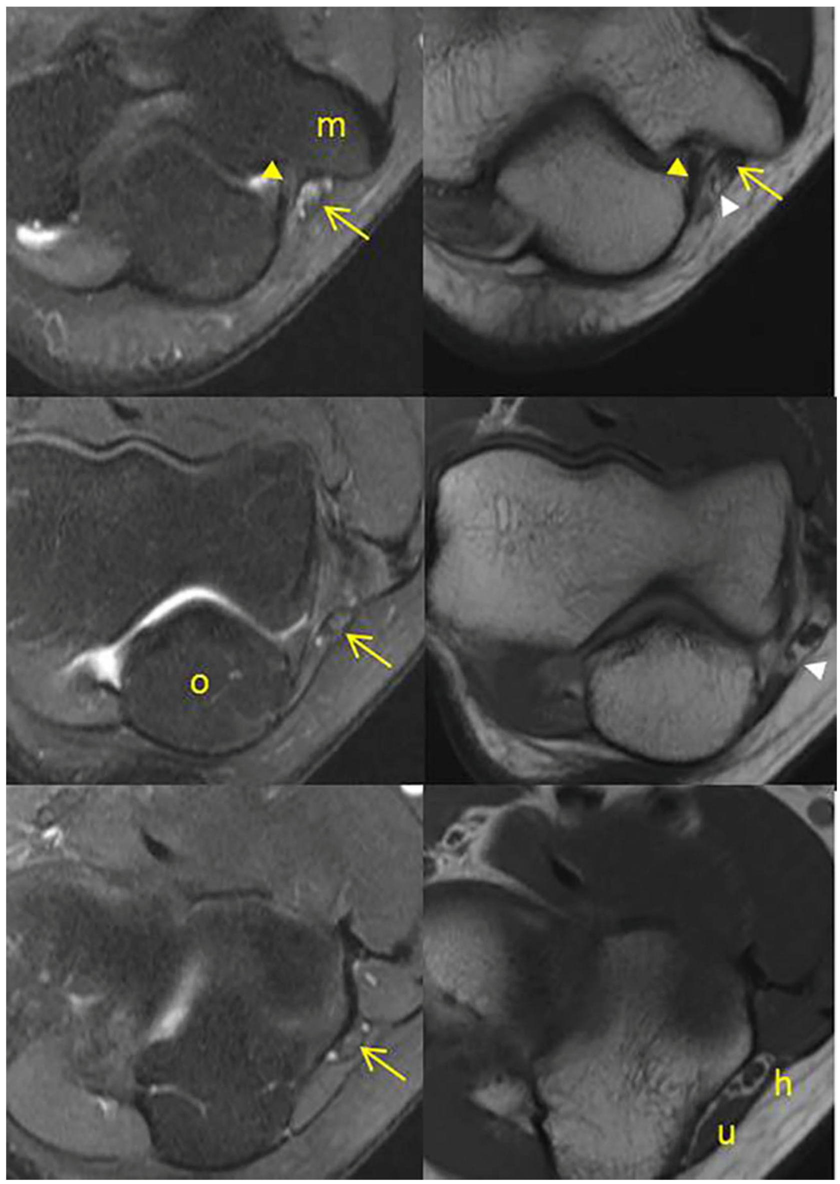
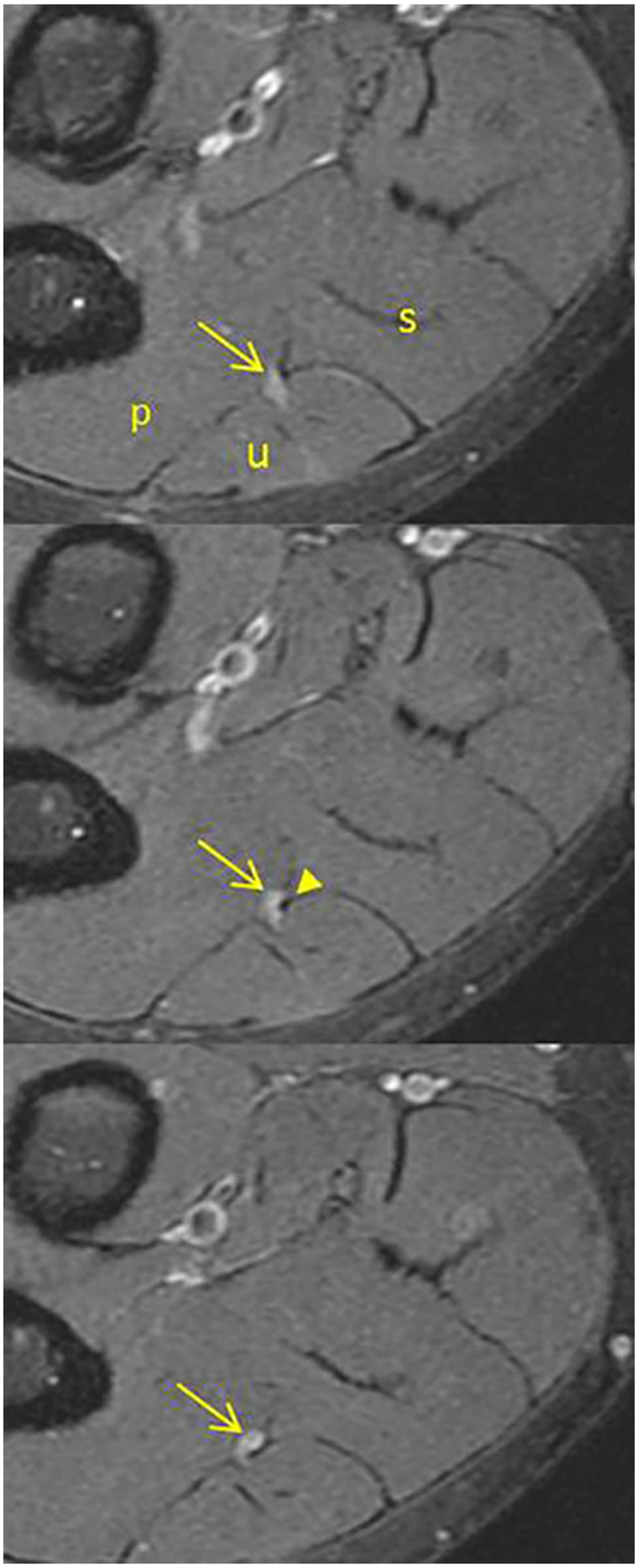


Fig. 2 T2 fs (*left*) and PD (*right*) images demonstrate the anatomy of the cubital tunnel, progressing distally (*top to bottom*). The ulnar nerve (*yellow arrows*) passes within the tunnel, well surrounded by fat. The medial humeral epicondyle (m), olecranon (o), and ulnar collateral ligament (*yellow arrowheads*) are labeled. The aponeurotic roof (*white arrowheads*) and the muscle heads of its origin, the flexor carpi ulnaris ulnar head (u) and humeral head (h), are shown. A small focus of increased T2 signal is present in the nerve at the level of the epicondyle. This is commonly observed, and can generally be assumed to represent an incidental finding, given that the nerve is not enlarged and the more proximal and distal nerve is normal in signal



◀ **Fig. 3** T2 fs images progressing distally (*top to bottom*) demonstrate the ulnar nerve (*yellow arrows*) hooking within the region of the deep flexor-pronator aponeurosis, with a thin fascial band (*yellow arrowhead*) extending between the flexor carpi ulnaris (u) and the flexor digitorum superficialis (s) along the flexor digitorum profundus (p). This patient was asymptomatic. Slightly increased T2 signal is commonly observed within the nerve at this level, but again can generally assumed to represent an incidental finding given that the nerve is not enlarged and the more proximal and distal nerve is normal in signal

Conservative treatment is preferred without progressive signs of neuropathy, and is generally effective [12]. Surgery is usually reserved for unrelenting sensory loss, progressive atrophy and/or weakness of the innervated muscles, and failure to improve [16]. Surgery at the cubital tunnel is ultimately performed to reduce traction and compression upon the ulnar nerve during elbow flexion.

