Review paper

Cite as: Walter WR, Burke CJ, Adler RS: Tips and tricks in ultrasound-guided musculoskeletal interventional procedures. J Ultrason 2023; 23: e347–e357. doi: 10.15557/JoU.2023.0039.

Submitted: 05.06.2023
Accepted: 09.08.2023
Published: 30.10.2023

Tips and tricks in ultrasound-guided musculoskeletal interventional procedures

William R. Walter, Christopher J. Burke, Ronald S. Adler

Radiology, NYU Grossman School of Medicine, New York, USA

Corresponding author: William R. Walter; e-mail: william.walter@nyulangone.org

DOI: 10.15557/JoU.2023.0039

Keywords
musculoskeletal ultrasound; US-guided; joint injection

Abstract

Ultrasound visualization affords proceduralists versatile and accurate guidance for a variety of percutaneous, minimally invasive procedures in the musculoskeletal system including joint (intra-articular) injections or aspirations, intra-bursal injections, peritendinous, and perineural injections. A variety of percutaneous procedures are traditionally performed blindly, but may be more easily or more accurately performed with the real-time assistance of ultrasound guidance. Other procedures are only possible utilizing image-guidance, due to the required precision of the injection because of delicate local anatomy or depth of the injection; ultrasound is a safe, portable, and widespread modality that can be used to assist the proceduralist in localizing the needle tip in such cases, to ensure safe and accurate delivery of the medication, most frequently a solution of steroid and anesthetic. This review aims to provide a foundational approach to ultrasound-guided procedures in the musculoskeletal system, offering tips and tricks that can be employed in many different procedures including intra-articular, juxta-articular, and perineural injections for a multitude of clinical scenarios. Technical considerations regarding ultrasound transducer selection, sonographic technique, as well as common indications, contraindications, and complications of these procedures, are presented. Additionally, a variety of pharmacologic considerations for proceduralists contemplating ultrasound-guided injections are discussed.

Introduction

Ultrasound (US)-guided interventional procedures of the musculoskeletal (MSK) system have blossomed in popularity due to the widespread availability, unequaled portability, and superior accuracy afforded by US-guided techniques[1,2]. Many medical and surgical subspecialties have adopted sonographic guidance for percutaneous procedures – including those traditionally performed without guidance – due to widespread adoption and familiarity with diagnostic US for the MSK system[2]. Reliable confirmation of needle placement accuracy and positive outcomes measures, including patient comfort, associated with US-guided procedures further explain this change in practice patterns.

Clinical considerations: indications, contraindications, and complications

The clinical indications for US-guided interventions are many and varied, and the specific clinical context of each patient should be taken in account prior to embarking on any interventional procedure. The most common injections are performed using a combination of local anesthetic and either a particulate or water-soluble steroid preparation to address symptoms of pain or swelling, usually localized to a joint (arthritis), bursa (bursitis), tendon sheath (tenosynovitis or tendinosis), or nerve (neuritis/neuroma). If more conservative measures exist for the management of patient symptoms, these should be attempted prior to entertaining an invasive procedure[3–5]. In many cases, the targeted approach of an US-guided injection can be beneficial to confirm accuracy and may improve patient experience due to increased ease of accurate needle placement. Sonographic guidance should also be considered if a prior blind injection has not achieved the desired clinical effect, as it may indicate an inaccurate or suboptimal injection. Evidence for the effectiveness of the most common injections in the MSK system has been well documented in the literature[3,6–8].

There are also potential absolute and relative contraindications to US-guided injections that must be addressed. Absolute contraindications are few, but active septic arthritis, bursitis, or tenosynovitis contraindicates steroid injection into the relevant space. Additionally, overlying superficial soft tissue infection should not be traversed with a needle en route to an injection target due to the risk of seeding that compartment. If an overlying cellulitis is encountered

in the setting of a proposed intra-articular intervention, an alternate route should be sought that avoids the contaminated soft tissues. In cases of severe allergy to a particular injectate, a suitable alternative should be utilized[7].

Relative contraindications will differ based on the management context of individual patients as well as the complement of treatment options available in each situation. Acute subchondral insufficiency fractures, most common in the femoral head, have been considered a relative contraindication due to the theoretical risk of worsening fracture and ischemic effects to the subchondral bone promoted by local steroid effects, increasing the likelihood of osteonecrosis[9]. Indeed, a causal relationship between steroid injection and subchondral insufficiency fracture and osteonecrosis has been proposed but never definitively proven[10,11]. Non-severe allergic reactions should be managed on a case-by-case basis, and appropriate pharmacologic modifications or pretreatment regimens can be utilized should the procedure be absolutely clinically necessary.

A common clinical context for patients receiving intra-articular steroid injections is pain management of arthritis, to avoid or at least delay definitive surgical management, namely arthroplasty. However, if a surgery is planned following steroid injection, the surgeon's preference should be discussed, as evidence suggests that intra-articular steroid injection increases risk of prosthetic joint infection if performed within three months of surgery[12].

An exhaustive list of reported complications is not presented here, but informed consent should be tailored to each patient, including both common and uncommon risks, as well as any risks relevant to the clinical context and pharmaceuticals used, for example skin depigmentation or soft tissue atrophy in the setting of a superficial particulate steroid injections[13]. Systemic effects of corticosteroids are well established and relatively common, including hyperglycemia, especially in those with diabetes mellitus, and an immediate or delayed flushing reaction that is possible within the first 24–48 hours of the injection[14]. Non-target injection and the subsequent potential complications associated with them should be mentioned, but it should also be explained that these are much less likely to occur in US-guided procedures compared to blind or landmark-guided procedures, as targeted injection will be confirmed in real-time[8,15]. An additional benefit of US's precision compared to blind injections is that lower volumes and doses of an anesthetic are required to produce the same clinical effect, thus minimizing potential local soft tissue complications related to high doses of anesthetics[16].

The most important preventable complication for any US-guided percutaneous MSK intervention is iatrogenic infection, including septic arthritis, which can be devastating if not promptly recognized and treated. Strict adherence to universal precautions, aseptic technique, and precise needle placement are critical to minimizing infection risk[17].

General technical considerations

Many US imaging systems are equipped with a range of interchangeable transducers, and appropriate selection is critical to a successful US-guided intervention. The optimal transducer for a given injection is mainly determined by the footprint size and frequency for the given size and depth of the desired target. A small footprint size is ideal for small injection targets with small or otherwise challenging surface anatomy (for example, a lesser toe interphalangeal joint or the peroneal tendons as they curve behind the lateral malleolus). The smaller footprint size will allow the relevant surface anatomy to accommodate both the transducer and the needle. Higher frequency transducers will optimally resolve more superficial structures in greater soft tissue detail but are suboptimal for deep or large injection targets. The latter are more optimally visualized by low-frequency transducers, which usually have a larger footprint and display a broader region of deeper anatomy, such as the hip joint (Fig. 1). One potential pitfall is that the high-frequency transducer may not penetrate thick skin or subcutaneous tissues, as can be seen in the sole of the foot or

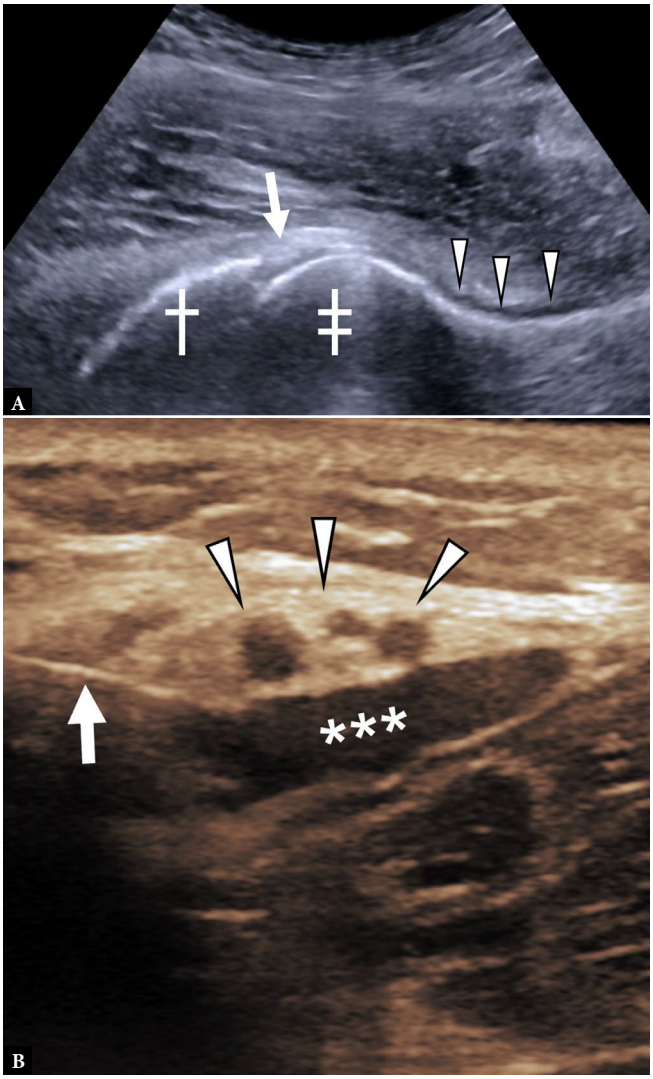

Fig. 1. A. *Ultrasound image of the hip joint utilizing a 5MHz curvilinear transducer ideal for imaging deep, large joints such as the hip joint. The acetabulum (cross), labrum (arrow), and femoral head (double cross) are depicted prior to joint injection. The potential intra-articular space deep to the joint capsule is indicated by arrowheads, depicting no significant native joint fluid or joint effusion prior to the injection.* **B.** *Ultrasound image of the common peroneal nerve obtained using an 18 MHz hockeystick transducer to guide a perineural anesthetic injection, depicting the needle (arrow) positioned deep to the common peroneal nerve, which demonstrates fascicular enlargement indicating neuritis (arrowheads). The injectate appears as hypoechoic material distending the perineural fat plane deep to the nerve (asterisks)*

the palm of the hand, and a lower frequency transducer may be necessary even if the target tissue depth is relatively superficial.

