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Ultrasound practice for chronic pain procedures: A comprehensive review

Alan David Kaye, Professor, Program Director & Chairman [a],
Mark W. Motejunas, Senior Resident [a],
Lauren A. Bonneval, Medical Student and Research Associate [a],
Ken P. Ehrhardt, Senior Resident [a],
Dustin R. Latimer, Medical Student and Research Associate [b],
Andrea Trescot, Physician [c],
Kyle E. Wilson, Medical Student and Research Associate [a],
Ibraham N. Ibrahim, Medical Student and Research Associate [b],
Elyse M. Cornett, Assistant Professor [b, *],
Richard D. Urman, Associate Professor [d],
Kenneth D. Candido, Professor and Chairman [e]

[a] *Department of Anesthesiology, LSU Health Sciences Center, Room 656, 1542 Tulane Ave., New Orleans, LA, 70112, USA*
[b] *Department of Anesthesiology, LSU Health Shreveport, 1501 Kings Highway, Shreveport, LA, 71103, USA*
[c] *Pain and Headache Center, Eagle River, AK, USA*
[d] *Department of Anesthesiology, Perioperative and Pain Medicine, Harvard Medical School, Brigham and Women's Hospital, 75 Francis St, Boston, MA, 02115, USA*
[e] *Department of Anesthesiology, Advocate Illinois Masonic Medical Center, Chicago, IL, USA*

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Chronic pain management techniques have evolved in recent years. With regard to this, ultrasound (US) technology has become a standard for most acute pain procedures and essential for post-surgical pain relief and enhanced recovery after surgery protocols. This manuscript summarizes clinical studies evaluating US use for chronic pain management and compares efficacy with standard techniques including fluoroscopy (FL). US possesses several unique benefits when compared with FL, including elimination of

* Corresponding author.
E-mail addresses: akaye@lsuhsc.edu (A.D. Kaye), mmotej@lsuhsc.edu (M.W. Motejunas), lbonn4@lsuhsc.edu (L.A. Bonneval), kehrh2@lsuhsc.edu (K.P. Ehrhardt), dlatim@lsuhsc.edu (D.R. Latimer), drtrescot@gmail.com (A. Trescot), kwil50@lsuhsc.edu (K.E. Wilson), iibra1@lsuhsc.edu (I.N. Ibrahim), ecorne@lsuhsc.edu (E.M. Cornett), rurman@bwh.harvard.edu (R.D. Urman), kdcandido@yahoo.com (K.D. Candido).

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radiation exposure while providing similar clinical outcomes. In summary, US use for chronic pain procedures is emerging as a viable, safe, and effective modality. Additional studies are needed to best appreciate US and its role in chronic pain management.

Introduction

Ultrasound (US) technology is used throughout medicine to visualize human anatomy ranging from superficial vascular structures to neonatal cardiac malformations. The advent of the technology not only gives medical providers detailed images of muscle, nerve, and vasculature but also has the distinct advantage of providing these views in real-time imaging. Contrary to prior landmark-based techniques used for interventional pain management procedures, which had providers attempting to access a certain space in the body based on expected anatomy, US allows physicians to visualize their target site, assess and follow an advancing needle tip, and reconcile surrounding structures. As data continue to accrue, which demonstrates the superior safety profile of US guidance compared to conventional modalities, an increasing number of physicians are opting US in anesthesia with hopes of increasing both the safety and the quality of procedural performance [1].

As early as 1970, the utilization of US technology in the field of anesthesia was seen to be an effective method for guiding nerve blocks as demonstrated by LeGrange and colleagues, but it was not until recent years that US guidance became a mainstay in chronic pain procedures [2]. US guidance in the management of acute pain and perioperative medicine has become widely accepted and is becoming a standard of care, as multiple studies have shown an increase in safety, success, and productivity when compared to anatomic landmark-based techniques [3]. Randomized controlled trials have typically shown that US guidance for peripheral nerve blocks results in faster and more accurate procedures with fewer needle passes and less discomfort than traditional anatomic landmark-based procedures [1]. In obstetric epidural studies, US guidance for needle placement significantly reduced the number of puncture attempts and puncture sites while also having significantly decreased pain scores in the US-guided epidural population [4]. Similarly, the ability to more accurately determine the proximity of a nerve block or regional anesthetic allows for use of the minimal effective dose of the anesthetic, which, in turn, reduces the incidence of systemic local anesthetic toxicity [5].

Historically, US guidance for chronic pain procedures has been comparatively underutilized. The reason for this lag compared to its use in regional anesthesia and acute pain is likely multifactorial, but the fact that most of the chronic pain involves articular bony surfaces may play a large role, as US demonstrates poor penetrance of these types of dense tissues. Nonetheless, as the quality of imaging produced by superior technology of the newer model machines themselves continues to improve combined with the fact that the patient suffers no radiation exposure with their use, US machines have become increasingly ubiquitous throughout chronic pain practices [3]. This chapter examines various procedures in the chronic pain field wherein the technology is currently applied to and investigates whether these benefits described in other fields of medicine demonstrate similar trends for chronic pain patients.

Ultrasound technology

To properly understand the strengths and weaknesses of US use for procedural purposes, it is important to first understand the basic physics principles of the technology itself. The next section discusses the US wave formation, importance of beam frequency, and, finally, interpretation of imaging results.

Piezoelectric crystals

Piezoelectric crystals are the most important part of the US machinery, and without these crystals, the images would not be visible. The piezoelectric crystals have a unique ability that allows them to induce mechanical vibrations fast enough to produce high-frequency sound pressure waves when an US probe applies an electric current to the piezoelectric crystals [6]. Most importantly, the piezoelectric crystals also can work in a reverse manner. When an US pressure wave reflects back off the identified object, the piezoelectric crystals are able to absorb the pressure and produce an electrical signal [6]. This trait of the piezoelectric crystals allows the US machine to detect the location of bones, organs, neural structures, and vasculature, and much more components beneath the skin that are not visible. Based on the degree of reflection, a grayscale image is produced. To generate these images, the piezoelectric crystals do not produce any radiation, affording medical personnel and the patient a safe environment [6].

Beam frequency

To visualize the images produced from the crystals, the frequency that the device emits through the probe must be modulated. The frequency of the US is the amount of times the waves are produced per second [7]. The US machine uses frequencies ranging between 2 and 15 MHz [7]. To put that into perspective, the human ear can typically detect sounds up to 20 KHz [7]. Modulating the frequency is how the operator is able to fine-tune the resolution and determine the depth of penetration of the US waves [7]. To achieve the highest resolution, the depth of penetration will be decreased by setting the US machine to a higher frequency [7]. The converse is true when the US machine is set to a low frequency. Low frequency allows the operator to visualize much deeper structures; however, this increased visualization comes at the cost of resolution quality [7].

Types of probes

Linear probes (see Fig. 1) are typically used to identify superficial structures such as muscles and superficially situated neural targets such as the roots and trunks of the brachial plexus, which may be found at depths of less than 3–5 cm below the skin surface [7]. These probes are set to a high frequency to obtain the highest resolution [7]. Related to the high frequency, these probes will have a lack of penetrance and be limited to viewing superficial structures [7].