Preoperative imaging

MR imaging, particularly on a 3-T magnet, allows for excellent visualization of the ulnar nerve and the neighboring structures [17] in the pre- and postoperative patient. Transverse and longitudinal plane, T1 and fluid-sensitive sequences are necessary. We attempt to utilize high-resolution techniques [18] and recognize volumetric 3D sequences can be helpful in problem-solving and tracing the nerve given its oblique course. We recommend gadolinium-enhanced, fat-saturated images to aid in the localization of mass or scar tissue. We do not perform diffusion-weighted MR neurography at our institution, though it may be of benefit [19]. However, we recognize that optimization of nerve imaging is often not possible. We commonly obtain MR studies as per a routine, non-neurographic protocol given an incomplete surgical history or a limited indication of "pain" at time of scanning. We review

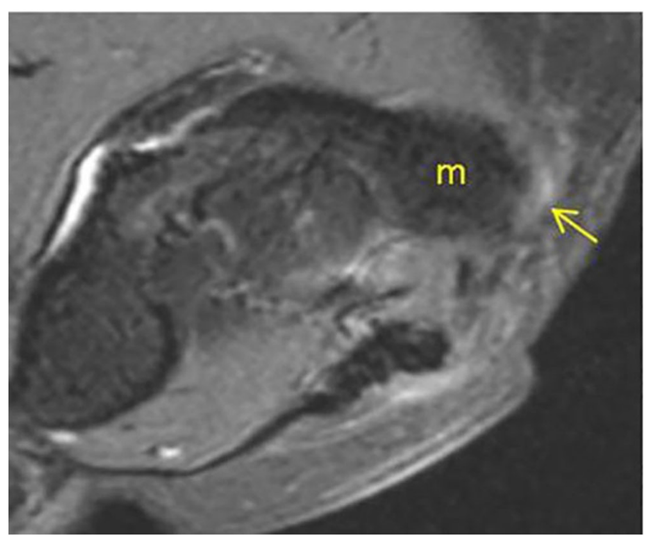


Fig. 4 T2 fs axial image (*left*) at the proximal aspect of the cubital tunnel in a patient with no prior surgery. The thickened and edematous ulnar nerve (*yellow arrows*) is subluxed anteromedially over the medial humeral epicondyle (m). There is small surrounding soft tissue edema

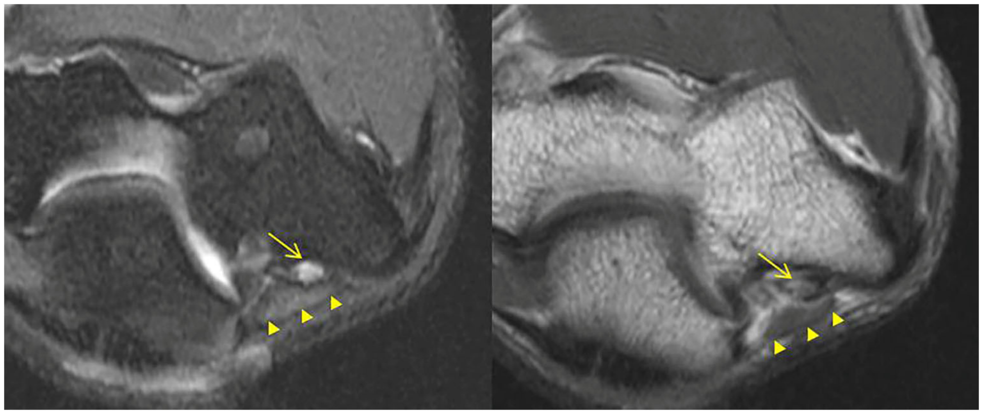


Fig. 5 Axial T2 fs (*left*) and PD (*right*) images at the cubital tunnel in an asymptomatic patient demonstrate mass effect upon the ulnar nerve (*yellow arrows*) in the cubital tunnel by an aberrant anconeus epitrochlearis muscle (*yellow arrowheads*). Note the bright, increased T2-signal of the normal caliber ulnar nerve in this asymptomatic patient. Again, the more proximal and distal nerve is normal in signal (*not shown*)

many outside MR studies that were similarly imaged. Much information may still be gleaned from these studies.

The common sites of ulnar nerve compression should be included on initial and follow-up MR imaging. The imaging should include the arcade of Struthers, located approximately 8 cm proximal to the elbow joint, and should extend at least 5 cm distal to the joint, to include the deep flexor-pronator aponeurosis. Though we attempt to obtain this coverage on all cases, review of our own cases shows an occasional lack of diligence on our part, which can be especially problematic in the postoperative setting. In between these points, attention should be paid to the medial epicondyle and the cubital tunnel. Attention should be paid for sites of extrinsic compression and mass effect upon the nerve.

The ulnar nerve is isointense to muscle on T1-weighted images and slightly hyperintense to muscle on T2-weighted images (Fig. 2). The normal nerve demonstrates a fine, organized fasciculation, and is at least partially surrounded by fat, allowing for good visualization on T1-weighted imaging. This is especially true within the "normal" cubital tunnel.

Inflamed nerves are thickened or thinned and are hyperintense to muscle on T2-weighted imaging. MR of the neuropathic ulnar nerve is highly sensitive, as nearly all cases will exhibit increased fluid-sensitive signal, and most will demonstrate an increase in caliber [20]. The finding of increased fluid-signal in the nerve, however, is not specific, as 60% of asymptomatic patients demonstrate increased T2 signal intensity of the ulnar nerve [9] (Fig. 5). It is hypothesized that this edema represents an underlying subclinical neuropathy [21]. The clinically neuropathic nerve generally trends larger than 8 to 12 mm squared in cross-sectional area [18, 22]. There is no correlation between the total length of either increased nerve signal or nerve enlargement and the clinical staging of ulnar neuropathy [20].

When an edematous and/or enlarged ulnar nerve is encountered on MR, a rigorous attempt should be made to identify a focal site of compression—from a normal or aberrant anatomic structure (Fig. 5), mass, and/or scarring—or a malpositioned ulnar nerve (Fig. 4). Of note, the ulnar nerve may be abnormal proximal and/or distal to any impinging site. When found, this can be valuable to the treating surgeon. Often, imaging fails to discreetly identify a compressing site on preoperative and postoperative studies. Additionally, we have observed many cases where a nerve impingement site is suggested, though the nerve itself is normal in signal and caliber. In our experience, most of these will not be the source of a patient's symptoms, though we have observed