The universal precautions exercised in accordance with individual institutional policies and common clinical practice guidelines for all interventional procedures should be no different for US-guided interventions. Indeed, US-guided interventions are not known to be associated with an increased risk of infectious complications[17]. However, the transducer utilized for real-time guidance is neither disposable nor single-use as is the case for all other instruments used in the procedure. Commonly, the transducer is covered with a single-use sterile plastic barrier, most often a condom-type cover. An alternative approach is to leave the transducer footprint uncovered and drape the sides of the transducer and its cord with a sterile adhesive drape. The footprint can be sterilized with a chlorhexidine, Betadine (Povidone-iodine), or a similar product. The advantage of this approach is that the transducer footprint is unencumbered by gel and plastic covering, significantly improving the guidance image quality. This approach to US transducer preparation has been shown to be safe from an infection control standpoint, with one study identifying no confirmed infectious complications in over 6,000 injections performed at a single center[18].

Geometry is important to the success of an US-guided injection, defining the correct needle trajectory by taking into consideration the depth of the target, distance of the target from the needle entry site, and distance of the needle entry site from the edge of the transducer footprint[14].

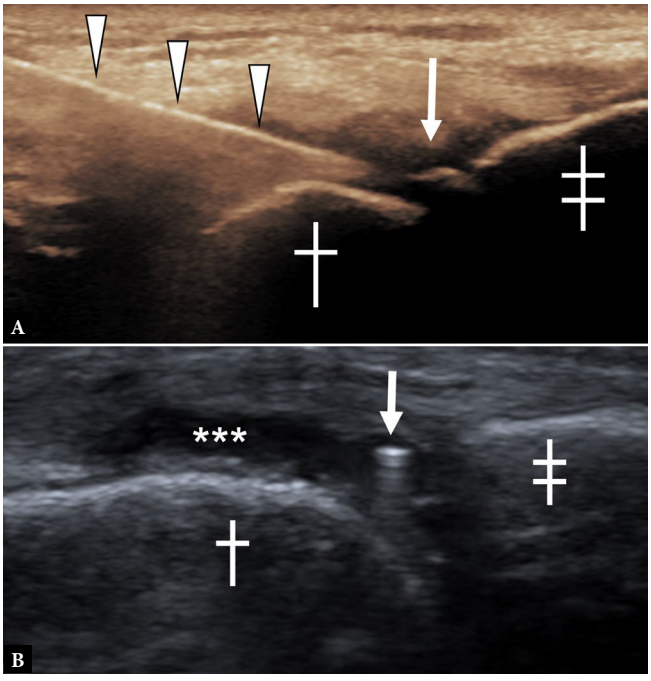

Fig. 2. A. *Ultrasound guidance image depicting the "in-plane" approach of a 25-gauge needle (arrowheads) to the dorsal radiocarpal joint (arrow), which is depicted longitudinally at the level of the lunate (cross) and distal radius (double cross). The entire length of the needle can be seen.* **B.** *Ultrasound guidance image depicting the "out-of-plane" approach of a 25-gauge needle (arrow) within the left fourth metatarsophalangeal joint for a therapeutic intra-articular injection in a patient with rheumatoid arthritis. A native joint effusion is seen (asterisks) at the level of the metatarsal head (cross) and proximal phalanx (double cross)*

In the so-called "long axis" or "in-plane" injection approach, the transducer is orientated such that the needle will be visualized along its length, with the length and tip of the needle kept in view at all times (Fig. 2 A). The so-called "short axis" or "out-of-plane" approach is achieved with the transducer positioned perpendicular to the trajectory of the needle, such that the needle will appear as a single point of reflection in short axis, often with a reverberation artifact deep to it, when it passes below the transducer (Fig. 2 B). While either method is acceptable, the surface anatomy or geometry of the injection site may necessitate favoring one approach over another[19]. Generally, small and narrow superficial joints, such as the interphalangeal joints of the finger or toe, are best accessed by the short axis approach, so the needle can be guided steeply into the center of the joint in contrast to a large, wide and deep joint that lends itself well to the more shallow approach of the long axis or in-plane technique (e.g. the hip or shoulder joints).

Fortuitously, needles are excellent specular reflectors[20,21], making them conspicuous on US images, but the more acute the angle of insonation from the transducer upon the needle, the less signal is detected and rendered on the image. Therefore, the best visualization is afforded by in-plane views, where the sound beam reflects off the needle at a ninety-degree angle (Fig. 3). Heel-toe maneuvering of the transducer or use of sonographic systems with beam steering capabilities may be useful to maximize the reflected signal from the needle. Specialized reflective needles with surface alterations or echogenic tip coatings designed to accentuate the reflection of the needle may be useful but are generally not necessary for most US-guided interventions[20–22].

General pharmacologic considerations

Local anesthesia

Various anesthetic formulations can be utilized in US-guided procedures. The main considerations include rate of onset of action, time to offset of action, and anesthetic volume, concentration, and potency[23]. The most common short-acting anesthetic is lidocaine,

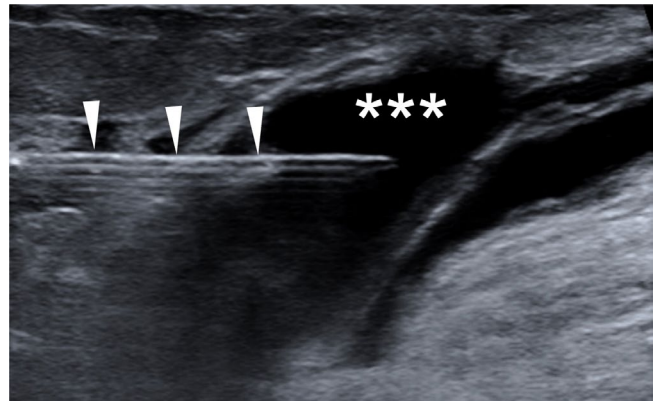

Fig. 3. *Ultrasound guidance image depicting an "in-plane" approach to a Baker's cyst (asterisks) in the popliteal fossa. The needle (arrowheads) is insonated at approximately 90 degrees and is therefore very well visualized with associated reverberation artifact at the deep margin of the needle*

with effective onset in <10 seconds, reaching peak effect by 30–180 seconds. The numbing effect of lidocaine, like other short-acting anesthetics, may only persist for 1–3 hours. Intermediate-term anesthetics, like ropivacaine, and longer-term anesthetics, like bupivacaine, have slower onset and longer lasting effects that vary based on concentration and formulation. Utilizing these differences, the appropriate agent can be selected for a given clinical scenario, and the patient should be informed of the expected offset of action as well[23,24].

Chondrotoxicity, thought to be due to interference of normal chondrocyte metabolism, is a known exposure time- and dose-dependent effect of most local anesthetic agents that may be further potentiated by concomitant corticosteroid administration[25]. Although the significance of in vivo effects in clinical settings is debated, minimal necessary intra-articular doses of local anesthetics should be adhered to. Additionally, ropivacaine in concentrations up to 0.5% has been shown to be the least chondrotoxic of commonly available agents and is therefore preferred over other agents like bupivacaine for intra-articular administration[25,26].

Functional effects of local anesthesia should also be considered. When using long-acting anesthetics, extra care should be taken to avoid unintentional nerve blocks, for example when injecting in a tissue plane near to or containing a neurovascular bundle. If the affected nerve is functionally important for gait (for example the sciatic or femoral nerve), lengthy observation of the patient may be required until resumption of normal neurological function, as the altered gait may present a significant fall risk.