Fig. 1. A linear transducer.

Curvilinear probes (see Fig. 2) are used when the medical professional needs to view a broader area or deeper situated target, such as the sciatic nerve deep in the buttocks or posterior thigh. The curvilinear probe has a convex-shaped head. This convex head emits a much wider beam with lower frequency than the straight probe; hence, this will allow for a broader and deeper view into the body [8]. The curvilinear probe also provides the ability to roll the probe to varying angles along the surface of the skin without losing the US image, a capability that the straight probe lacks [8].

The phase array probes can be extremely useful when needing to view regions around bones, such as ribs. This probe produces a pie-shaped image with the same frequency as that of the curvilinear probe; however, US waves are produced from a precise focal origin at the head of the probe and become broader as it advances [7]. For example, the phase array probe is capable of providing a view precisely between ribs to achieve an excellent broad view of the heart compared to the curvilinear probe whose scanning beam would be blocked from the ribs.

Hypoechoic, anechoic, and hyperechoic structures

The three major terms used to categorize the echogenicity of structures observed are hypoechoic, anechoic, and hyperechoic. The term hypoechoic refers to structures that are observed as whiter on a gray background on the US screen. The reason these structures are whiter is due to the US waves not being able to penetrate the structure as well as others [8]. The classic hyperechoic structure is bone. When the US waves reflect off the bone, the lack of penetration will cause a white image to be seen as well as casting a hypoechoic black shadow behind the end of the bone [8]. The term hypoechoic refers to structures being observed as gray on the US screen, and the reason structures are seen as hypoechoic is due to the ability of US waves to penetrate the structure compared to hyperechoic structures where the large majority of the sound waves are reflected back to the US probe [8]. Cartilage and muscle are examples of hypoechoic structures that are observed to be more grayish on the screen. The last term is anechoic, which refers to structures that appear black on the US screen. The internal lumen of blood vessels is an example of anechoic structures. This is because fluid does not cause a reflection of the US wave as it passes through. Blood vessels are a very important structure to identify for most US-guided

Fig. 2. A curvilinear transducer.

interventional procedures. One of the reasons is that virtually all major neural structures are anatomically linked to feeding arterial structures, and hence, identifying such vascular targets is a key toward enhancing success with nerve blocks while minimizing vascular trespass. A key way to demonstrate the difference between arteries and veins is by simply pressing on them, as veins will collapse due to the absence of thick intima walls as compared to arteries.

3D and 4D imaging

US for chronic pain procedures has historically been performed employing 2D ultrasonography; however, research is beginning to show the potential effectiveness of using 3D and 4D. Real-time 3D and 4D US approaches have advantages compared to simple 2D imaging that allows for images to be seen only in a single plane [9]. 3D and 4D provide the ability to visualize the tissues and organs as the procedures are performed. Real-time 3D US is currently preferred over 2D US for surgical tasks and complex procedures owing to its accuracy and efficacy [9]. The ability of an US machine to be transported in and used quickly affords the surgeons and pain management physicians the opportunity to have imaging performed concurrent with their procedure without any exposure to radiation [6]. Unfortunately, the major drawback to this is that CT and MRI can produce clearer high-resolution images. However, ultrasonography is evolving with new and improved probes that continue to increase the resolution [8].

Stellate ganglion block

A stellate ganglion block is a local anesthetic block of the sympathetic nerves of stellate ganglion, which represents the confluence of the inferior cervical sympathetic ganglion and the first thoracic sympathetic ganglion in up to 80% of individuals [10]. A stellate ganglion block can be indicated as a potential treatment for many neurologic and pain disorders. One of the main indications for a stellate ganglion block is the treatment of complex regional pain syndrome when there is a component of sympathetically mediated type pain. Other indications for the procedure include Raynaud's disease, post-frost bite injury, post-traumatic stress disorder, cluster headaches, postherpetic neuralgia, hyperhidrosis of an upper extremity, and phantom limb pain [10]. As with all invasive interventional procedures, there are risks and contraindications with the stellate block, including avoiding their use in light of a recent myocardial infarction, anticoagulant use, glaucoma, lateral nerve palsy, emphysema, and cardiac conduction abnormalities [10].

The physician will consider recommending the stellate ganglion block after reviewing the indications, patient's lifestyle, and contraindications to the proposed procedure. The stellate ganglion block procedure has evolved from the original blind palpation technique to the use of fluoroscopy (FL), and more commonly now to the US-guided technique [10]. The US approach begins with having the patient in the supine position. The patient's neck is extended by placing a small pillow under the neck, and the head is minimally turned to the contralateral side of the stellate ganglion being blocked. The area is then sterilized, and the patient receives a local anesthetic skin infiltration using a hypodermic needle. An US may be used on the patient's neck to identify the following structures: the longus colli muscle, anterior scalene muscle, longus capitis muscle, carotid artery, internal jugular vein, thyroid gland, trachea, paravertebral fascia, and the root of the C6 spinal nerve leaving the neuroforamen, which has a transverse process possessing an anterior and posterior tubercle [10]. Once oriented, a 22- to 25-gauge echogenic needle is passed deep into the prevertebral fascia and anterolateral to the fascia of the longus colli muscle (for anatomy and technique, see Figs. 3–6 for US views and Figs. 7 and 8 for fluoroscopic views). The longus colli muscle is located between the carotid artery and thyroid gland. At this point, an aspiration test is performed to ensure the needle has not penetrated a blood vessel or is mistakenly positioned in cerebrospinal fluid. Once placement is confirmed, the local anesthetic is injected incrementally as divided doses, the spread of which can be visualized in real time due to the benefit of using US [11].

The US-guided technique is currently showing most promise compared to FL and blind techniques [10]. With US, every major structure, including the fascial planes, that is vital for confirming the correct placement of the needle can be appropriately visualized for the successful performance of the block

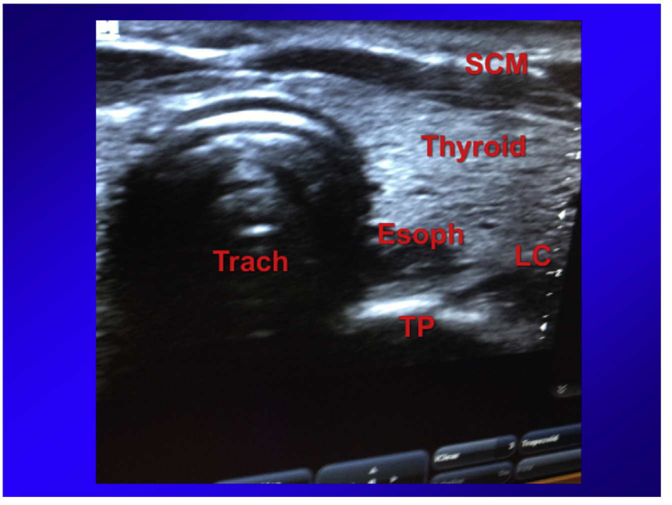

Fig. 3. Ultrasound anatomy relevant for stellate ganglion block: Trach = Trachea; TP = Transverse process; LC = Longus colli muscle; Esoph = Esophagus; SCM = Sternocleidomastoid muscle.