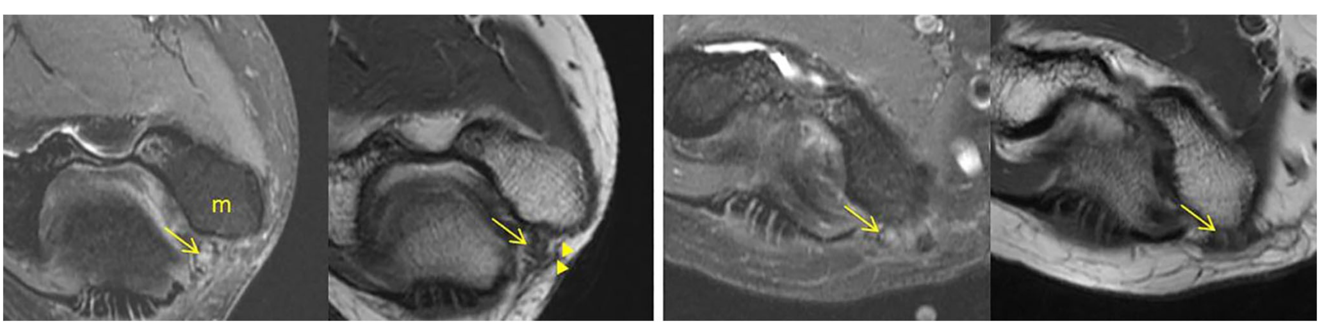


Fig. 6 The left-most T2 fs (*left*) and PD (*right*) images demonstrate the normal postoperative appearance after cubital tunnel release. Note the increased T2 signal in the ulnar nerve (*yellow arrows*) that was present on the preoperative study (not shown) in this now asymptomatic patient. There is small surrounding soft tissue edema. The cubital tunnel retinaculum (*yellow arrowheads*) is thickened posteriorly and is diminutive anteriorly. The right-most T2 fs (*left*) and PD (*right*) images obtained 3.5 years later from the same patient demonstrate medial subluxation of the ulnar nerve (*yellow arrows*) upon the medial epicondyle (m). The ulnar nerve is further thickened and edematous in this now symptomatic patient. There is increased surrounding soft tissue edema

exceptions. We therefore tend to report on possible impingement sites, as these may impact the surgeon's planned intervention.

Soft tissue and muscle edema about the nerve may draw attention to sites of possible ulnar nerve impingement. As an example, snapping triceps syndrome may demonstrate a hypertrophic or redundant muscle and edema overlying the medial epicondyle, in addition to a thickened and edematous nerve [17]. Non-entrapment causes of ulnar neuropathy, such as chronic inflammatory demyelinating polyradiculoneuropathy or a more proximal brachial plexopathy, may complicate preoperative diagnosis, and may be suggested on imaging based on long segmental or multiple nerve abnormalities and/or denervation edema in multiple nerve distributions [17].

The normal nerve should not enhance, though an abnormal nerve may demonstrate post-contrast enhancement [23]. When a direct nerve abnormality is not seen, indirect signs, such as muscle atrophy or denervation edema of the innervated muscles, especially the flexor digitorum profundus and flexor carpi ulnaris muscles, may be visualized. Neurogenic muscle edema may occur within 24 h after denervation.

There is certainly a powerful role for US evaluation of both the preoperative and postoperative ulnar nerve. While both allow for the potential localization of nerve compression, ultrasound is especially helpful in differentiating compression of the nerve from nerve instability [24]. It can well evaluate a long length of nerve, allowing for comparison to the contralateral nerve [25]. Given the utilization of imaging in our region, an MR is often obtained early in the work-up of "elbow pain" and may precede evaluation by the neurologist and/or surgeon. Our surgeons do often obtain a focused ultrasound, especially in cases of persistent neuropathy after surgery. We limit our discussion to MR to highlight the postsurgical appearance of the ulnar nerve.

Surgical techniques and expected imaging findings

Controversy regarding the most appropriate surgical technique for ulnar cubital tunnel syndrome exists. Many surgeons prefer to begin with the simple decompression, especially in patients with mild symptoms, as most studies demonstrate equivalent results between these surgeries in terms of outcomes [26]. Of note, employed surgeries are commonly a variation of those described here. Endoscopic intervention is beyond the scope of this text. It is gaining popularity and may be performed as an in situ decompression or as a transposition.

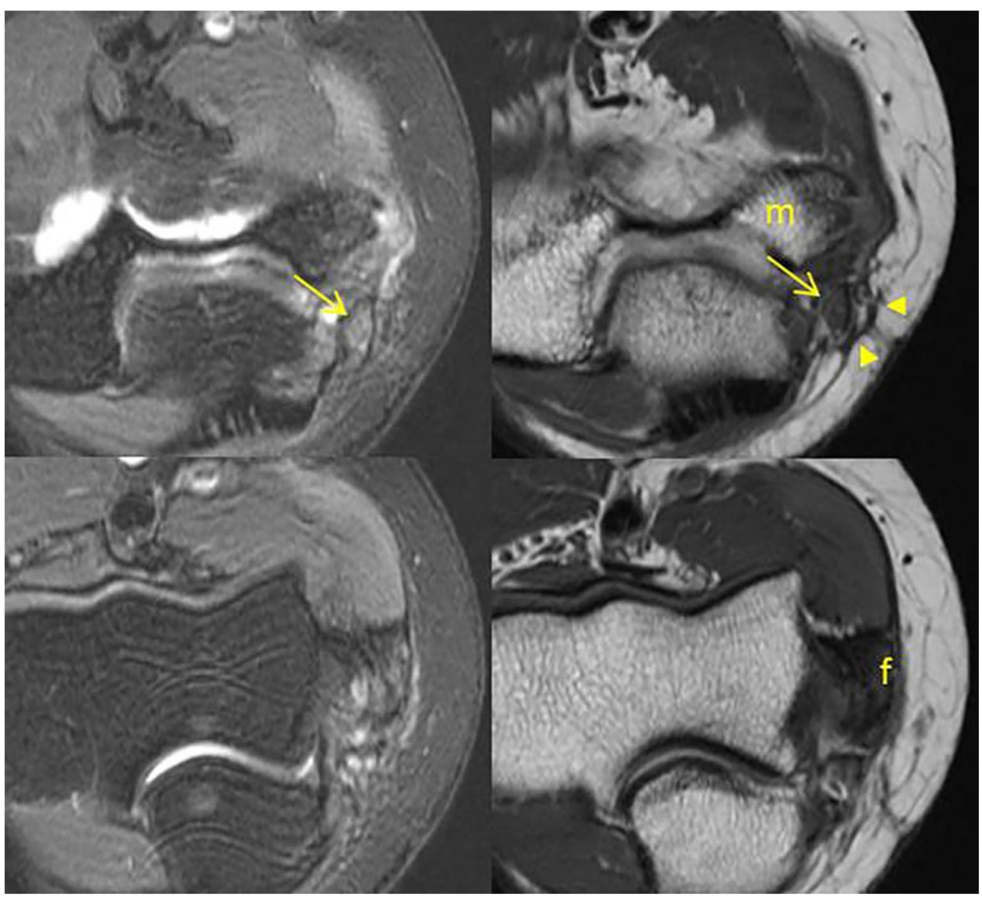


Fig. 7 T2 fs (*left*) and PD (*right*) images, progressing distally (*top to bottom*), demonstrate change of medial epicondylectomy with tiny tearing of the common flexor tendon (f). Note edema in the medial epicondyle (m) and thickening of the ulnar nerve (*yellow arrows*), with edema in the neighboring soft tissues. Note the outward bowing and thickening of the cubital tunnel retinaculum (*yellow arrowheads*). Clinically, the patient did not exhibit ulnar nerve-related symptoms

The surgical incision and tissue disruption is generally less than the more classical surgeries, but the resultant nerve course is similar to that observed in the open procedures described below.

I. Simple decompression: Also known as in situ release. The cubital tunnel retinaculum and flexor carpi ulnaris are released.

Briefly, a 6-cm surgical incision is made over the medial aspect of the elbow, centered over the cubital tunnel retinaculum. The cubital tunnel retinaculum is separated, as is the fascia between the two heads of the flexor carpi ulnaris. Proximal release and resection of the medial intermuscular septum is not performed routinely [16], though many surgeons will free the nerve proximal and/or distal to the tunnel, if indicated.