Corticosteroids and steroid selection

Corticosteroids have been utilized for localized pain relief and anti-inflammatory effects in the setting of MSK therapeutic procedures for decades. Although many formulations exist, no single steroid has proven superior for a given indication[27,28]. Nevertheless, individual practice patterns have been shaped by considerations such as steroid solubility, bioavailability, cost, and other institutional factors. Insoluble, particulate steroid suspensions are most commonly used due to their theoretically increased local tissue dwell times, being less soluble in the blood pool and, therefore, subject to slower systemic absorption. Examples of particulate steroids include methylprednisolone, betamethasone, and triamcinolone. Particulate steroids have theoretical drawbacks as well, including a relatively increased risk of local tissue effects (due to prolonged dwell time) and rare potential ischemic effects from the particles or particle complexes, including tissue atrophy and skin depigmentation. US guidance ensures more accurate medication administration, likely minimizing the effects of non-targeted doses that may occur in blind injections. A commonly utilized alternative to particulate steroid suspensions is the soluble formulation, dexamethasone, which has a decreased risk of these potential complications. The main drawback for dexamethasone is its diminished local tissue dwell time, a limiting factor in the potency of its therapeutic benefit[28]. We avoid the combination of dexamethasone and ropivacaine, well known in the literature to form a crystalline precipitate, which may pose an embolic risk and defeat the purpose of selecting a soluble, non-particulate steroid in many situations[29,30].

Hyaluronic acid

Many products deriving from the glycosaminoglycan known as hyaluronic acid have entered the marketplace as injectable agents utilized in many US-guided interventions. The most common application in MSK procedures is intra-articular injection of the knee joint, generally utilizing a high-molecular-weight formulation, of which many are available[6,31]. Other lesser known indications for hyaluronic acid injections have shown benefit in the literature, including therapeutic injections of the thumb carpometacarpal joint[32] and for Achilles and patellar tendinopathies[33,34]. The main desirable effects of hyaluronic acid include its pro-hydration and lubricant properties thought to directly combat the symptom-generating mechanisms of osteoarthritis. A secondary anti-nociceptive effect is thought to derive from the interaction of hyaluronic acid and substance P, which may explain more dramatic symptomatic responses from patients receiving these injections[5,6,31].

Platelet-rich plasma (PRP)

Autologous PRP has been touted as a useful biotherapeutic in countless clinical contexts, with ever-expanding therapeutic uses. PRP is rich in growth factors, released upon platelet activation, that have been shown to be vital in stimulating and propagating tissue regeneration, such as healing of tendinopathy, tendon or ligament tears, and bone healing in the context of chondromalacia and osteoarthritis. In general, the goal in PRP preparation is to maximize platelet concentration in the plasma layer above the physiologic concentration by 3–5 times, ideally around 1,000,000 platelets per microliter of injectate. Refrigerated centrifuges, if available, should be used to maximize platelet concentration; this technique has been shown to double the concentration obtained from autologous blood samples[35]. Many local tissue factors are hypothesized to affect the efficacy of PRP injections. Intratendinous PRP injection is often accompanied by dry needling to promote bleeding and angiogenesis[36]. If avoidable, local anesthetic, such as lidocaine, should not be injected directly at the site of PRP delivery, as it has been shown to decrease platelet aggregation response and theoretically may diminish the growth factor and cytokine release thought to initiate a therapeutic benefit[37]. No consensus exists on the ideal needle caliber for the delivery of PRP, and may be dictated by the volume of PRP injectate and the site of injection. Specifically, thin needle gauge has not been shown to disrupt platelet viability or activity.

Intra-articular injections

US-guided injection or arthrocentesis of both large joints, such as the shoulder (glenohumeral) and hip (femoroacetabular) joints as well as the small joints, such as tarsometatarsal or metatarsophalangeal joints, are commonplace. Although many intra-articular injections are feasible without direct visualization, using surface landmarks or palpation, US offers excellent real-time visualization to ensure accurate positioning of the needle tip in the joint throughout an injection, while minimizing trauma to adjacent structures. Confirmation of target injections and increased confidence of the needle position on the part of the practitioner additionally benefit patient comfort and potentially improve clinical outcomes.

Each joint presents a slightly different scenario for needle approach and patient positioning, which will not be reviewed exhaustively here. But the principles guiding successful sonographic injections in each of these joints are similar and will be discussed here in the context of the glenohumeral joint. We will provide several practical tips for successful US-guided intra-articular injections.

The glenohumeral joint is easily visualized and injected with the assistance of US (Fig. 4, Fig. 5 A). If desired, diagnostic images of the joint, rotator cuff muscles and tendons, and subacromial/subdeltoid bursa can be obtained at the time of US-guided intervention. Findings such as a rotator cuff tear, osteoarthritis, bursitis, and calcific tendinitis, to name a few, may be revelatory regarding the etiology of a patient's symptoms, and may assist in appropriate management of the patient, even informing the type of percutaneous intervention that may be required.

Most commonly, US-guided glenohumeral joint injections are performed with the patient lying in an oblique prone, lateral decubitus position, with the posterior aspect of the targeted shoulder exposed for injection. This so-called "posterior approach" to the glenohumeral joint is safe, with no major nerves or vasculature along the planned needle trajectory[38]. A major advantage of US guidance, over other imaging modalities and blind injections, is the ability to visualize neurovascular structures accurately in real-time. Patients may also prefer the posterior approach, as the practitioner and any instruments are not in the patient's direct sightline during the procedure.

With the transducer footprint placed longitudinally with respect to the glenohumeral joint, the joint will be imaged as depicted (Fig. 5 A). Because the needle trajectory traverses the infraspinatus tendon and posterior joint capsule, visualization can often be improved with further adduction and internal rotation of the ipsilateral arm. We prefer orienting the injection such that the interventionalist faces the console screen to easily view the real-time guidance images as they proceed. To facilitate this, an approach can be planned either from medial to lateral or from lateral to medial (Fig. 4, Fig. 5 B), both of which are reasonable trajectories.

Infiltration of the subcutaneous soft tissues with a thin (for example, 25 gauge) needle is followed by advancement of a longer, lower gauge needle depending on the required depth of the injection. Many joints can be accessed with a single 1.5-inch thin-gauge needle. Care should be taken to anesthetize at the puncture site in the immediate superficial subcutaneous adipose tissue, and deeper anesthesia should also be provided, noting that the joint capsule is richly innervated, so pericapsular anesthesia may significantly improve patient comfort. In the case of glenohumeral joint injections, additional anesthesia instillation within the subacromial/subdeltoid bursa, which is innervated and can be an independent pain generator, may also enhance comfort.

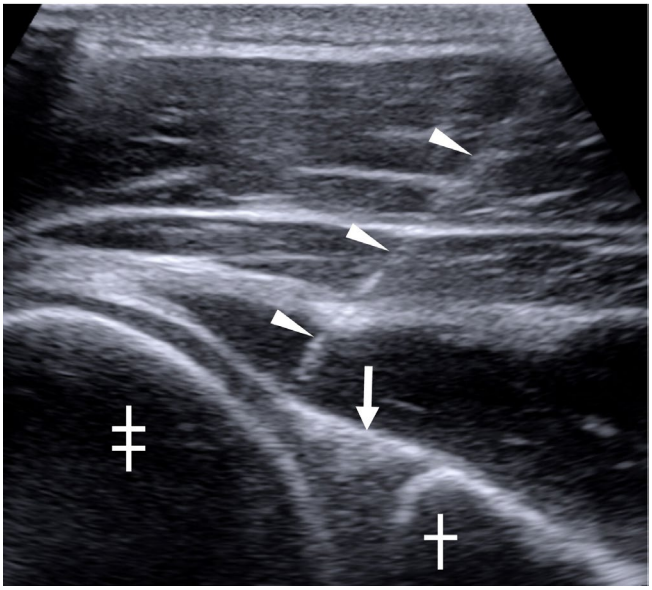

Fig. 4. *Ultrasound guidance image depicting the "in-plane" approach of a 22-gauge spinal needle into the posterior glenohumeral joint. The needle (arrowheads) trajectory in this case passes from medial to lateral, over the glenoid (cross), landing on the humeral head (double cross) at a relatively acute angle, avoiding the glenoid labrum (arrow)*