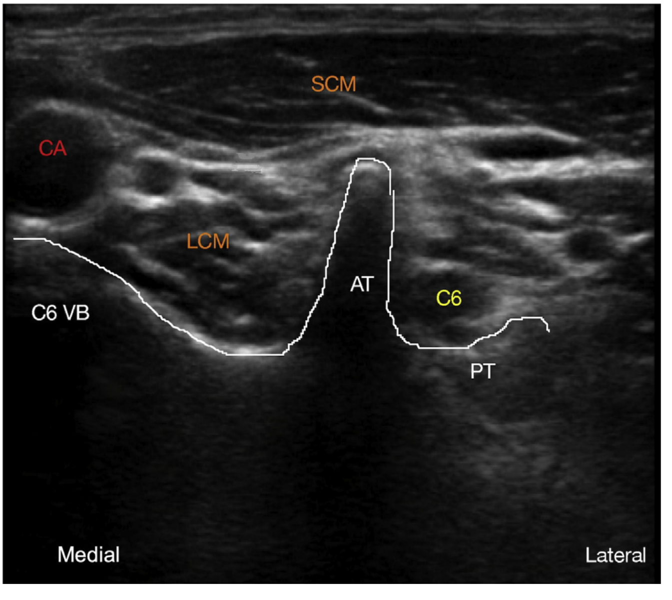

Fig. 4. Another view of ultrasound anatomy relevant for stellate ganglion block: Trach = Trachea; TP = Transverse process; LCM = Longus colli muscle; SCM = Sternocleidomastoid muscle; C6 VB = the C6 vertebral body; AT and PT = Anterior and posterior transverse processes; CA = Carotid artery.

[11]. The FL approach is based on identifying bony surfaces; however, this is only a surrogate marker compared to US visualization of the relevant structures [11]. Using the US-guided technique, analysis has found an increase in efficacy of the stellate ganglion block due to the ability to better confirm the placement of the injections of the anesthetic [11]. Similarly, complications such as esophageal puncture and vascular puncture as evidenced by hematoma formation were also minimized, although not completely avoided with the technique [11]. A definitive head-to-head comparison study between US

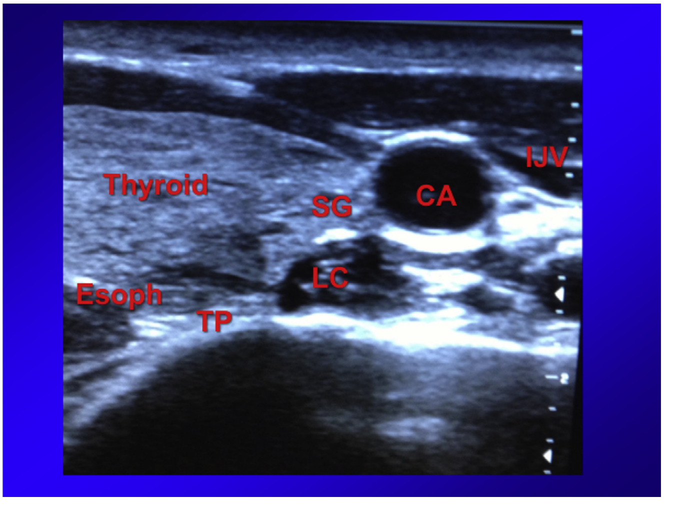

Fig. 5. Stellate ganglion block: Relevant US anatomy: SG = Stellate ganglion; CA = Carotid artery; IJV = Internal jugular vein.

Fig. 6. Proper needle placement for US-guided SGB.

use for SGB and FL use remains to be completed, however, and hence, despite the enthusiasm for an intuitive advantage incurred using US, caution must be exercised before adopting a firm stance regarding superiority of US compared to FL.

Glenohumeral joint injections

The glenohumeral joint is a ball-and-socket synovial joint formed by the head of the humerus and glenoid cavity of the scapula. The articulation between these two structures allows for a multiaxial joint with a high degree of mobility [12]. To accomplish movement, joint stability is compromised, thereby resulting in increased incidence of injury and pain [13]. Depending on a patient's clinical presentation, shoulder pain is typically treated conservatively with nonsteroidal anti-inflammatory

Fig. 7. Fluoroscopy-guided SGB. Needle advancement to transverse process of C-6.

Fig. 8. Lateral fluoroscopic image of contrast for SGB.

drugs (NSAIDs), physical therapy, and activity modification. Diseases in which conservative therapy is first line include osteoarthritis, rheumatoid arthritis, adhesive capsulitis, and impingement syndrome. If these therapies fail and shoulder pain persists, therapeutic injections should be considered for additional medical management [13].

Depending on the imaging modality of choice, shoulder injections are performed using an anterior or posterior approach. US techniques typically use a posterior approach, with the patient in the lateral recumbent position and the affected shoulder facing up. With the transducer in a transverse oblique plane, the posterior glenohumeral joint is viewed and the medication is injected near the posterior humeral head or posterior labrum [12,13]. Alternatively, FL uses an anterior approach where the needle is inserted 1 cm lateral to the coracoid process and directed superior and lateral with the goal of entering the joint space (see Fig. 9).

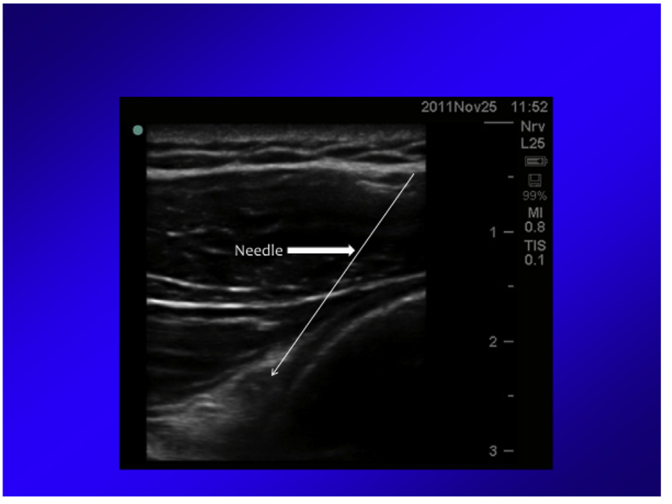

Fig. 9. Ultrasound-guided glenohumeral joint injection.

Although studies have shown better efficacy for the treatment of shoulder pain when using imaging-guided techniques, there is little evidence to suggest that one imaging modality is superior to the other. In a systematic review, Amber et al. compared the accuracy of US-guided glenohumeral injections with that of FL-guided glenohumeral injections. They concluded that although US techniques were found to be more accurate with a rate of 93% than that of 80% for FL, the data were not statistically significant [14]. However, they argued that because US does not require contrast or radiation, it ought to be the preferred modality in the clinical setting.

Intercostal injections

Intercostal blocks are historically useful in the surgical setting for providing postoperative pain relief from thoracic incisions. In addition to decreasing pain, intercostal nerve blocks are a useful diagnostic tool in determining whether the source of pain is likely somatic or visceral [15]. Although the risk of pneumothorax exists when performing these kinds of procedures, research suggests that it is relatively low and imaging modalities such as FL and US help in mitigating such risks [16].