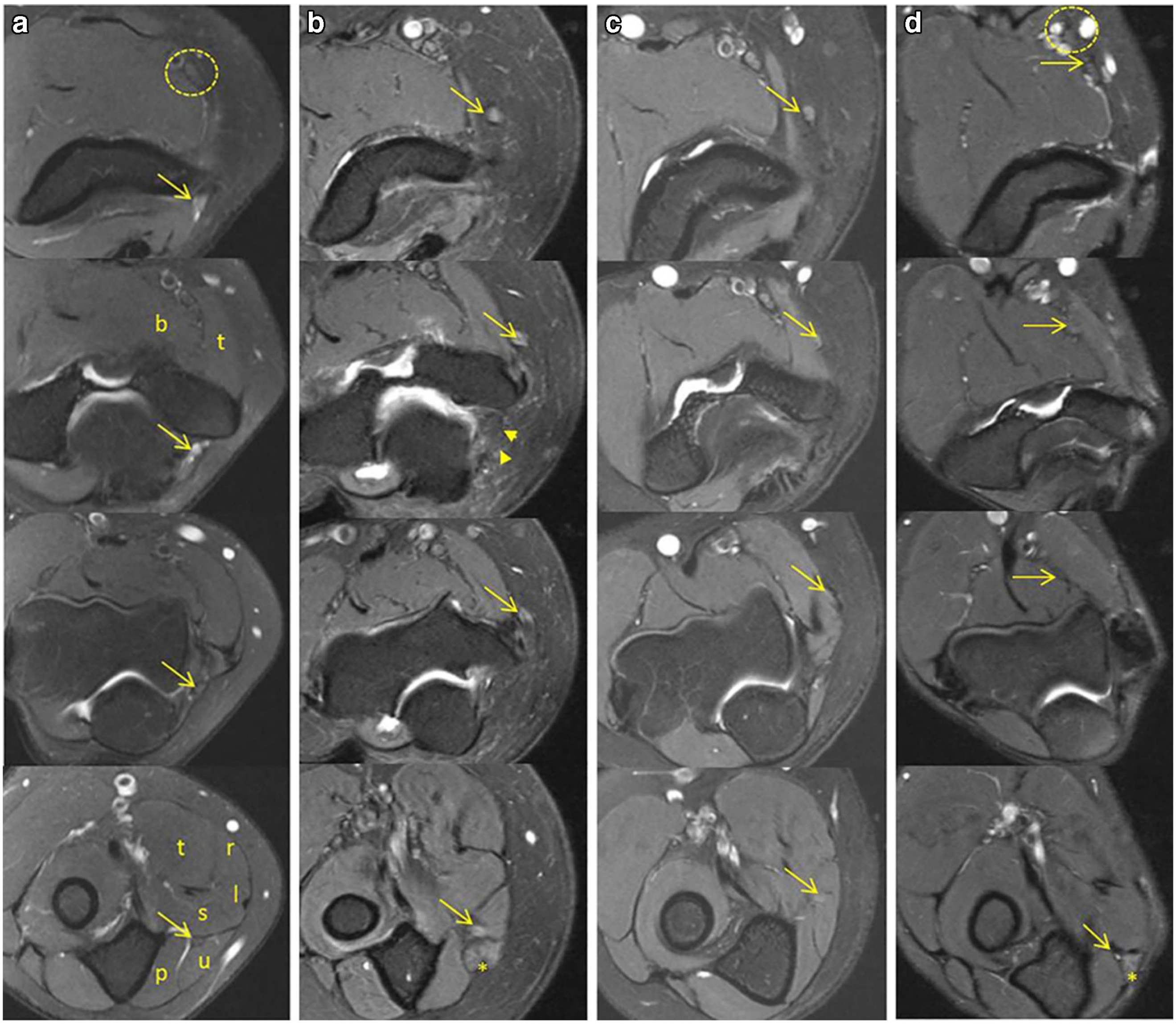


Fig. 8 T2 fs images demonstrate the course of the ulnar nerve, progressing distally (*top to bottom*), in four asymptomatic people. Normal anatomy (**a**) of the ulnar nerve shown as it passes along the elbow. The expected postoperative courses of the ulnar nerve after anterior subcutaneous (**b**), anterior intramuscular (**c**), and anterior submuscular (**d**) transposition are also displayed. *Small yellow arrows* highlight the course of the ulnar nerve. Other marked structures include: the median nerve (*dashed yellow circle*) and the brachialis (b), pronator teres (t), flexor carpi radialis (r), palmaris longus (l), flexor digitorum superficialis (s), flexor digitorum profundus (p), and flexor carpi ulnaris (u). In **b**, note the far anterior course of the ulnar nerve within the subcutaneous fat, as well as the absence of the cubital tunnel retinaculum (*yellow arrowheads*), soft tissue stranding, and focal atrophy of the flexor carpi ulnaris muscle (*). In **c**, note the anterior course of the ulnar nerve, routed along the superficial aspect of the pronator teres muscle (t), before it passes deep to the flexor-pronator mass (*bottom image*). In **d**, note the far anterior course of the ulnar nerve, which follows deep to the pronator teres (t) and the flexor musculature. Note the parallel course to the neighboring median nerve. Thickening of the common flexor tendon and focal atrophy of the flexor carpi ulnaris muscle (*) are present

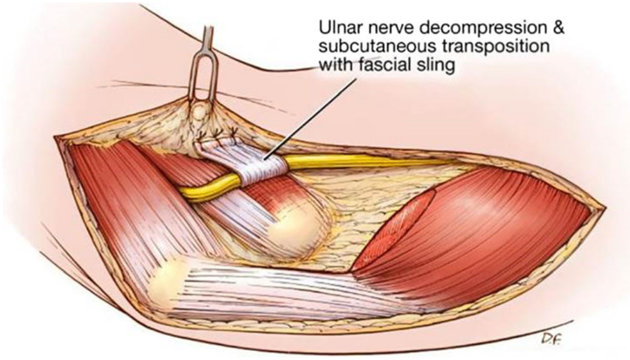


Fig. 9 Diagram showing basic placement of the ulnar nerve for subcutaneous transposition (image *right* is proximal). Note passage of the ulnar nerve along the superficial aspect of the flexor-pronator mass

This procedure gives generally successful outcomes, and is often favored due to its relative surgical ease and relatively lower surgical risk, especially in the comorbid patient. The main disadvantages include worsening of instability for ulnar nerve subluxation and inadequate decompression, especially if more proximal and/or distal sites of impingement are present. The surgery allows for early mobilization of the patient's arm and preserves the vascularity of the nerve. It will not address subluxing ulnar nerve.

The postoperative appearance is shown and described in Fig. 6.

II. Medial epicondylectomy and simple decompression: Medial epicondylectomy is preformed to increase the space available for the cubital tunnel or to remove impinging osteophytes. The nerve is exposed as in simple decompression. The common flexor origin is separated subperiosteally from the medial epicondyle. Sharp edges of the posterior epicondyle are removed. The common flexor origin is reconstructed, with care to preserve the anterior bundle of the medial collateral ligament to avoid valgus instability.