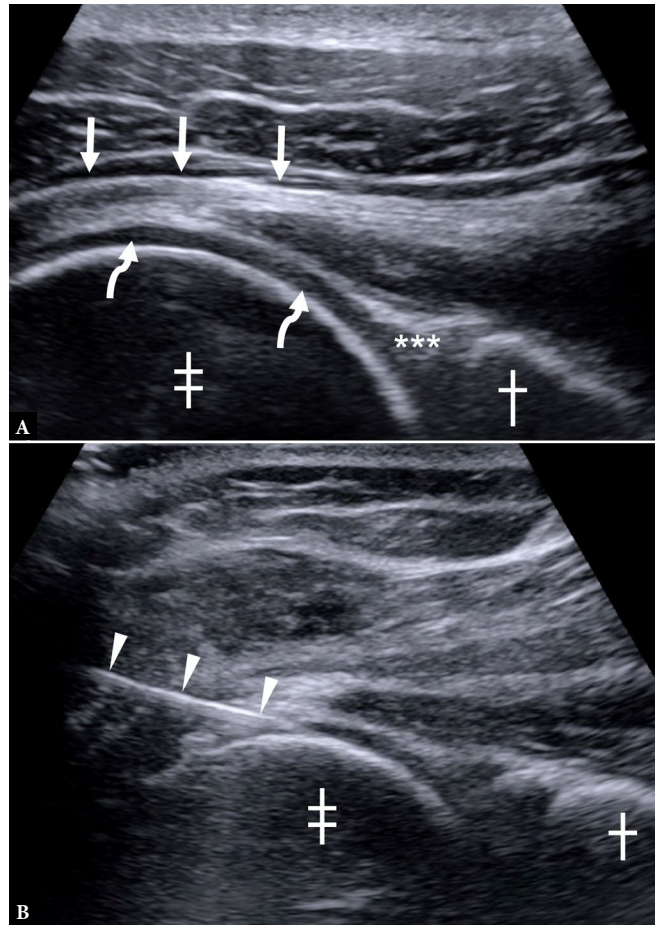

Fig. 5. A. *Longitudinal ultrasound image of the posterior glenohumeral joint demonstrating normal findings of an intact infraspinatus tendon (arrows), articular cartilage (curved arrows) along the posterior humeral head (double cross) at the level of the glenoid (cross) and posterior glenoid labrum (asterisks). These landmarks can be used to identify appropriate trajectory for intra-articular injection, and detect pathology such as bursitis, rotator cuff tear, joint effusion, or synovitis.* **B.** *Ultrasound guidance image depicting the "in-plane" approach of a 22-gauge spinal needle into the posterior glenohumeral joint. The needle (arrowheads) trajectory in this case passes from lateral to medial, over the humeral head (double cross) toward the glenoid (cross), and landing on the humeral head (double cross) at a relatively obtuse angle*

Once the needle reaches an intra-articular location, the desired medication can be administered. Real-time visualization is important to ensure an accurately targeted injection. The particulate nature of many steroid formulations can be used to the practitioner's advantage in that the particles are small reflectors, which may create a "contrast effect" in the joint (Video 1)[39]. In smaller joints, especially using an out-of-plane approach, the "waterfall" appearance may be seen (Video 2), confirming an intra-articular injection. Otherwise, progressive distension of the joint capsule is a reliable sign (Video 3). Although injection of gas bubbles should be avoided in many injections (e.g. intra-articular contrast injections for magnetic resonance arthrograms) occasionally, small gas bubbles accompanying a test injection may either be intentionally or accidentally introduced, collecting anti-dependently, deep to the joint capsule, producing a typical ringdown artifact that can be recognized and confirm adequate subcapsular positioning of the needle tip (Fig. 6 A). Use of color or power Doppler has also been described as a reliable method for imaging the jet of injectate administered deep to the joint capsule (Fig. 6 B and C)[40].

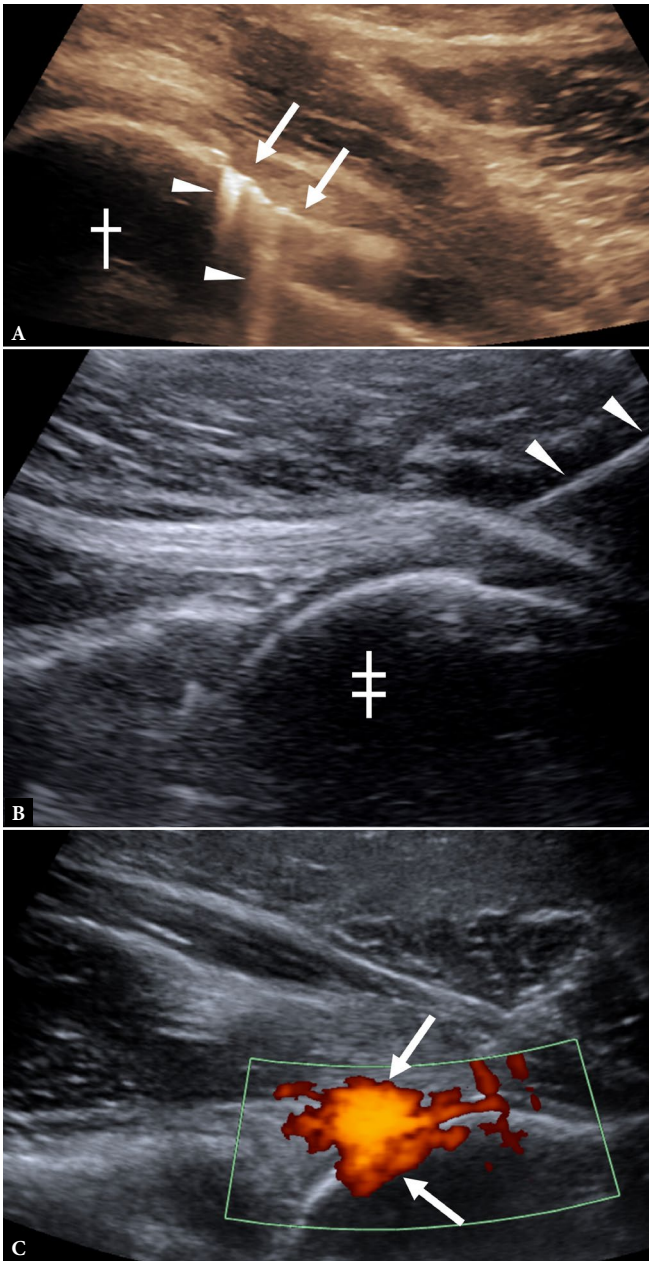

Fig. 6. A. *Ultrasound guidance image of an intra-articular hip injection depicting intra-articular gas indicated by subcapsular, anti-dependent echogenic material (arrows) with typical ringdown artifact (arrowheads) at the level of the femoral head (cross). This finding indicates intra-articular position of the needle tip and injectate, but large volumes of gas may hinder visualization.* **B.** *Ultrasound guidance image depicting the "in-plane" approach of a 22-gauge spinal needle into the posterior glenohumeral joint from lateral to medial, over the humeral head (double cross).* **C.** *Ultrasound guidance image with power Doppler depicting a test injection utilizing the approach shown in Fig 6b, confirming subcapsular, intra-articular positioning of the needle tip (not directly seen) and injectate as the flow jet (arrows) from the test injection is bounded by the joint capsule*

Juxta-articular interventions

Bursal injections are commonly performed juxta-articular interventions to address bursitis, a painful inflammatory condition that can be confused for intra-articular pathology such as arthritis or other structural pathology around the joint. Commonly injected bursae include the subacromial/subdeltoid bursa and the scapulothoracic bursa at the shoulder, and the greater trochanteric and iliopsoas bursae at the hip. Pre-injection sonography of these potential spaces can confirm evidence of bursitis, usually indicated by bursal thickening, fluid distension, proliferative synovium, and hypervascularity (Fig. 7 A). US guidance ensures accurate injection of the bursal space, which can be a very narrow target, difficult to accurately inject blindly[41,42]. Nevertheless, these are safe injections that can be visualized well by US, given the generally superficial location of the bursae. Intra-bursal injection is confirmed by real-time visualization of bursal distension by the injectate (Fig. 7 B, Video 4).

US-guided aspiration of calcium deposits in the context of calcific tendinopathy, bursitis, and periarthritis is known as barbotage[43]. Most commonly occurring along the bursal-sided fibers of the rotator cuff tendons, hydroxyapatite calcium deposits can occur throughout the MSK system, also appearing regularly in the peritrochanteric region of the proximal femur, involving the gluteus minimus/medius tendon insertions, and about the joint capsules of the knee or in the hands and feet (so-called calcific periarthritis). Both single-needle and dual-needle lavage techniques have been described[43–46]. At our institution, we find the single-needle technique suffices in the majority of situations. Barbotage may not be possible when the calcium is small or fragmented; in such cases, needle fenestration and mechanical disruption followed by therapeutic bursal injection may suffice[47,48]. For single-needle barbotage, the deposit can be accessed with an 18–20 gauge needle, utilizing a delicate single pass to avoid rupturing the pericalcific pseudocapsule containing the calcification[49] (Fig. 8). Pulsed lavage with lidocaine and saline disrupts the organized deposit, allowing aspiration of calcium into the lavage syringe, and creating a characteristic "fish-mouth" appearance on dynamic US imaging (Video 5). If intraosseous migration of the calcium has occurred, barbotage will be a less effective therapy[50]. It is essential that barbotage procedures of calcium occurring near or in a bursa (most often the subacromial/subdeltoid or trochanteric bursae) be completed with an intrabursal steroid injection as the final step in the procedure. The injection will offset and alleviate any symptoms associated with