To safely access the nerves, both techniques (FL and US) use a posterior approach and target the posterior axial line. FL-guided techniques begin by identifying the ribs in the anteroposterior view. The needle, parallel to the fluoroscopic beam, is advanced until it reaches the inferior costal margin, then aspirated, and subsequently injected with contrast to confirm placement (see Fig. 10) [17]. US-guided interventions use a similar approach beginning with the patient in the prone position (see Figs. 11 and 12). Using a linear high-frequency transducer in the longitudinal view, the proceduralist can visualize two sequential ribs, the intercostal space, and the pleura.

While both imaging modalities have their own advantages, there is little research to date that suggests one technique is more effective than the other. In a retrospective study comparing US-guided and FL-guided intercostal nerve injections, Shankar et al. compared visual analog scales and duration of pain relief between the two techniques. It was concluded that both techniques provided similar results and provided adequate pain relief. A key component not explored by the study was whether the ability of US to directly visualize the pleura resulted in decreased rates of pneumothoraxes.

Hip injections

The hip joint is a ball-and-socket synovial joint formed by the femoral head and the acetabulum of the pelvis. This joint supports the weight of the human body and is critical for providing ambulation

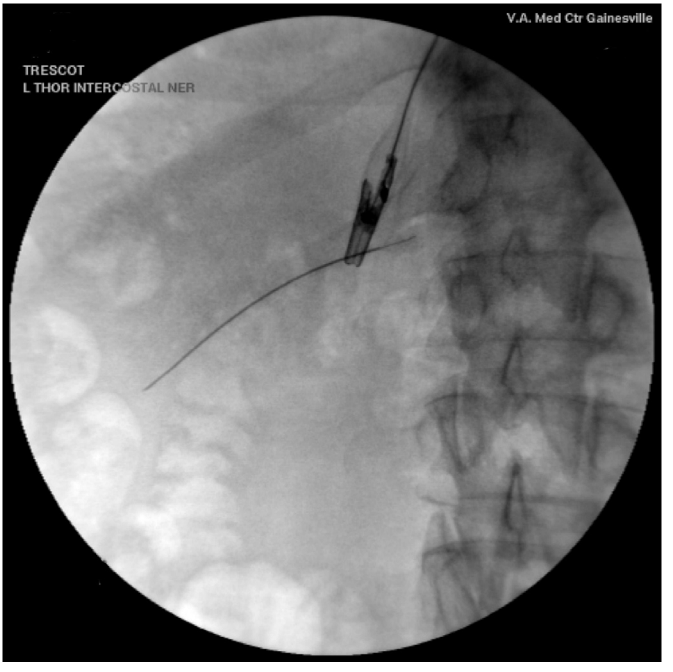

Fig. 10. Fluoroscopic image of intercostal nerve block.

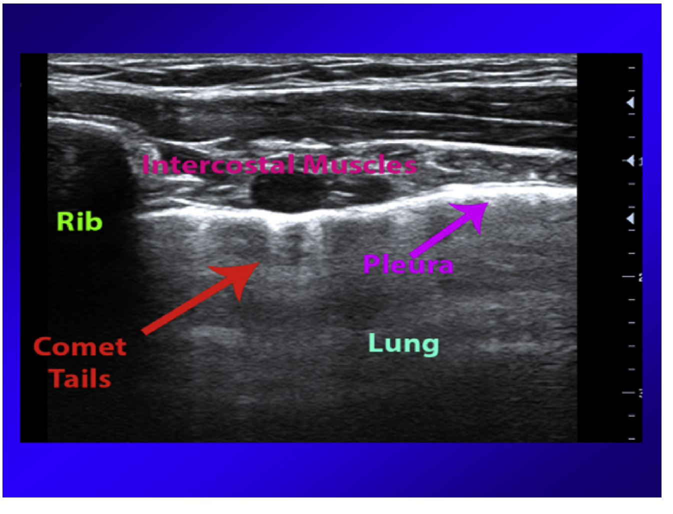

Fig. 11. Ultrasound-guided intercostal nerve block anatomy.

and stability [18]. The differential diagnosis of hip pain is relatively broad, but hip osteoarthritis has become increasingly more common among the elderly population, resulting in significantly debilitating disease. After conservative therapies such as lifestyle changes, NSAIDs, and physical therapy have failed, intra-articular injections should be considered as an alternative for refractory pain [19]. Related to the complexity of the hip joint, imaging modalities such as FL, and more recently, US, has been used to avoid nearby neurovascular structures, visualize and access intra-articular structures, and improve the accuracy of medical interventions [19,20].

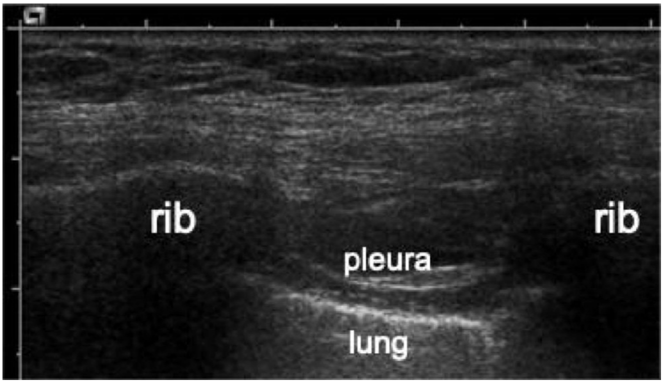

Fig. 12. Another view of an ultrasound-guided intercostal nerve block anatomy.

Both FL and US imaging techniques use an anterior approach with the patient in the supine position (see Figs. 13 and 14). After identifying the femoral artery and accompanying structures by palpating the inner thigh, the area should be marked and avoided throughout the procedure [18,20].

Although US-guided techniques have gained momentum in recent years owing to decreased exposure to radiation and contrast, decreased cost, and the ability to view soft tissue structures, studies suggest that the efficacy and accuracy of both imaging modalities are equivalent. In a prospective study by Rita et al., they compared the effectiveness of both techniques for treating hip pain. They concluded that there was no statistical significance to suggest that one technique was more effective in providing therapeutic pain relief than the other and that either modality was sufficient for treating hip pain [21].