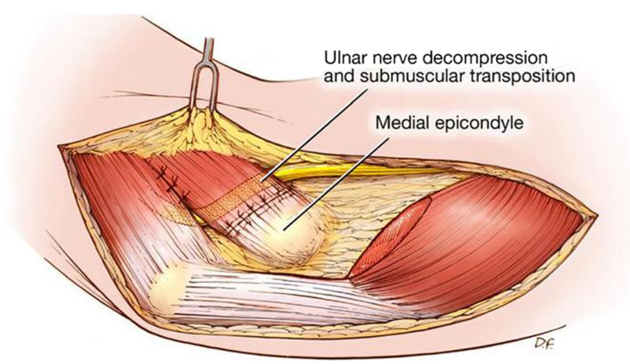


Fig. 10 Diagram showing basic placement of the ulnar nerve for submuscular transposition (image *right* is proximal). Note passage of the ulnar nerve deep to the flexor-pronator mass

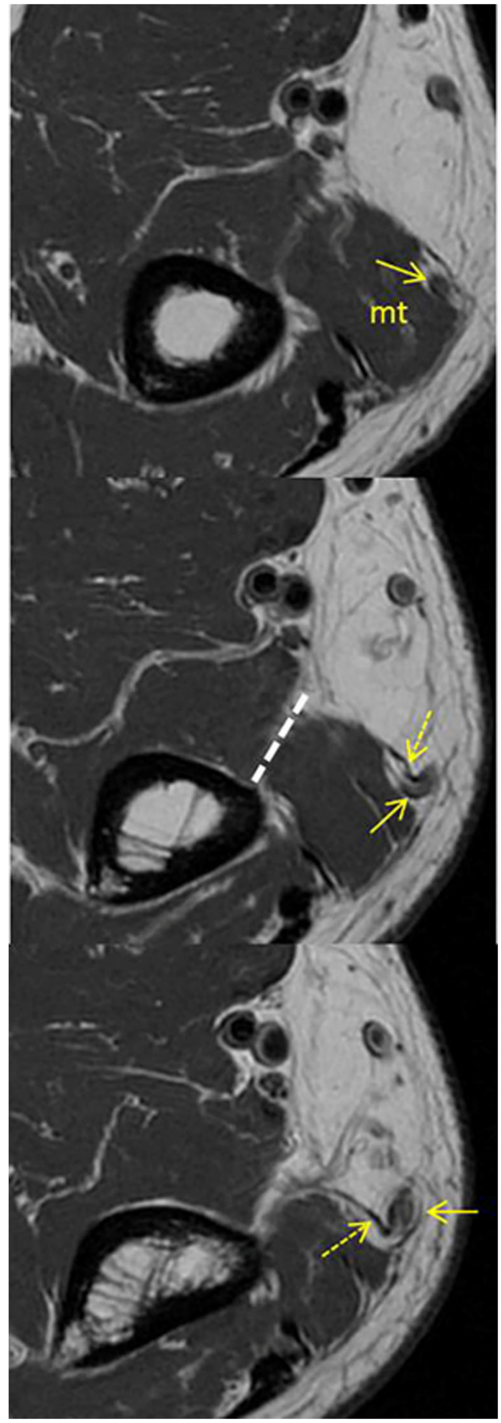
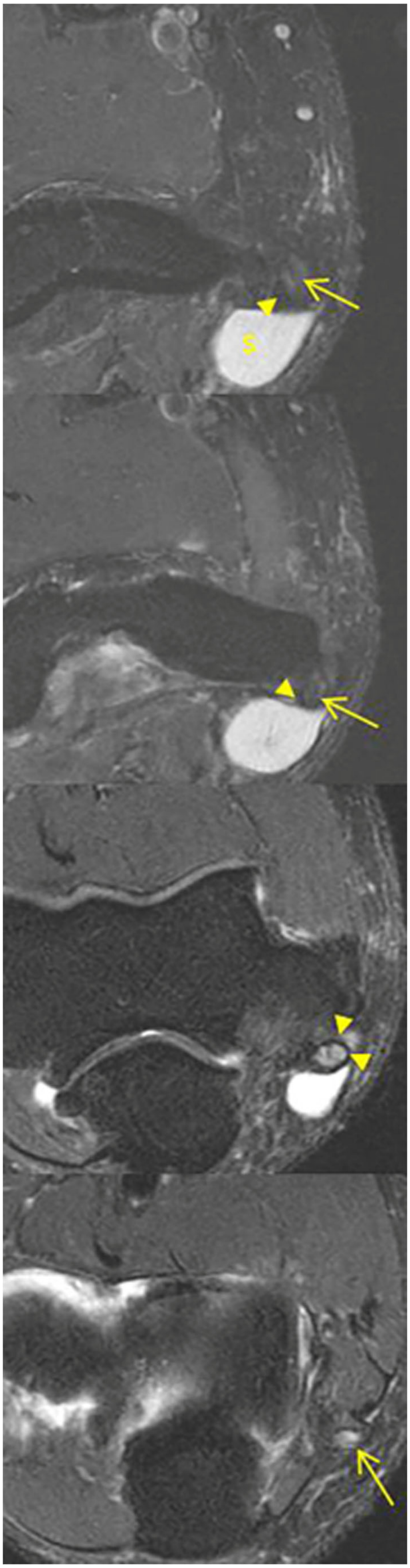


Fig. 11 Proton density (PD) images demonstrate the ulnar nerve (*yellow arrows*) progressing distally (*top to bottom*) at a level approximately 8 cm proximal to the medial humeral epicondyle. Note the hooking of the nerve about the thickened aponeurotic extension (*dashed yellow arrows*) from the superficial margin of the medial head of the triceps muscle. This extension, termed the arcade of Struthers, extends toward the intermuscular septum (*dashed white line*), in this postoperative patient after anterior subcutaneous ulnar nerve transposition. This patient was asymptomatic. The nerve proximal and distal to the "hooking" is not enlarged or edematous, favoring this to represent a normal, incidental appearance of the prominent arcade of Struthers. There is a small amount of postoperative soft tissue about the nerve on the bottom image



◀ **Fig. 12** Postoperative organized hematoma and scarring: T2 fs axial images progressing distally (*top to bottom*) after anterior subcutaneous transposition. Prominent organized hematoma (s) noted. This was noted by the radiologist as a "seroma", as was the thickened and T2-hyperintense ulnar nerve (*yellow arrows*). Not noted by the radiologist, but observed in the operating room, was prominent, rind-like scarring (*yellow arrowheads*) along the course of the ulnar nerve in the region of the hard, organizing hematoma. The nerve additionally demonstrates an acute course and caliber change, as well as internal edema. Both the hematoma and scarring were thought by the surgeon to contribute to ulnar nerve symptoms