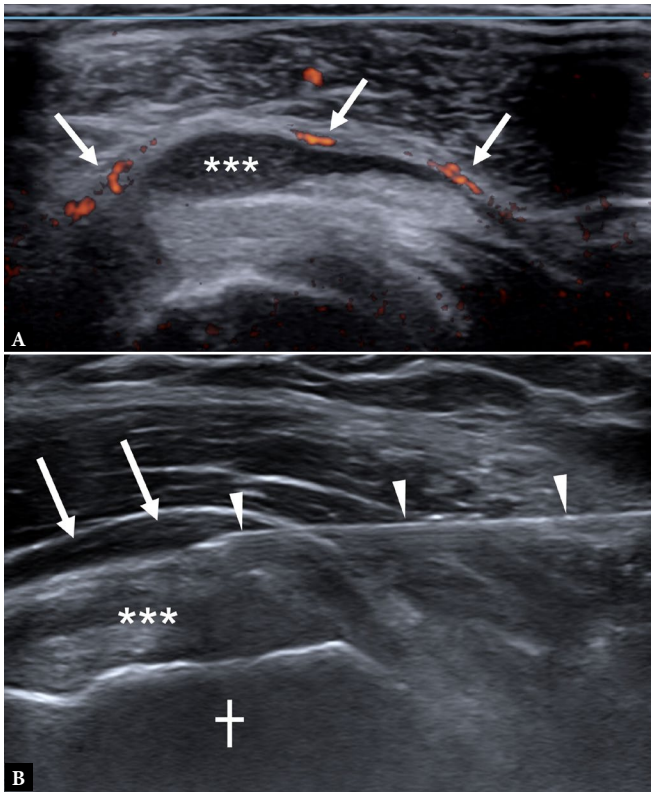

Fig. 7. A. *Pre-injection ultrasound image of the posterosuperior glenohumeral joint in a patient with subacromial/subdeltoid bursitis, represented by complex fluid distension of the bursa (asterisks) and proliferative, hypervascular synovitis (arrows).* **B.** *Ultrasound guidance image demonstrates an in-plane approach of a 25-gauge needle (arrowheads) advanced into the subacromial/subdeltoid bursa (arrows) overlying the infraspinatus tendon (asterisks) at the level of the lesser tuberosity of the humerus (cross)*

reactive chemical bursitis caused by the mobilized calcium during the procedure[43,44].

Ischiofemoral impingement is a commonly encountered cause of buttock and posterior thigh pain that can be difficult to diagnose and for which many treatments exist, although no single therapeutic approach has been shown to be the most effective[51]. US-guided ischiofemoral interval injections are among the non-surgical therapeutic options for patients suffering from buttock pain or sciatica related to this entity. US guidance for injection into this deep subcutaneous space is vital to prevent iatrogenic neurovascular injury or non-target injections. Recognition of the anatomic landmarks on US is vital (Fig. 9 A–C) and will aid in accurately targeting the injection. Potential therapeutic maneuvers include steroid and anesthetic injections into the quadratus femoris muscle or the perisciatic fat[52]. Additionally, ischiofemoral interval prolotherapy or intramuscular botulinum toxin injection of the quadratus femoris or piriformis muscles (Fig. 10 A and B) have been reported with positive, though temporary, therapeutic outcomes[51,53,54].

Tendon dry needling

Ultrasound-guided dry needling (tenotomy) of tendons has been utilized to treat chronic painful tendinopathy and chronic partial tendon tears at various anatomic sites. The technique involves serial

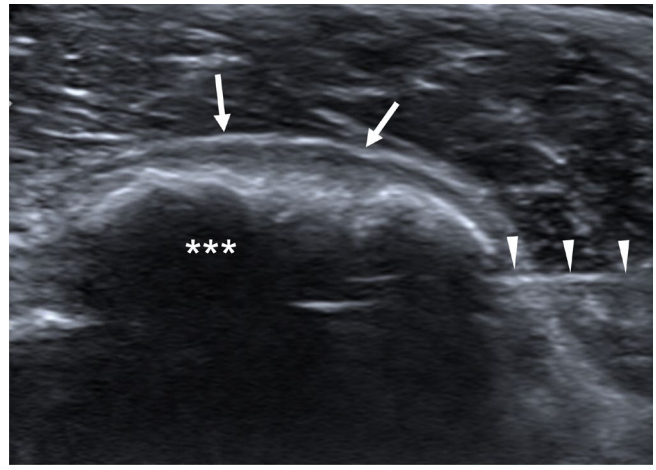

Fig. 8. *Ultrasound guidance image demonstrates an in-plane approach of a 20-gauge needle (arrowheads) advanced into a calcific deposit (asterisks) along the bursal fibers of the supraspinatus tendon. The overlying bursa is displaced (arrows)*

fenestration of the affected tendon with ultrasound guidance. Needle gauges ranging from 22- to 25-gauge have been reported to have good outcomes in the literature, with serial fenestration performed by taking multiple (usually 20 or more) passes through the most abnormal appearing portion of the tendon, orienting the needle parallel to the tendon fibers. Dry needling may be used in isolation to promote local angiogenesis, fibroblastic proliferation, and collagenization within the fenestrated tissue[55–57].

Perineural injections

US affords excellent soft tissue resolution, especially for superficial structures such as peripheral nerves in the extremities. Therefore, the peripheral nerves are optimal targets for US-guided diagnostic and therapeutic maneuvers. Indeed, US has long been an important guidance technique for performing peripheral nerve blocks in many locations throughout the body across a wide variety of clinical specialties[58,59].

The diagnostic utility of US should not be ignored when performing an US-guided perineural injection for diagnostic or interventional purposes. The nerve should be scanned in its entirety to recognize and localize any imaging abnormality of the nerve such as extrinsic compression, overt neuritis, or a mass like a neuroma or peripheral nerve sheath tumor[23,60,61].

To confirm a particular nerve or imaging abnormality of a nerve as a symptom generator, diagnostic perineural injections can be performed utilizing a long-acting local anesthetic agent such as bupivacaine, which will produce a nerve block of the desired nerve distribution. Patients can then record their symptoms and compare them to baseline, revealing the extent of response to the nerve block, often informing the need or utility of subsequent intervention upon the nerve in question.

Neuritis is commonly treated with a combination of steroid and local anesthetic injected in the perineural fat at the site of maximal visual abnormality of the nerve or at the site of presumed nerve compression or irritation[23,60]. When approaching the nerve, care

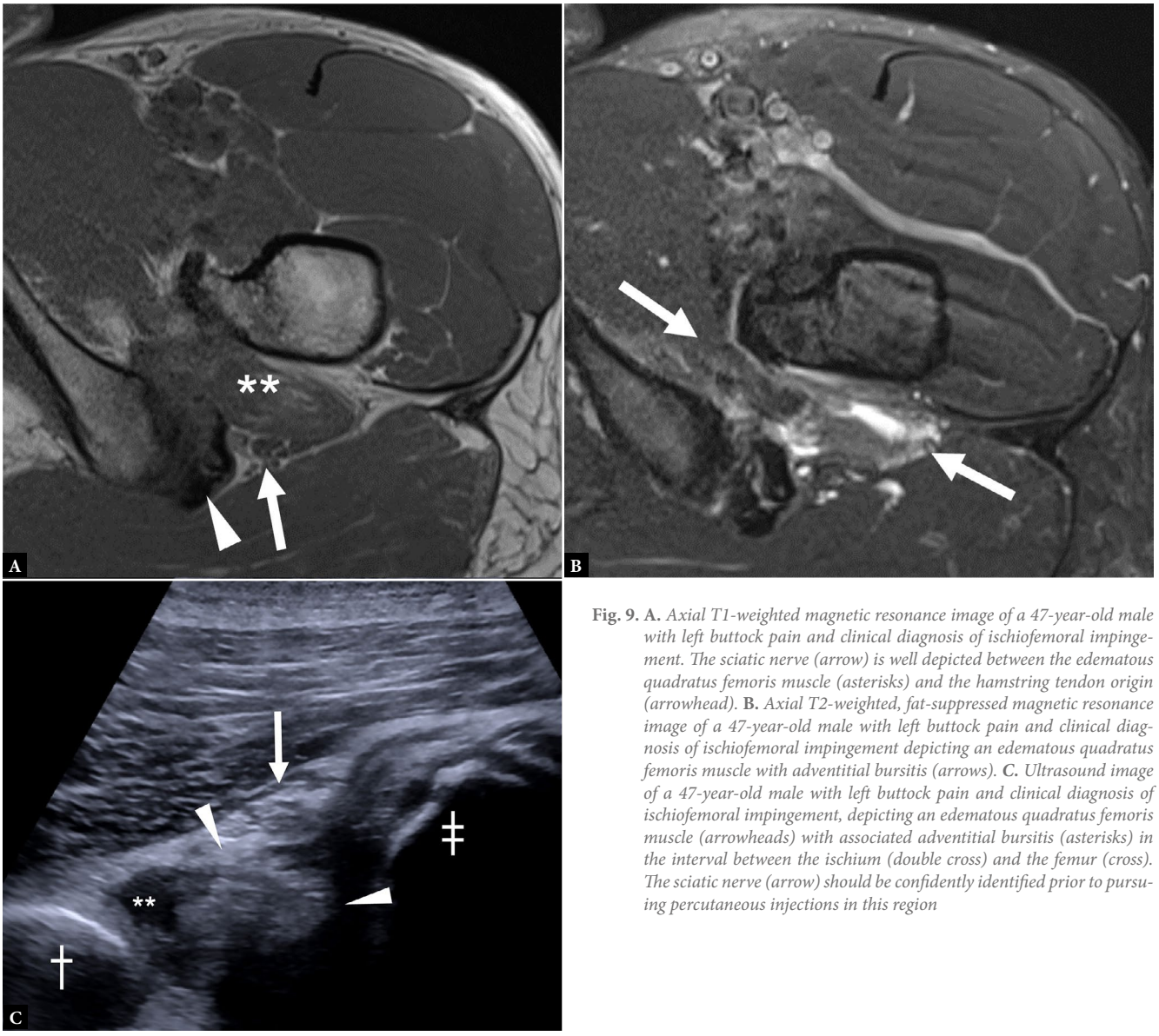

Fig. 9. A. *Axial T1-weighted magnetic resonance image of a 47-year-old male with left buttock pain and clinical diagnosis of ischiofemoral impingement. The sciatic nerve (arrow) is well depicted between the edematous quadratus femoris muscle (asterisks) and the hamstring tendon origin (arrowhead).* **B.** *Axial T2-weighted, fat-suppressed magnetic resonance image of a 47-year-old male with left buttock pain and clinical diagnosis of ischiofemoral impingement depicting an edematous quadratus femoris muscle with adventitial bursitis (arrows).* ***C.*** *Ultrasound image of a 47-year-old male with left buttock pain and clinical diagnosis of ischiofemoral impingement, depicting an edematous quadratus femoris muscle (arrowheads) with associated adventitial bursitis (asterisks) in the interval between the ischium (double cross) and the femur (cross). The sciatic nerve (arrow) should be confidently identified prior to pursuing percutaneous injections in this region*