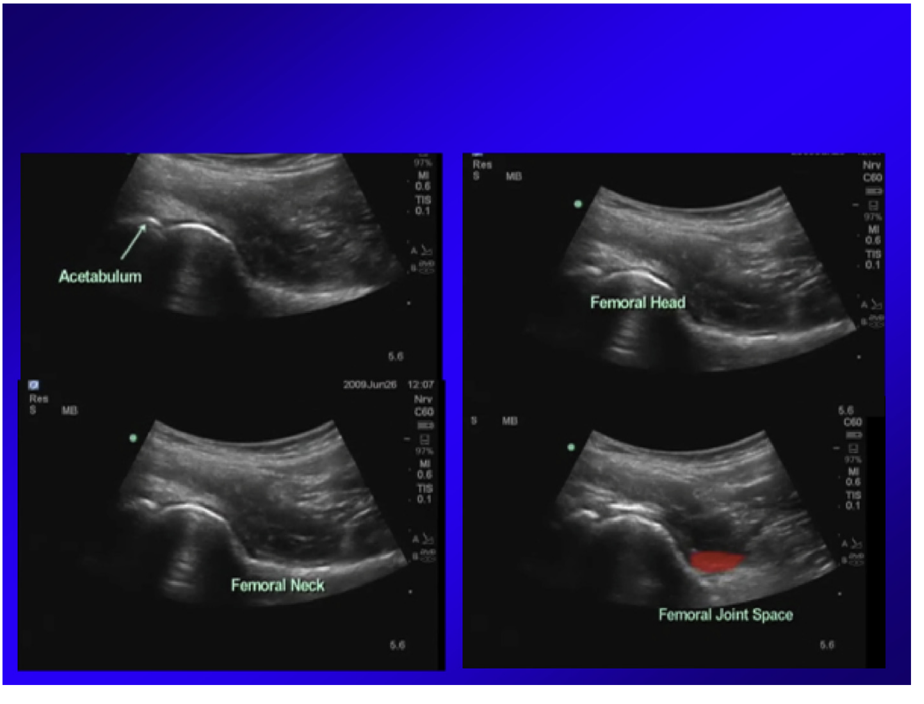

Fig. 13. Ultrasound-guided hip injections.

Fig. 14. Fluoroscopy-guided hip injections.

Knee injections

The knee is a complex synovial hinge joint formed by the distal femur, the proximal tibia, and the patella. It coordinates with the hip and ankle to produce movement of the lower extremities and bears the majority of the weight of the body [22]. Therefore, it is particularly prone to degenerative disease and injury. Osteoarthritis of the knee becomes increasingly prevalent with age and is a common cause of knee pain in older populations.

When performing injections, there are multiple approaches depending on available resources. Although anatomical approaches are still in practice, imaging guidance helps to improve the accuracy of medication administration [23]. Current modalities include FL and US techniques (see Figs. 15 and 16). Both use a superolateral, retro-patellar approach with the patient in the supine position.

Imaging modalities enhance the accuracy of medication administration, improving therapeutic pain relief. In a systematic literature review, Daley et al. compared the accuracy of joint injections using different imaging techniques. It was concluded that the accuracy of knee injections was 99% with FL when compared with that of 79% with US, but there was no evidence to suggest one imaging technique was more accurate than the other [24]. However, many people question whether improved accuracy results in better clinical outcomes. In a systematic literature review comparing the clinical utility of US-guided and anatomical approaches to knee injections, Berkoff et al. reported multiple instances in which US resulted in improved clinical outcomes. It was determined that US-guided techniques resulted in decreased procedural pain, significantly improved joint function at 6 weeks, and had a longer duration of therapeutic effect. These positive outcomes suggest that if the resources are available, US image-guided therapeutic injections have better clinical outcomes and should be used when possible [23].

Sacroiliac joint injections

The sacroiliac joint is a diarthodial joint supported by several strong ligaments and is the largest axial joint in the human body [25]. Its mobility is inversely proportional to a patient's age, and mobility

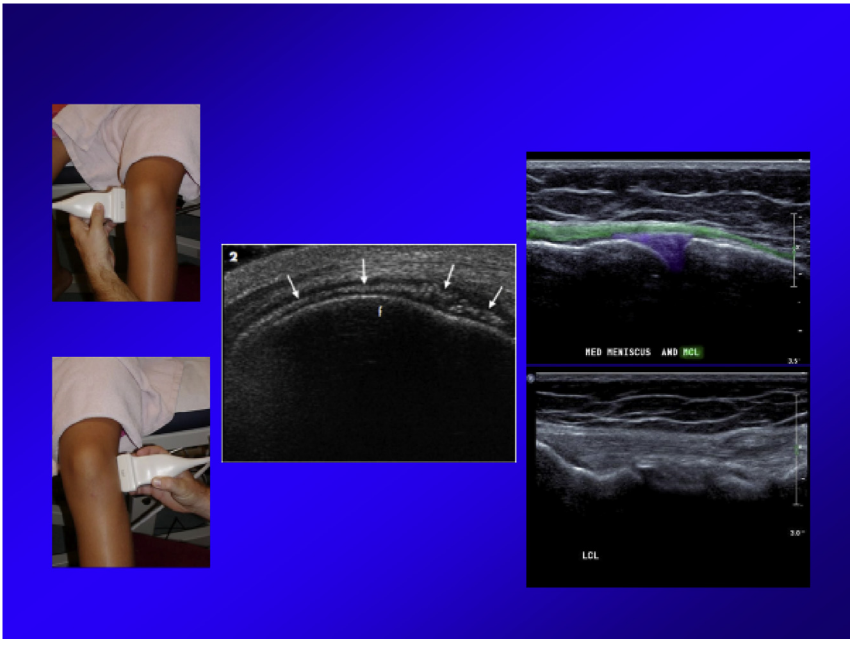

Fig. 15. Ultrasound-guided knee injection.

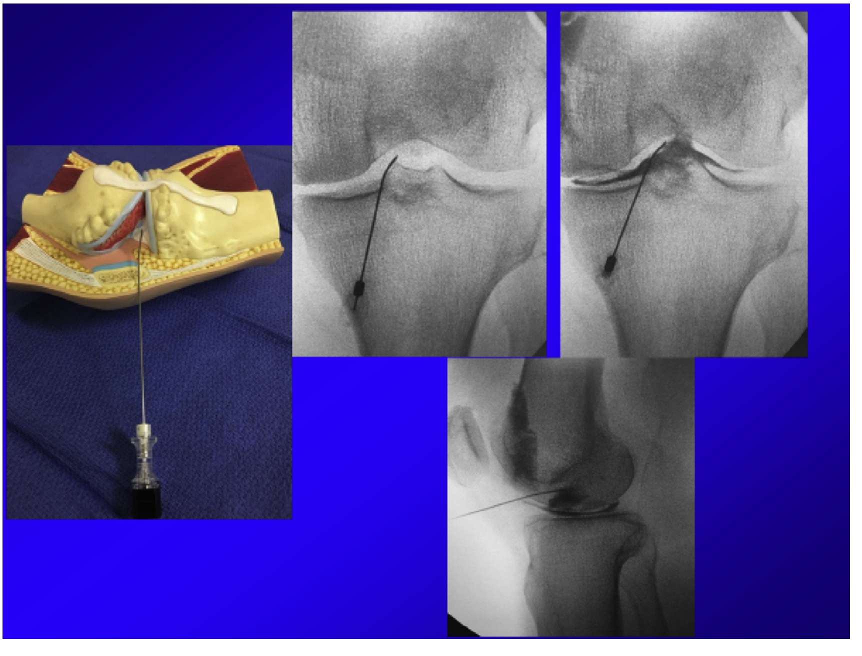

Fig. 16. Fluoroscopy-guided knee injection.

can become increasingly restricted with time [25]. Sacroiliac joint pain has been shown to be the source of 10–27% cases of chronic back pain and also a source of referred pain in the lower extremities [26,27]. Pain in the sacroiliac joint can be idiopathic, a result from direct trauma, inflammation, repetitive and torsional forces, or unidirectional pelvic sheer [27]. Related to the rich innervation of the sacroiliac joint, nerve blocks have become the gold standard as a diagnostic tool and therapeutic measure [26–28].