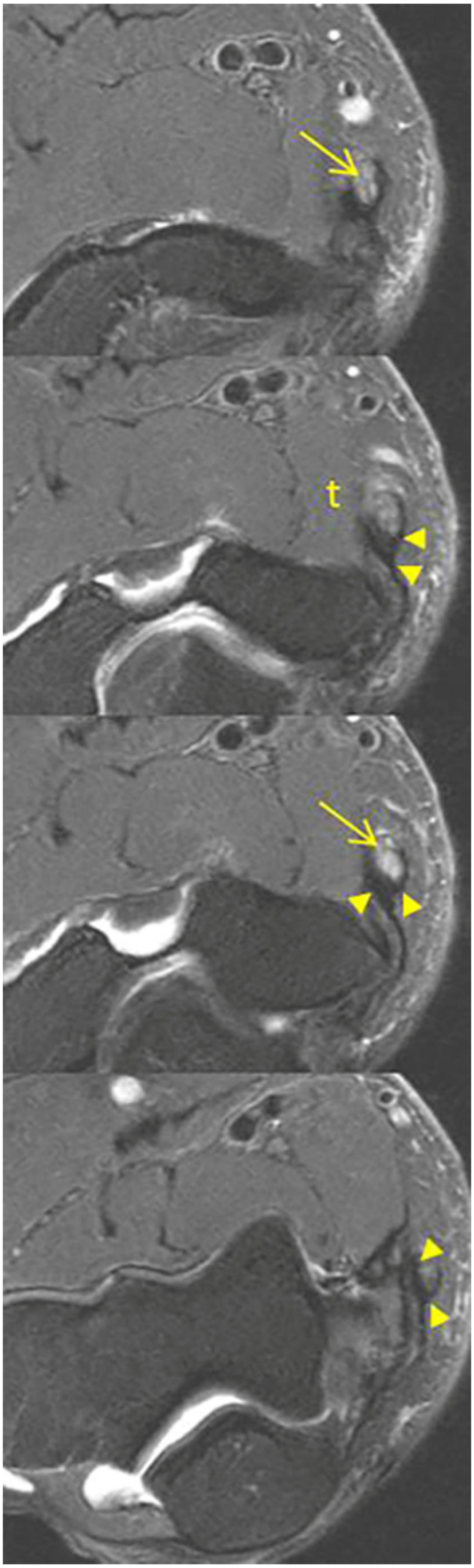
Favorable outcomes are generally reported, though the risk inadequate decompression of more proximal and distal sites remains present, as well as risk of elbow instability from injury to the medial collateral ligament. Patients may complain of flexor-pronator muscle issues, including persistent weakness or focal pain at the bony attachment [27].

The postoperative appearance is shown and described in Fig. 7.

III. Anterior transposition: For symptoms caused by a subluxing ulnar nerve and for more severe ulnar nerve involvement with more pronounced EMG findings [16]. These procedures remove the nerve from the cubital tunnel. As such, each may produce more proximal and distal "kinking" of the nerve secondary to this mobilization.

The postoperative appearance of the variant anterior transposition surgery types are shown and described in Fig. 8.

A. *Subcutaneous transposition:* A longer (10 to 12 cm), curved surgical incision is made posterior to the medial epicondyle, centered on the epicondyle. The medial cutaneous nerves are again protected. The ulnar nerve proximal the elbow joint is mobilized with the vessels supplying it. The arcade of Struthers is frequently released, lying approximately 8 cm proximal to the epicondyle, as is the medial intermuscular septum. If crossing muscle fibers are seen at this arcade, the nerve is mobilized [16]. The cubital tunnel retinaculum and the flexor carpi ulnaris aponeurosis are released. Care is taken to preserve and mobilize the ulnar motor branches to the flexor carpi ulnaris and flexor digitorum profundus. The nerve is transposed anteriorly in the subcutaneous plane, with care taken to prevent kinking of the nerve distal to the epicondyle by the common aponeurosis lying between the humeral head of the flexor carpi ulnaris and the flexor digitorum superficialis of the ring finger [16]. The nerve is optionally secured by placing a fascial or muscular flap developed from the anterior surface of the flexor-pronator musculature (i.e., the flexor carpi ulnaris, flexor carpi radialis, and pronator teres) (Fig. 9).



◀ **Fig. 13** Proximal postoperative scarring: T2 fs axial images from proximal to distal (*top to bottom*) in a patient after anterior subcutaneous transposition. Note marked scarring (*yellow arrowheads*) funneling about the thickened and bright ulnar nerve (*yellow arrows*). Scarring predominantly extends along the nerve's proximal course, overlying the flexor-pronator musculature (t)

This approach leaves the nerve exposed to trauma anterior to the epicondyle and places the nerve in a hypovascular bed, especially in the very thin patient. Outcomes are generally similar to simple decompression [28]. It is commonly performed in the posttraumatic elbow to free the nerve from fracture deformity and subsequent scar tissue.

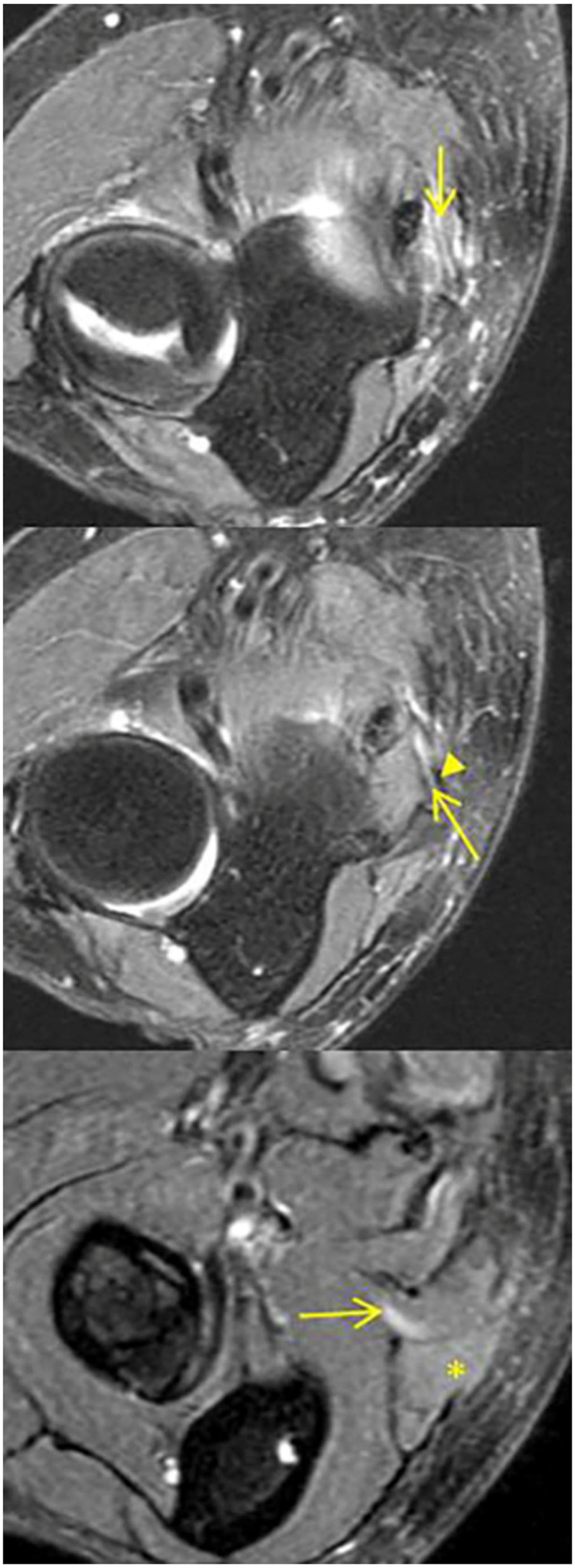
B. *Intramuscular transposition:* The nerve is released as in subcutaneous transposition. A trough slightly larger than the nerve is carved out of the muscles of the flexor-pronator mass. The nerve is placed within the groove and the fascia is closed over top [28]. The translocated ulnar nerve should parallel the median nerve. Proponents state this places the nerve in a more protected and straighter course, while opponents note increased scarring.

C. *Submuscular transposition:* A longer (16 cm) incision is made, with similar initial technique as in a subcutaneous transposition. Care is taken to preserve the vascular supply to the nerve and to keep the nerve straight, running parallel to the median nerve. The lacertus fibrosus is identified, as is the median nerve, which passes deep to this structure. The overlying fascia is released, allowing for visualization of the flexor-pronator muscles. This group is cut approximately 2 cm distal to the medial epicondyle and the muscles are stripped distally. The ulnar nerve is translocated atop the brachialis muscle and is covered by the flexor-pronator group, which is placed in its original location or elongated (Fig. 10) [16].