should be taken to avoid direct injury with the needle or intraneural injection of steroid or anesthetic. In our experience, an in-plane approach with the needle, while visualizing the nerve in short axis, allows optimal visualization of the outer epineurium and nerve fascicles. Following a low-volume test injection with 1% lidocaine to achieve initial hydrodissection of the nerve, perineural spread of the injectate can be visualized in both short and long axis (Video 6 and Video 7, Fig. 11) after which the desired medication(s) can be administered into this potential space. For therapeutic perineural injections, we prefer to use a long-acting anesthetic, such as 0.5% ropivacaine or 0.75% bupivacaine, and a rapidly absorbed corticosteroid, such as betamethasone. The rapid systemic absorption of betamethasone is preferred to avoid long dwell time of the steroid in the local soft tissue, which may impair the healing reaction if a surgical intervention is planned. Hydrodissection with local anesthetic in the setting of nerve impingement or perineural scar entrapment has been described in association with positive clinical outcomes in such clinical scenarios as piriformis syndrome and carpal tunnel syndrome[52,62]. For large-volume perineural injections, for example along the sciatic nerve, we utilize sterile saline or a dilute anesthetic-saline solution to avoid a strong sciatic nerve block.

Hydrodissection

Large-volume hydrodissection of peripheral nerves is frequently utilized to address impingement or entrapment neuropathy related to soft tissue entrapment of a peripheral nerve by a scar or other anatomic features such as muscle or fascia[63]. Release of the nerve by fluid dissection is thought to have both a mechanical consequence in the setting of entrapment and vascular consequences improving perineural venolymphatic flow by increasing potential perineural space. Hydrodissection is best performed utilizing ultrasound guidance for precise, careful placement of injectate about the nerve, ideally allowing circumferential separation of the nerve from surrounding structures. The hydrodissection should be performed at the site of maximal impingement or entrapment, if it is

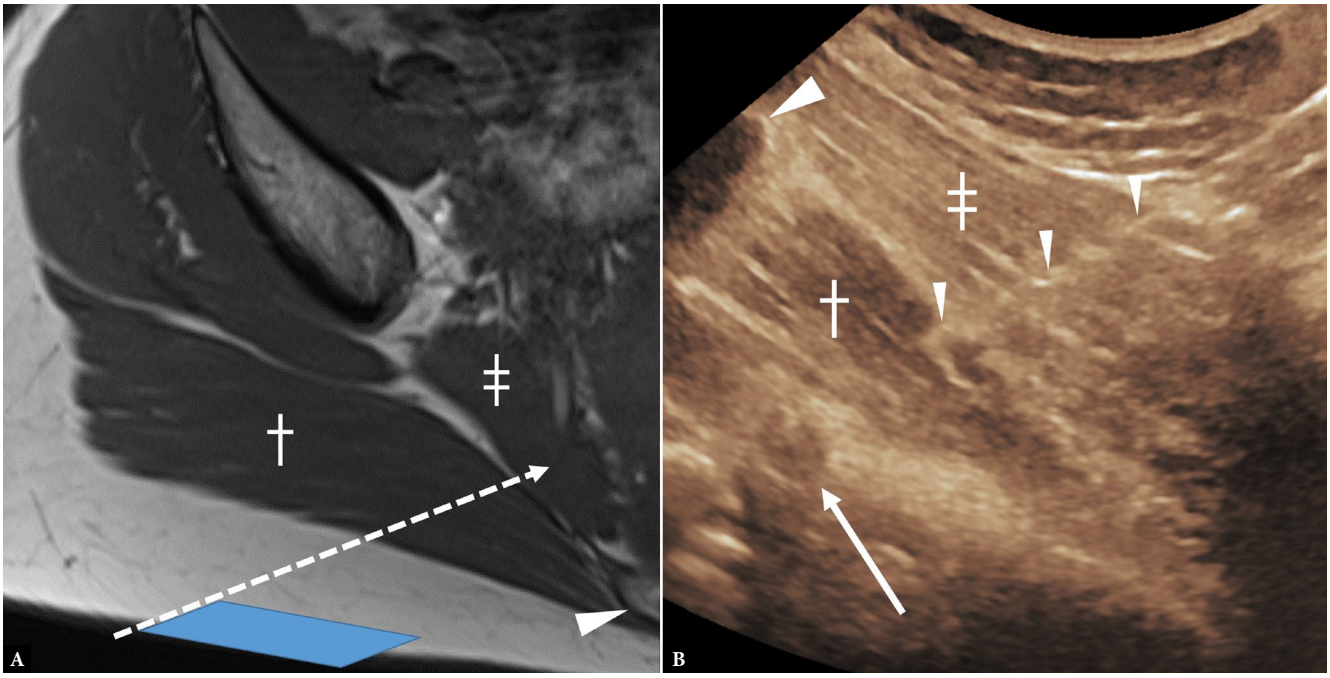

Fig. 10. A. *Axial T1-weighted magnetic resonance image of a 33-year-old female with right buttock pain and clinical diagnosis of piriformis syndrome and muscle spasm, referred for an injection of botulinum toxin. The ultrasound transducer footprint (blue rectangle) and planned injection approach is shown (white arrow) traversing the gluteus maximus muscle (cross) into the piriformis muscle (double cross). The sacrum (arrowhead) is partially imaged and can also be a useful landmark on ultrasound.* **B.** *Ultrasound guidance image of a 33-year-old female with right buttock pain and clinical diagnosis of piriformis syndrome and muscle spasm, referred for an injection of botulinum toxin into the piriformis muscle. The patient is positioned prone. The needle (arrowheads) is seen in in-plane approach, introduced into the piriformis muscle belly (cross), just deep to the gluteus maximus muscle (double cross). The sacrum (arrowhead) provides a useful landmark medially, and the sciatic nerve (arrow) should be identified deep to the piriformis muscle*

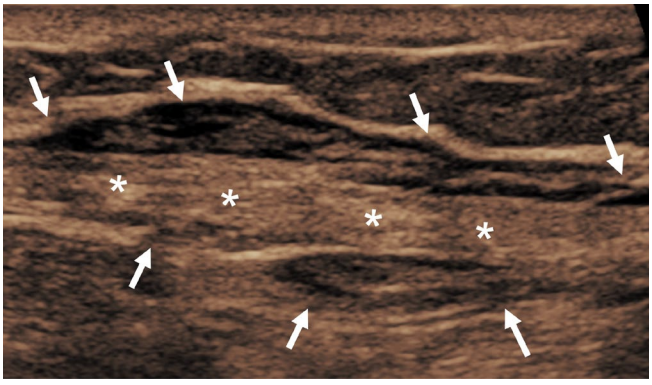

Fig. 11. *Post-injection ultrasound image demonstrating a long segment of longitudinal perineural spread of injectate (arrows) along the common peroneal nerve (asterisks) following hydrodissection and subsequent steroid injection*

visible on ultrasound and percutaneously accessible. A 25-gauge or 27-gauge needle is best suited for small, superficial peripheral nerves, whereas a 22-gauge needle may be necessary for larger and deeper nerves such as the sciatic nerve. Many injectates have been utilized and reported to show benefit, the most popular being a large-volume injection of normal saline or local anesthetic diluted by normal saline. Non-dilute anesthetic such as lidocaine will produce a dense nerve block, which may be undesirable. A water-5% dextrose solution has shown superiority to normal saline alone for median nerve hydrodissection in patients with carpal tunnel syndrome[64].

These minimally invasive procedures can be useful alternatives to potentially morbid surgical interventions, or at least serve to confirm a nerve or specific site along the nerve as the symptom generator to be addressed by subsequent definitive therapy[52,23].

Conclusion

This review intends to provide tips and tricks to a variety of US-guided interventions that can be applied throughout the MSK system. With myriad indications, US-guided MSK procedures provide a safe, accurate, and comfortable procedural approach for many intra-articular, periarticular, and perineural interventions.