Image guidance for this procedure is necessary because of the complex anatomical structures associated with this region. Without image guidance assistance, success rates of sacroiliac joint injections are as low as 22% [29]. FL-guided intra-articular injections have become the most common and trusted modality, and although this method drastically improves accuracy, it exposes patients to radiation and contrast media (see Fig. 17) [25,28]. US-guided sacroiliac joint intra-articular injections (see Fig. 18) have proved to be a relatively reliable method of using image guidance without running the risk of patient's exposure to radiation [28].

In a 2014 study, 120 patients were evaluated to determine the efficacy of US-guided versus FL-guided sacroiliac joint intra-articular injection [28]. There was a 98.2% accuracy rate in the FL-guided sacroiliac joint injection compared to an 87.3% accuracy rate in the US-guided injection [28]. Another study showed an 88.2% accuracy rate in US-guided sacroiliac joint injection on 17 cadavers that were later confirmed upon dissection [25]. While these studies show a decrease in accuracy for the US-guided sacroiliac injection when compared to the use of FL, the patient is not exposed to radiation with a relatively good accuracy when compared with a non-image-guided injection. More studies need to be conducted with a larger sample size to determine a more accurate success rate with US-guided injections. As technology progresses and US-guided injections are more frequently used, the use of US-guided injections may become first-line therapy for chronic sacroiliac joint pain.

Medial branch blocks

Medial branch blocks (MBBs) are indicated in patients with chronic poorly controlled axial spine pain revealed by examining the patient or when conducting a provocation injection. Spine pain suggests facet disease (pain exacerbated by lumbar extension and rotation or associated with lumbar rigidity) and with evidence of pain present for at least 2 months. To be eligible for an MBB, candidates should lack evidence of discogenic or sacroiliac joint pain, disc herniation, radiculitis, or functional disability. Candidates should also have failed to respond to conservative nonoperative therapy management such as physical therapy or medications [30].

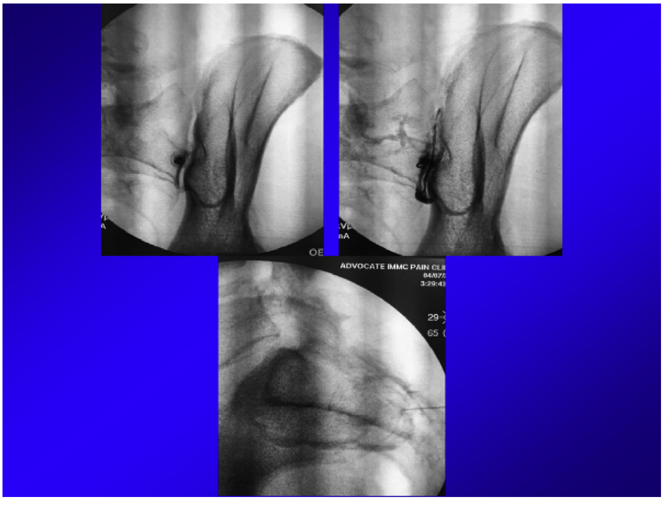

Fig. 17. Fluoroscopy-guided SI joint injection.

Fig. 18. Ultrasound-guided SI joint injection.

Lumbar facet joints are synovial joints that enable an individual to perform movements such as flexion, extension, and rotation of their lumbar spine. These joints are innervated by the medial branch of the spinal dorsal ramus. Facet capsules and tissues nearby are rich in nociceptive receptors, which cause pain to the individual when the capsules experience mechanical or chemical stimulation or inflammation [31]. The technique of medial dorsal branch block is achieved by blocking each of the medial branches that innervate a facet above and below their corresponding roots and also by further blocking the multifidus and interspinous muscles in the region of the corresponding dermatome [32].

US vs. FL-guided MBBs were compared in a retrospective study to determine whether one technique had a better outcome than the other. MBBs performed under fluoroscopic guidance require exposure to radiation, have a higher cost relative to other methods, and involve large devices. In contrast, blocks under US guidance provide an imaging form that is not related to radiation exposure and can detect soft tissue targets. However, US-guided procedures do have their limitations. With US-guided procedures, resolution is limited in deeper layers owing to the physical characteristics of the sound waves. These limitations make it difficult to check whether the needle tip is reliably located at the target point. Several techniques may be performed to overcome this limitation such as the trichotomous technique of alignment, rotation, and tilting movements of the US transducer while scanning to allow for the improved placement of the needle tip and shaft for better visualization. Another limitation of US-guided MBBs is that intravascular injections or inadvertent foraminal spread cannot be clearly detected by this method [33].

In summary, the US-guided procedure does not show significant difference in treatment outcome for pain reduction and functional improvements compared with FL-guided procedures. US, however, lacks the associated risks of radiation exposure. Therefore, US-guided MBBs are deserve consideration for the conservative management of lower lumbar facet joint pain [33].

Caudal epidural injections

A caudal epidural steroid injection is a chronic pain procedure used to treat radicular lower back pain. During this approach, steroid medication is injected into the most inferior aspect of the epidural space by using the sacral hiatus as the landmark and advancing the needle through the sacral canal into the epidural space [34]. Caudal epidural steroid injections may be preferred compared to other epidural techniques in patients who receive anticoagulants, as the caudal technique decrease the risk of epidural hematomas and adverse events caused by bleeding [34]. This caudal technique is also used commonly in patients with previous lumbar spine surgeries, as it potentially decreases the incidence of spinal headache and dural punctures. The caudal epidural procedure also helps to avoid any metal implants placed from previous lumbar spine surgeries [34].

During a caudal epidural block, the patient is placed in the prone position and prepped appropriately under sterile conditions. The sacral hiatus can be identified by palpation as the dimple midline between two bony structures called the sacral cornua [35]. Padding is often placed under the patient's sacrum in the prone position to make the patient's sacral hiatus more prominent for the procedure. Once the sacral hiatus is identified and the patient is given local anesthesia in the skin and subcutaneous tissues, the needle enters the skin at a 45-degree angle to the sacrum and is advanced through the sacral hiatus [35]. When the needle transverses the sacrococcygeal ligament, the provider will feel a loss of resistance, identifying entry into the caudal canal [35]. The pain medicine physician then confirms epidural placement with the lack of cerebrospinal fluid and blood return as well as noting the filling patterns if using contrast under FL (Figs. 19 and 21) or the patterns of Doppler flow images under US (see Fig. 20). The provider then completes the procedure by injecting the local anesthetic or steroid of choice into the epidural space of the patient for pain relief [36].