The main disadvantage is that this procedure is technically demanding and the patient may have weakness of the flexor-pronator mass [27].

Postsurgical complications and imaging

Many issues and items may contribute or result in failure of ulnar nerve surgery, including initial misdiagnosis of the compression site, incomplete decompression, multiple unrecognized sites of compression, kinking at a proximal or distal structure, or postoperative seroma or hematoma, granulation tissue, and/or scarring. Gabel and Amadio [29] described full exploration of the ulnar nerve at the elbow and found an



◀ **Fig. 14** Flexor-pronator mass region postoperative scarring: T2 fs axial images from proximal to distal (*top to bottom*) in a patient after anterior subcutaneous transposition. A relatively normal ulnar nerve (*yellow arrows*) is drawn thin and becomes T2-hyperintense over a short segment on the subsequent two images. Note the flanking segmental scar (*yellow arrowhead*) and the prominent edema about the nerve. The most distal image (*bottom*) demonstrates a bright, normal-sized nerve (*yellow arrow*), and denervation edema in the flexor carpi ulnaris (*). Scarring is often observed as the nerve passes through the flexor-pronator mass

average of one level of compression at time of initial surgical intervention; and an average of 2.2 levels of compression at repeat surgery [29]. This finding was thought secondary to failure to release an initial lesion, creation of a new lesion by "rerouting" of the nerve, or postoperative scarring.

Care should be made to review any prior imaging to find a preoperatively "missed" lesion responsible for nerve impingement. As many initial corrective surgeries are performed with a standard "simple" decompression, it is especially important to evaluate for a possible lesion proximal and/or distal to the cubital tunnel. The prior surgery itself may have led to a worsening of symptoms. In situ decompression leads to inherent instability of the ulnar nerve. Prominent soft tissue edema about a subluxed nerve, often with bone marrow edema in the medial humeral epicondyle, with focal or segmental ulnar nerve abnormality (Fig. 6), suggests impingement of the nerve.

New compression may be created during nerve transposition, as the native course of the ulnar nerve has been changed. This is most common proximally at the arcade of Struthers and distally at the flexor-pronator mass. Figure 11 demonstrates the hooking of the ulnar nerve about the normal arcade of Struthers after anterior subcutaneous transposition. In this case, the nerve remains normal both proximally and distally, suggesting this to be an incidental finding. This was subsequently confirmed clinically.

Edema and granulation tissue may make identification of an offending compressive lesion difficult, especially in the early postoperative period. Prior medial epicondylectomy commonly demonstrates prominent bone and soft tissue edema that is not symptomatic (Fig. 7). Furthermore, we have observed many post-operative ulnar nerve cases in which the ulnar nerve remains thickened and edematous, though the patient is currently symptom free. To our knowledge, the change in appearance of the ulnar nerve after surgery has not been rigorously studied. Vosbikian et al. [30] documented thickening of the nerve by ultrasound after failed transposition, but did not image an asymptomatic postoperative control group. We have seen many cases where presurgical imaging has been helpful in identifying true sites of impingement on postsurgical MR by confirming a relative, interval increase in ulnar nerve caliber and edema.

As in preoperative imaging, a rigorous attempt should be made to interrogate the ulnar nerve along its full course. Compression may occur at a focal site, but given the prevalence of postoperative scarring, it is often observed over a short segment and may be present at multiple sites. As such, it is imperative that the radiologist evaluate for scars, and be vigilant for a second focus of impingement. Again, depending on site and type of compression, this information may influence any subsequent surgery.

Granulation tissue and scarring is ubiquitous in the postoperative patient [31, 32]. Many times we comment on its presence, with the surgeon subsequently clearing it clinically. We have found that a denser, rind-like focal or segmental scarring about the nerve, especially when associated with an acute course change, acute caliber change, and internal signal abnormality of the nerve, should strongly raise suspicion as a possible site of impingement. All of these findings are present in the case presented in Fig. 12. We have occasionally observed these same findings with prominent scarring demonstrating a sort of "funneling" appearance about the nerve (Fig. 13).

Nerve transposition repositions the ulnar nerve relative to the flexor-pronator mass. As a result, a somewhat focal course change of the nerve is present as it exits this region. Moreover, we commonly observe associated ulnar nerve signal abnormality and surrounding soft tissue edema, granulation tissue, and/or small scarring in asymptomatic patients. We have found that a dense rind of scar about the nerve or obliteration of the fat about the nerve to be most helpful at parsing out the true impingement cases in the region of the flexor-pronator mass. We have observed a few cases of surgically confirmed impingement at the flexor-pronator mass with scarring severe enough to give a segmental "pulled-taffy" appearance of the narrowed and scarred-in, edematous ulnar nerve flanked by edematous soft tissue (Fig. 14).

Postoperative seroma or hematoma may create mass effect upon a nerve, as previously demonstrated on Fig. 12. Obliteration of the expected fat about the nerve, especially in the presence of an abnormal nerve may suggest nerve entrapment (Fig. 15). Postoperative neuroma from cutaneous nerves injured during ulnar nerve decompression or transposition