Conflict of interest

The authors do not have any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: WRW, CJB, RSA. Writing of manuscript: WRW, CJB, RSA. Analysis and interpretation of data: WRW, CJB, RSA. Final approval of manuscript: WRW, CJB, RSA. Collection, recording and/or compilation of data: WRW, CJB, RSA. Critical review of manuscript: WRW, CJB, RSA.

References

1. Roll SC, Asai C, Tsai J: Clinical utilization of musculoskeletal sonography involving non-physician rehabilitation providers: a scoping review. Eur J Phys Rehabil Med 2016; 52: 253–262.
2. Kara M, Gürçay E, Ekiz T, Sekizkardeş M, Yorulmaz E, Ata AM *et al.*: EURO-MUSCULUS/USPRM global report on musculoskeletal ultrasound publications. Am J Phys Med Rehabil 2020; 99: 847–852. https://doi.org/10.1097/phm.0000000000001390.
3. Kumar Sahu A, Rath P, Aggarwal B: Ultrasound-guided injections in musculoskeletal system – an overview. J Clin Orthop Trauma 2019; 10: 669–673. https://doi.org/10.1016/j.jcot.2019.05.013.
4. Sirisena D: Injections. In: Sirisena D (ed.): Ultrasound Guided Musculoskeletal Procedures in Sports Medicine. Academic Press, 2021: 7–8.
5. Sirisena D: Indications and contraindications for injections. In: Sirisena D (ed.): Ultrasound Guided Musculoskeletal Procedures in Sports Medicine. Academic Press, 2021: 9–11.
6. Robotti G, Canepa MG, Bortolotto C, Draghi F: Interventional musculoskeletal US: an update on materials and methods. J Ultrasound 2013; 16: 45–55. https://doi.org/10.1007/s40477-013-0018-9.
7. Draghi F, Robotti G, Jacob D, Bianchi S: Interventional musculoskeletal ultrasonography: precautions and contraindications. J Ultrasound 2010; 13: 126–133. https://doi.org/10.1016/j.jus.2010.09.004.
8. Deng X, Zhu S, Li D, Luo Y, Zhang X, Tan Y *et al.*: Effectiveness of ultrasound-guided versus anatomic landmark–guided corticosteroid injection on pain, physical function, and safety in patients with subacromial impingement syndrome: a systematic review and meta-analysis. Am J Phys Med Rehabil 2022; 101: 1087–1098. https://doi.org/10.1097/phm.0000000000001940.
9. Kompel AJ, Roemer FW, Murakami AM, Diaz LE, Crema MD, Guermazi A: Intra-articular corticosteroid injections in the hip and knee: perhaps not as safe as we thought?. Radiology 2019; 293: 656–663. https://doi.org/10.1148/radiol.2019190341.
10. Kijowski R: Risks and benefits of intra-articular corticosteroid injection for treatment of osteoarthritis: what radiologists and patients need to know. Radiology 2019; 293: 3664–3665. https://doi.org/10.1148/radiol.2019192034.
11. Jevsevar DS, Brown GA, Jones DL, Matzkin EG, Manner PA, Mooar P, Schousboe JT *et al.*: The American Academy of Orthopaedic Surgeons evidence-based guideline on: treatment of osteoarthritis of the knee, 2nd edition. J Bone Joint Surg Am 2013; 95: 1885–1886. https://doi.org/10.2106/00004623-201310160-00010.
12. Yang X, Li L, Ren X, Nie L: Do preoperative intra-articular injections of corticosteroids or hyaluronic acid increase the risk of infection after total knee arthroplasty? A meta-analysis. Bone Joint Res 2022; 11: 171–179. https://doi.org/10.1302/2046-3758.113.bjr-2021-0350.R1.
13. Pace CS, Blanchet NP, Isaacs JE: Soft tissue atrophy related to corticosteroid injection: review of the literature and implications for hand surgeons. J Hand Surg Am 2018; 43: 558–563. https://doi.org/10.1016/j.jhsa.2018.03.004.
14. Shi J, Mandell JC, Burke JC, Adler RS, Beltran LS: Review of interventional musculoskeletal US techniques. Radiographics 2020; 40: 1684–1685. https://doi.org/10.1148/rg.2020200036.
15. Fang WH, Chen XT, Vangsness CT Jr: Ultrasound-guided knee injections are more accurate than blind injections: a systematic review of randomized controlled trials. Arthrosc Sports Med Rehabil 2021; 3: e1177–e1187. https://doi.org/10.1016/j.asmr.2021.01.028.
16. Di Filippo A, Falsini S, Adembri C: Minimum anesthetic volume in regional anesthesia by using ultrasound-guidance. Braz J Anesthesiol 2016; 66: 499–504. https://doi.org/10.1016/j.bjane.2014.05.002.
17. Hynes JP, Kavanagh EC: Complications in image-guided musculoskeletal injections. Skeletal Radiol 2022; 51: 2097–2104. https://doi.org/10.1007/s00256-022-04076-8.
18. Gorelik N, Darwish Y, Walter WR, Burke CJ, Sarpel D, Chong J *et al.*: Incidence of infectious complications following ultrasound-guided percutaneous musculoskeletal interventions with the use of an uncovered transducer footprint. Eur Radiol 2022; 32: 6759–6768. https://doi.org/10.1007/s00330-022-08849-6.
19. Patel RP, McGill K, Motamedi D, Morgan T: Ultrasound-guided interventions of the upper extremity joints. Skeletal Radiol 2023; 52: 897–909. https://doi.org/10.1007/s00256-022-04148-9.
20. Malamal G, Panicker MR: On the physics of ultrasound transmission for in-plane needle tracking in guided interventions. Biomed Phys Eng Express 2023; 9. https://doi.org/10.1088/2057-1976/acc338.
21. Scholten HJ, Pourtaherian A, Mihajlovic N, Korsten HHM, A Bouwman R: Improving needle tip identification during ultrasound-guided procedures in anaesthetic practice. Anaesthesia 2017; 72: 889–904. https://doi.org/10.1111/anae.13921.
22. van de Berg NJ, Sánchez-Margallo JA, van Dijke AP, Langø T, van den Dobbelsteen JJ: A methodical quantification of needle visibility and echogenicity in ultrasound images. Ultrasound Med Biol 2019; 45: 998–1009. https://doi.org/10.1016/j.ultrasmedbio.2018.10.004.
23. Walter WR, Burke CJ, Adler RS: Ultrasound-guided therapeutic injections for neural pathology about the foot and ankle: a 4 year retrospective review. Skeletal Radiol 2017; 46: 795–803. https://doi.org/10.1007/s00256-017-2624-7.
24. Caballero M, Kobayashi Y, Gottschalk AW: Local anesthetic use in musculoskeletal injections. Ochsner J 2022; 22: 200–203. https://doi.org/10.31486/toj.22.0061.
25. Jayaram P, Kennedy DJ, Yeh P, Dragoo J: chondrotoxic effects of local anesthetics on human knee articular cartilage: a systematic review. PM R 2019; 11: 379–400. https://doi.org/10.1002/pmrj.12007.
26. Kreuz PC, Steinwachs M, Angele P: Single-dose local anesthetics exhibit a type-, dose-, and time-dependent chondrotoxic effect on chondrocytes and cartilage: a systematic review of the current literature. Knee Surg Sports Traumatol Arthrosc 2018; 26: 819–830. https://doi.org/10.1007/s00167-017-4470-5.
27. Bellamy N, Campbell J, Robinson V, Gee T, Bourne R, Wells G: Intraarticular corticosteroid for treatment of osteoarthritis of the knee. Cochrane Database Syst Rev 2006; 19: CD005328. https://doi.org/10.1002/14651858.cd005328.pub2.
28. Shah A, Mak D, Davies AM, James SL, Botchu R: musculoskeletal corticosteroid administration: current concepts. Can Assoc Radiol J 2019; 70: 29–36. https://doi.org/10.1016/j.carj.2018.11.002.
29. Watkins TW, Dupre S, Coucher JR: Ropivacaine and dexamethasone: a potentially dangerous combination for therapeutic pain injections. J Med Imaging Radiat Oncol 2015; 59: 571–577. https://doi.org/10.1111/1754-9485.12333.
30. MacMahon PJ, Huang AJ, Palmer WE: Spine injectables: what is the safest cocktail?. AJR Am J Roentgenol 2016; 207: 526–533. https://doi.org/10.2214/ajr.16.16379.
31. Tagliafico A, Serafini G, Sconfienza LM, Lacelli F, Perrone N, Succio G *et al.*: Ultrasound-guided viscosupplementation of subacromial space in elderly patients with cuff tear arthropathy using a high weight hyaluronic acid: prospective open-label nonrandomized trial. Eur Radiol 2011; 21: 182–187. https://doi.org/10.1007/s00330-010-1894-4.
32. Monfort J, Rotés-Sala D, Segalés N, Montañes FJ, Orellana C, Llorente-Onaindia J *et al.*: Comparative efficacy of intra-articular hyaluronic acid and corticoid injections in osteoarthritis of the first carpometacarpal joint: results of a 6-month single-masked randomized study. Joint Bone Spine 2015; 82: 116–121. https://doi.org/10.1016/j.jbspin.2014.08.008.
33. Frizziero A, Vittadini F, Bigliardi D, Costantino C: Low molecular weight hyaluronic acid (500–730 kDa) injections in tendinopathies-a narrative review. J Funct Morphol Kinesiol 2021; 7: 3. https://doi.org/10.3390/jfmk7010003.
34. Fogli M, Giordan N, Mazzoni G: Efficacy and safety of hyaluronic acid (500–730kDa) Ultrasound-guided injections on painful tendinopathies: a prospective, open label, clinical study. Muscles Ligaments Tendons J 2017; 7: 388–395. https://doi.org/10.11138/mltj/2017.7.2.388.
35. Amable PR, Carias RB, Teixeira MV, da Cruz Pacheco I, Correa do Amaral RJ, Granjeiro JM *et al.*: Platelet-rich plasma preparation for regenerative medicine: optimization and quantification of cytokines and growth factors. Stem Cell Res Ther 2013; 4: 67. https://doi.org/10.1186/scrt218.
36. Lee JJ, Harrison JR, Boachie-Adjei K, Vargas E, Moley PJ: platelet-rich plasma injections with needle tenotomy for gluteus medius tendinopathy: a registry study with prospective follow-up. Orthop J Sports Med 2016; 4: 2325967116671692. https://doi.org/10.1177/2325967116671692.
37. Bausset O, Magalon J, Giraudo L, Louis ML, Serratrice N, Frere C *et al.*: Impact of local anaesthetics and needle calibres used for painless PRP injections on platelet functionality. Muscles Ligaments Tendons J 2014; 4: 18–23.
38. Messina C, Banfi G, Orlandi D, Lacelli F, Serafini G, Mauri G *et al.*: Ultrasound-guided interventional procedures around the shoulder. Br J Radiol 2016; 89: 20150372. https://doi.org/10.1259/bjr.20150372.
39. Luchs JS, Sofka CM, Adler RS: Sonographic contrast effect of combined steroid and anesthetic injections: in vitro analysis. J Ultrasound Med 2007; 26: 227–231. https://doi.org/10.7863/jum.2007.26.2.227.
40. Bhakta P, Harmon D, Mishra S: Feasibility of colour doppler ultrasound for detection of intraarticular sacroiliac joint injection: a case series. Ulster Med J 2020; 89: 42–43.
41. Wu T, Song HX, Dong Y, Li JH: Ultrasound-guided versus blind subacromial-subdeltoid bursa injection in adults with shoulder pain: a systematic review and meta-analysis. Semin Arthritis Rheum 2015; 45: 374–378. https://doi.org/10.1016/j.semarthrit.2015.05.011.