FL-guided caudal epidural steroid injections have been the standard for pain medicine physicians for many years (Figs. 19 and 21), but US-guided caudal blocks have been recently studied, showing them to be an acceptable alternative. In 2013, Park et al. studied the use of US versus FL for image-guided caudal epidural steroid injections for patients with unilateral lower lumbar radicular pain [37]. One hundred twenty patients were randomly assigned to either the US or the FL group of caudal injections. Both groups were compared for efficacy, side effects, and functional improvement. The verbal numerical rating and Oswestry Disability Index scores showed improvement in both the US- and the FL-guided caudal epidural steroid injection at both 2 and 12 weeks [37]. The injection effectiveness did not show a statistical difference between the US- and the FL-guided injection groups. There were 2 intravascular injections in the FL-guided group, which showed that the US approach with color Doppler may be an effective method for preventing this complication [37]. Pain relief and functional status after the procedures were similar in the US and FL groups in this study [37].

In 2015, a retrospective case–control study was performed to compare US- to FL-guided caudal epidural steroid injections in patients with unilateral radicular pain. One hundred ten patients were

Fig. 19. Fluoroscopically-guided caudal injection with an epidurogram.

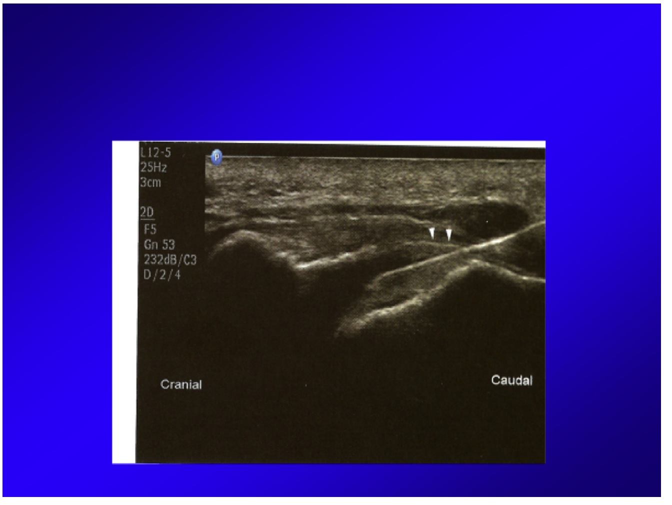

Fig. 20. US-guided caudal injection.

compared using the verbal numerical scale as well as the Oswestry Disability Index. Both the US and the FL groups showed improvements at 3, 6, and 12 months after injection. No statistically significant difference was noted between the two groups [38]. US-guided caudal epidural steroid injections are an acceptable alternative to the use of FL-guided injections for patients suffering from radicular lower back pain.

Transforaminal epidural injections

A transforaminal epidural steroid injection (TFESI) is another chronic pain procedure used to treat radicular lower back pain that is triggered predominately by a single-level, unilateral intervertebral disc pathology. This technique maximizes medication and steroid concentration at the dorsal root ganglion and ventral epidural space at the level of the radiculopathy [36]. Mastering of the technique involves injections into the area posterior to the exit of spinal nerve root and vascular feeding artery. Segmental radicular medullary arteries pass through the superior portion of the foramina to bring oxygen and blood supply to the spinal cord. The artery of Adamkiewicz, which is found approximately by thoracic level 10 down to L2, predominantly on the left side, is the largest of the radicular medullary arteries, as it innervates most of the lower spinal cord [36]. Avoidance of the artery of Adamkiewicz and other vasculature around the foramina is paramount to prevent catastrophic complications.

Understanding anatomy as well as patient-to-patient anatomic variation is key to placing the needle in a safe location to facilitate successful block and to avoid intervascular injection. This area includes the dorsal portion of the intervertebral foramen, the base of the pedicle as the superior border, and the nerve root serving as the inferior structure [36]. When the needle is placed appropriately, this allows the injection to be placed posterior and lateral to the nerve root away from vasculature, which is typically superior (fluoroscopic view, see Fig. 21). This also helps with the spread of the medication into the ventral epidural space, alleviating pain caused from herniated intervertebral discs [36]. Intra-arterial injection can lead to the distal embolism of steroid particles, resulting in devastating complications such as paraplegia. Further methods of identifying intra-arterial needle placement include live FL and US with Doppler flow [36].

In 2013, Jee et al. completed a randomized, blinded, and controlled study to evaluate the treatment of cervical radicular pain with transforaminal epidural steroid injections comparing FL-guided with US-guided techniques [39]. One hundred twenty patients with cervical spine stenosis or disc herniation causing radicular pain were enrolled in the study and randomly assigned to an US or a FL group. Patients were then assessed for functional improvement and pain relief at 2 and 12 weeks after

Fig. 21. Lumbar transforaminal epidural steroid injection under fluoroscopy.

transforaminal injection [39]. Verbal Numerical Scale and Neck Disability Index were used to assess the patients' pain relief and functionality after the procedures. In both the US and FL groups, pain scale and patient functionality improved significantly in patients at 2 and 12 weeks, but no statistical differences were found between the groups [39]. Intravascular injection occurred 5 times only in the FL group but without statistical difference between either group. Despite the lack of differences between the two groups in providing pain relief, US has been shown to be effective in identifying vasculature in unexpected locations in patients with anatomic variations. This information can help pain medicine physicians avoid critical vasculature variations that is in what should be the "safe area" but is not necessarily a "safe area" for injection. It remains unclear and is proven that US can reliably detect intravascular injection. During transforaminal epidural steroid injections, the use of real-time US imaging can aid in identifying abnormal vasculature close to the intervertebral foramen, which can help prevent intra-arterial injection, the most common side effect of transforaminal injections [39].

Deep cervical plexus blocks

Deep cervical plexus blocks are another type of pain procedure used to treat cervicogenic headaches refractory to conservative therapy. These headaches are described as unilateral referred from normally the C2 and C3 nerve roots of the cervical spine [40]. Deep cervical plexus blocks target 3 nerves in the paravertebral space, namely, C2, C3, and C4. These nerves can be targeted by either a single injection or up to three separate injections [41]. In addition to its use in treatment for chronic cervicogenic headaches, deep cervical plexus blocks can be used for pain relief for many different types of surgeries including carotid endarterectomies, thyroid, parathyroid, and in tissue injury or fractures along the cervical sensory distribution. Complications of this procedure are rare but do include phrenic nerve injury, epidural or subarachnoid injection, and intravascular injection [41]. The technique for injection differs whether the pain medicine physician is using US-guided or FL-guided techniques. While using US, the provider identifies either the C2 or the C3 spinous process. The probe is moved laterally to identify the transverse process of C2 or C3 as the target while the vertebral artery is avoided. A 22 G spinal needle is inserted until it reaches the transverse process, and after negative aspiration, a local anesthetic and steroid is injected [42]. The FL procedure is started by identifying C2 and C3 on lateral and AP views. A 22 G spinal needle is inserted into the lateral recess of C2 and C3. It is verified by FL-guided imaging and negative aspiration, before injection of medication [42].