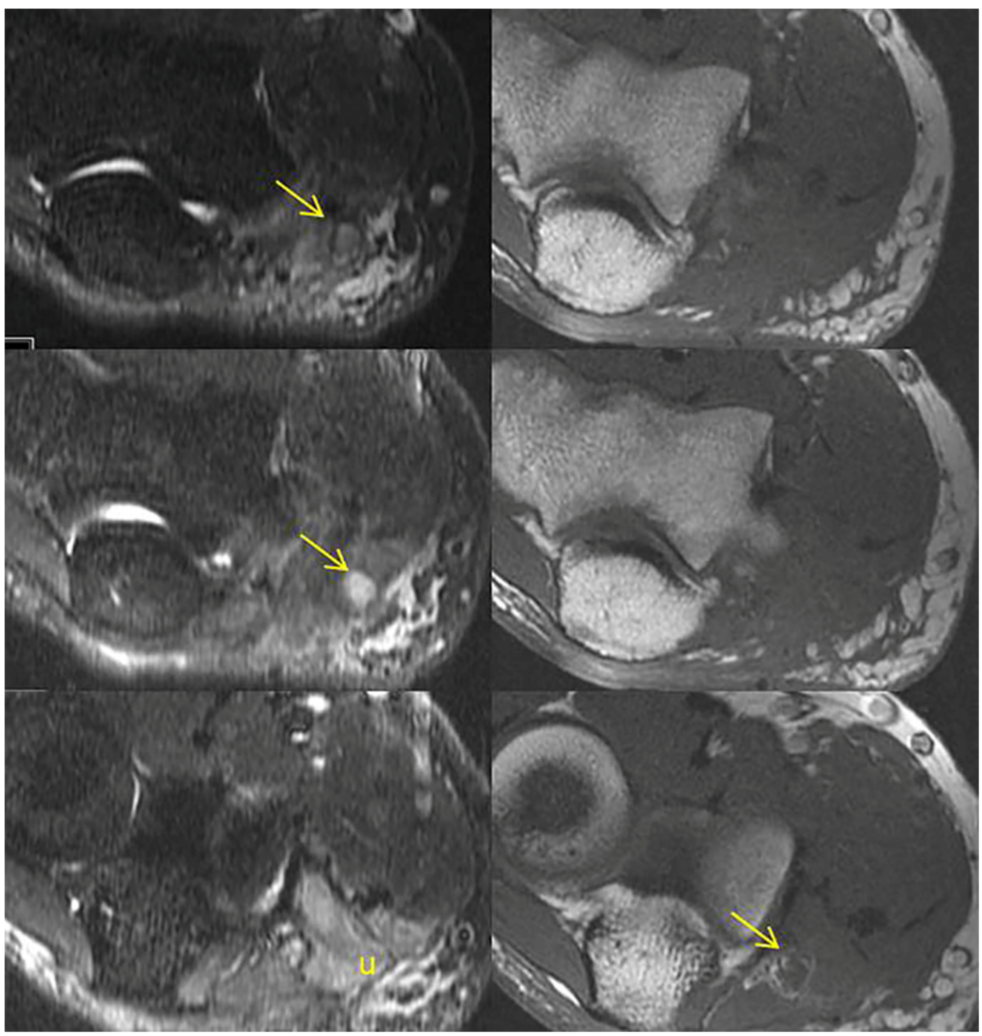


Fig. 15 Diffuse postoperative scarring. T2 fs (*left*) and PD (*right*) axial images from proximal to distal (*top to bottom*) in a patient after medial epicondylectomy. Note the thickened and T2-hyperintense ulnar nerve (*yellow arrows*) with obliteration of the surrounding fat by edema and/or granulation tissue/scarring, seen best on the PD images. Denervation edema noted in the flexor carpi ulnaris muscle (u)

may also result in pain, and the radiologist is reminded to evaluate for post-operative change to the ulnar nerve and the adjacent small nerves in the post-operative bed.

Interestingly, on review of our cases, it is common to find cases recorded as one type of surgery and to find imaging changes consistent with an altogether different procedure (Fig. 16). This serves as a reminder to check the course of the ulnar nerve in any case, especially in the case of reported "prior surgery", and even when an operative report is available. It also serves as a reminder to evaluate the course of the ulnar nerve on other imaging modalities, including CT (Fig. 17), where the redirected ulnar nerve can often be visualized.

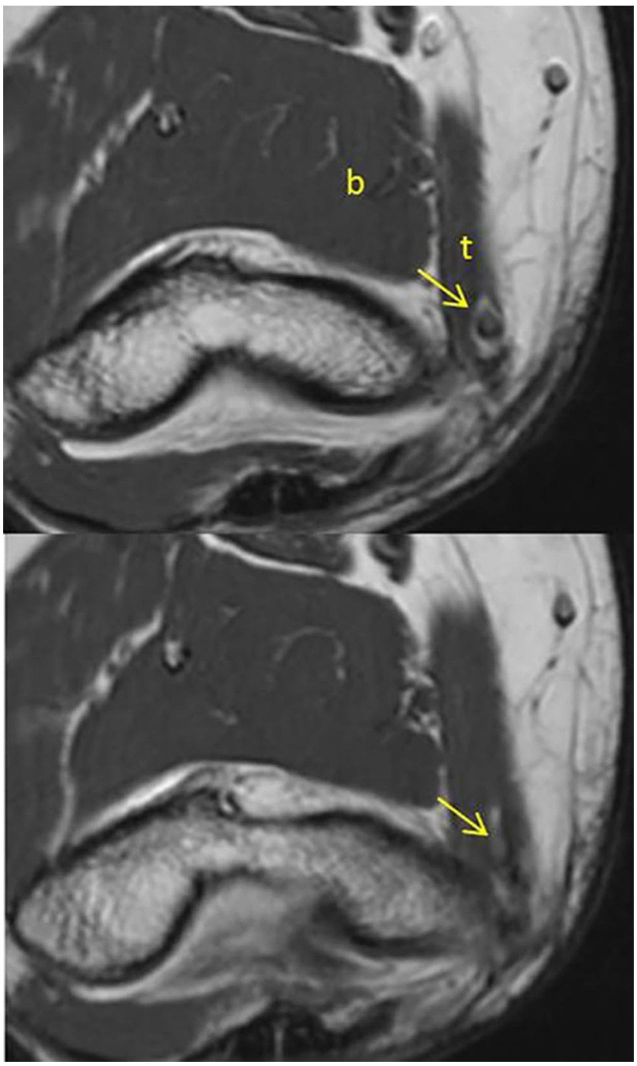


Fig. 16 PD images progressing distally (*top to bottom*) demonstrates a variant course of a reported "submuscular" transposition. Note the ulnar nerve (*yellow arrows*) passes within the muscle and tendon slips of the flexor-pronator mass (t), not fully deep to them to overlie the brachialis (b) muscle, as was seen in the submuscular transposition example in Fig. 8c. This would be better described as an "intramuscular" transposition, though the typical intramuscular transposition does not place the nerve this deep within the muscle

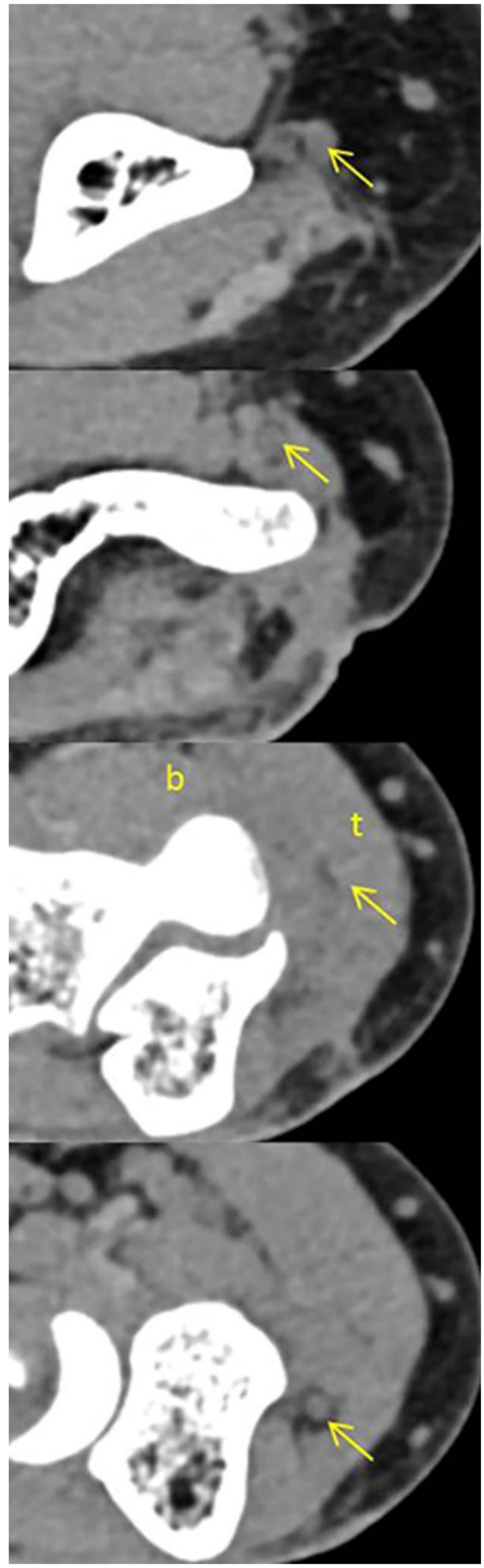


Fig. 17 CT images progressing distally (*top to bottom*) demonstrate the ulnar nerve (*yellow arrows*) after submuscular transposition. Small fat surrounding the nerve can often be noted along much of the nerve's course to help in its localization

Conclusions

Imaging can aid in the evaluation of cubital tunnel syndrome by displaying the appearance and course of the ulnar nerve and by identifying sites of possible extrinsic compression and postoperative scarring. Numerous decompressive surgeries are used in the treatment of this syndrome. Familiarity with these procedures, and with common sites of postoperative compression upon the nerve, is important for the evaluating radiologist.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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