42. Kumar P, Bains T, Shejale N, Kaur V: Image-guided versus blind corticosteroid injections in adults with shoulder pain: a systematic review and meta-analysis. Cureus 2021; 13: e17032. https://doi.org/10.7759/cureus.17032.
43. Chianca V, Pietto FD, Albano D, Corvino A, Del Grande F: Ultrasound-guided percutaneous irrigation of rotator cuff calcific tendinosis. What radiologist should know. Pol J Radiol 2022; 87: e87–e92. https://doi.org/10.5114/pjr.2022.113491.
44. Kim MS, Kim IW, Lee S, Shin SJ: Diagnosis and treatment of calcific tendinitis of the shoulder. Clin Shoulder Elb 2020; 23: 210–216. https://doi.org/10.5397/cise.2020.00318.
45. Gatt DL, Charalambous CP: Ultrasound-guided barbotage for calcific tendonitis of the shoulder: a systematic review including 908 patients. Arthroscopy 2014; 30: 1166–1172. https://doi.org/10.1016/j.arthro.2014.03.013.
46. Sconfienza LM, Viganò S, Martini C, Aliprandi A, Randelli P, Serafini G *et al.*: Double-needle ultrasound-guided percutaneous treatment of rotator cuff calcific tendinitis: tips & tricks. Skeletal Radiol 2013; 42: 19–24. https://doi.org/10.1007/s00256-012-1462-x.
47. Alna R, Cardinal E, Bureau NJ, Aubin B, Brassard P: Calcific shoulder tendinitis: treatment with modified US-guided fine-needle technique. Radiology 2001; 221: 455–461. https://doi.org/10.1148/radiol.2212000830.
48. Vignesh KN, McDowall A, Simunovic N, Bhandari M, Choudur HN: Efficacy of ultrasound-guided percutaneous needle treatment of calcific tendinitis. AJR Am J Roentgenol 2015; 204: 148–152. https://doi.org/10.2214/ajr.13.11935.
49. Lin JT, Adler RS, Bracilovic A, Cooper G, Sofka C, Lutz GE: Clinical outcomes of ultrasound-guided aspiration and lavage in calcific tendinosis of the shoulder. HSS J 2007; 3: 99–105. https://doi.org/10.1007/s11420-006-9037-9.
50. Kalaycı CB, Kızılkaya E: Calcific tendinitis: intramuscular and intraosseous migration. Diagn Interv Radiol 2019; 25: 480–484. https://doi.org/10.5152/dir.2019.18593.
51. Nakano N, Shoman H, Khanduja V: Treatment strategies for ischiofemoral impingement: a systematic review. Knee Surg Sports Traumatol Arthrosc 2020; 28: 2772–2787. https://doi.org/10.1007/s00167-018-5251-5.
52. Burke CJ, Walter WR, Adler RS: Targeted ultrasound-guided perineural hydrodissection of the sciatic nerve for the treatment of piriformis syndrome. Ultrasound Q 2019; 35: 125–129. https://doi.org/10.1097/ruq.0000000000000360.
53. Kim DH, Yoon DM, Yoon KB: Ultrasound-guided quadratus femoris muscle injection in patients with lower buttock pain: novel ultrasound-guided approach and clinical effectiveness. Pain Physician 2016; 19: E863–E870.
54. Chen YT and Jenkins KM: ultrasound finding of ischiofemoral impingement syndrome and novel treatment with botulinum toxin chemodenervation: a case report. PM R 2018; 10: 665–670. https://doi.org/10.1016/j.pmrj.2017.11.010.
55. Chiavaras MM, Jacobson JA. Ultrasound-guided tendon fenestration. Semin Musculoskelet Radiol 2013; 17: 85–90. https://doi.org/10.1055/s-0033-1333942.
56. Burke CJ, Adler RS: Ultrasound-guided percutaneous tendon treatments. AJR Am J Roentgenol 2016; 207: 495–506. https://doi.org/10.2214/ajr.16.16089.
57. Sharif F, Ahmad A, Gilani SA, Bacha R, Hanif A, Arif MA: Efficacy of ultrasound guided dry needling as an adjunct to conventional physical therapy for patients with jumper's knee: A randomized controlled trial. Front Surg 2022; 4: 1023902. https://doi.org/10.3389/fsurg.2022.1023902.
58. Exsteen OW, Svendsen CN, Rothe C, Lange KHW, Lundstrøm LH: Ultrasound-guided peripheral nerve blocks for preoperative pain management in hip fractures: a systematic review. BMC Anesthesiol 2022; 22: 192. https://doi.org/10.1186/s12871-022-01720-7.
59. Amini R, Kartchner JZ, Nagdev A, Adhikari S: ultrasound-guided nerve blocks in emergency medicine practice. J Ultrasound Med 2016; 35: 731–736. https://doi.org/10.7863/ultra.15.05095.
60. Walsh PJ, Walter WR, Burke CJ, Adler RS, Beltran LS: percutaneous ultrasound-guided intervention for upper extremity neural and perineural abnormalities: a retrospective review of 242 cases. AJR Am J Roentgenol 2019; 212: W73–W82. https://doi.org/10.2214/ajr.18.20047.
61. Burke CJ, Walter WR, Adler RS: interventional imaging techniques as alternative to surgery of the foot and ankle. Semin Musculoskelet Radiol 2022; 26: 744–754. https://doi.org/10.1055/s-0042-1760120.
62. Mathieu T, Lemmens E, Stassijns G: A safe and easy-to-use ultrasound-guided hydrodissection technique for the carpal tunnel syndrome: a minimally invasive approach. J Ultrasound 2022; 25: 451–455. https://doi.org/10.1007/s40477-021-00597-5.
63. Lam KHS, Hung CY, Chiang YP, Onishi K, Su DCJ, Clark TB *et al.*: ultrasound-guided nerve hydrodissection for pain management: rationale, methods, current literature, and theoretical mechanisms. J Pain Res 2020; 4: 1957–1968. https://doi.org/10.2147/jpr.s247208.
64. Wu YT, Ho TY, Chou YC, Ke MJ, Li TY, Tsai CK *et al.*: Six-month efficacy of perineural dextrose for carpal tunnel syndrome: a prospective, randomized, double-blind, controlled trial. Mayo Clin Proc 2017; 92: 1179–1189. https://doi.org/10.1016/j.mayocp.2017.05.025.