In a 2017 study by Wan et al., the efficacy of deep cervical plexus blocks was compared using US versus FL for the treatment of cervicogenic headaches [42]. Fifty-six patients were randomly placed in either the FL or the US group. Using both imaging methods, 2–4 cc of 1% lidocaine and 7 mg of betamethasone were injected at the transverse process of either C2 or C3. Patients' pain scores were evaluated at 2, 12, and 24 weeks using the numerical pain scale. A statistically significant reduction in pain score was noted at the 2-, 12-, and 24-week interval in both the US and FL groups; however, no statistical difference was noted in the amount of pain reduction between both groups. US has been shown to be an effective alternative method for performing deep cervical plexus blocks with similar efficacy of pain relief as in the use of FL. US allows pain medicine physicians to identify the vertebral artery to avoid injury as well as limiting radiation exposure [42].

Peripheral nerve stimulation with ultrasound

Peripheral nerve stimulation is a method of neuromodulation that applies electric currents to peripheral nerves to induce paresthesias within areas causing pain [43]. Evidence has shown that intense US applied directly to a peripheral nerve can transiently and safely reduce its function. This technique has been extremely favorable given the noninvasive nature of US technology. When tested on the sciatic nerve of bullfrogs, US stimulation significantly reduced up to 60% of the nerves' action potential, which then reverted back to baseline several minutes after US application [44]. In a study describing a patient presenting with chronic, bilateral foot pain after multiple surgeries performed on his foot, US-guided, percutaneous tibial nerve stimulation was utilized at the level of the thigh to provide pain relief on the patient's right lower extremity, and open peripheral nerve stimulation on the left lower extremity [44].

The results of the study describe that the patient experienced desired stimulation paresthesias and excellent pain relief on the plantar aspect of the right foot with the percutaneous electrode. On the left side, the stimulation paresthesia was unable to be localized to the sole of the foot. When a subsequent, open placement of a left tibial nerve stimulator was performed, it revealed that the correct electrode position against the tibial nerve was immediately adjacent to the popliteal artery and was thus not appropriate for percutaneous placement. In conclusion, US-guided peripheral nerve stimulation avoids invasiveness of electrode placement through open procedure while providing excellent pain relief.

Pain is a personal experience requiring brain function; therefore, deactivation of relevant brain regions by US, or activation of parts of the brain that can inhibit downstream function, can prove to be extremely beneficial for patients. Focused US neuromodulatory effects of stimulating or suppressing neural activity may potentially enable a range of therapeutic benefits including verifying targets in the brain prior to ablative procedures, suppressing epileptic seizures or symptoms of psychiatric disorders, or temporarily blocking nerves to treat pain. During ablation procedures to treat chronic and therapy-resistant neuropathic pain, in which high-intensity focused US (HIFU) was used at a power required to achieve a peak temperature of 53–60 °C with continuous wave sonication at individual durations of 10–20 s, patients experienced temporary pain relief, vestibular feelings, and dysesthesias. It should be mentioned that this form of treatment created lesions of 3–5 mm in length, with pain relief ranging from 30% to 100% relative to the baseline score. Adverse effects were not observed or experienced by the patients who underwent this procedure. An image of a peripheral nerve stimulator placed for chronic knee pain is shown in Fig. 22. It has also been shown that transcranial US with significantly

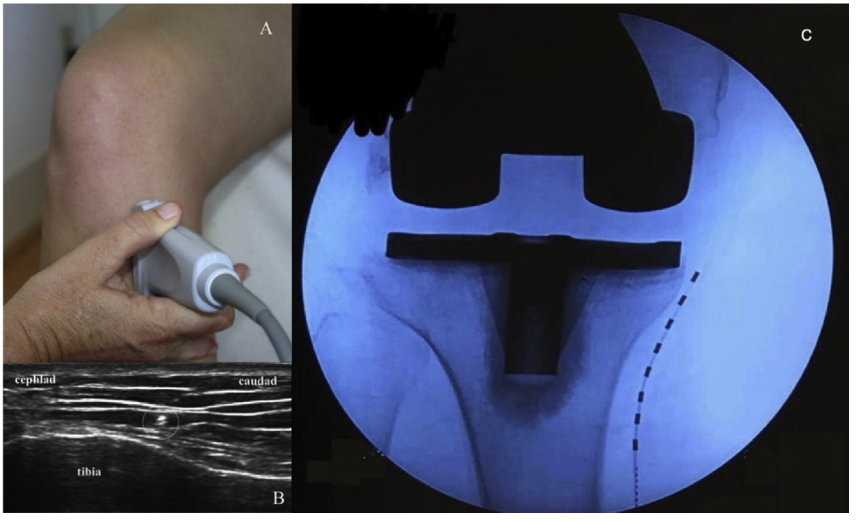

Fig. 22. Peripheral nerve stimulator placed through ultrasound for chronic knee pain.

reduced intensity relative to ablative US can nondestructively and transiently activate as well as suppress brain function in animal models and modulate brain function in people. Although information is extremely limited on the therapeutic results of this modality of treatment, perhaps one day, US can reduce patients' pain, at least temporarily [44].

Conclusion

Compared to both landmark-based techniques as well as FL, US technology has the distinct advantage of the ability to visualize not only one's target site for an interventional procedure but also the surrounding structures that ought to be avoided, such as the lung pleura or nearby vasculature. These advantages have been demonstrated throughout many studies in multiple other areas of medicine, but the data remain somewhat murky with regard to interventional pain procedures. For certain procedures such as stellate ganglion, cervical plexus, and transforaminal blocks, studies have suggested an improved safety profile given the ability to minimize the risks of vascular violation or arterial injection. That being said, while patient outcomes and efficacy of intervention demonstrated some improvement with regard to stellate ganglion blocks and knee injections, the large majority of interventional procedures did not yield similar results. While for many procedures actual outcome advantages have not been demonstrated, most studies have established non-inferiority of US use to that of FL. Along with both decreased radiation exposure and decreased overall procedural time, these advantages might allow us to infer a superiority of US imaging modality and allow for encouragement for its use of the technology throughout pain practices. Lastly, the use of US for needle guidance has been demonstrated to be highly variable based on operator experience. Studies examining the use of US during central line placements have shown increased safety profiles with the use of US and also have caveats regarding the experience of the operators. As members of the pain community become more accustomed to using the technology and the source data grow, it will be interesting to see whether there is a more definitive advantage of the technology.

Disclosure

Dr. Alan Kaye, MD, PhD, is a speaker for Merck.

Practice points

- Ultrasound allows physicians to visualize their target site, assess and follow an advancing needle tip, and reconcile surrounding structures.
- The quality of imaging produced by superior technology of the newer model machines themselves continues to improve combined with the fact that the patient suffers no radiation exposure with their use; ultrasound machines have become increasingly ubiquitous throughout chronic pain practices.
- As members of the pain community become more accustomed to using the technology and the source data grow, it will be interesting to see whether there is a more definitive advantage of the technology.

Research agenda

- A definitive head-to-head comparison study between ultrasound (US) use for SGB and fluoroscopy (FL) use remains to be completed, however, and so despite the enthusiasm for an intuitive advantage incurred using US, caution must be exercised before adopting a firm stance regarding superiority of US compared to FL.
- A key component yet unexplored is whether US can directly visualize the pleura and result in decreased rates of pneumothoraxes.
- There is little research to date suggesting whether FL—or US-guided imaging modalities is more effective than the other.

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