Ultrasound in interventional pain management

Urs Eichenberger, MD, a Manfred Greher, MD, a Michele Curatolo, MD, PhD b

a From the Department of Anesthesiology and General Intensive Care, Division B, University of Vienna, Vienna, Austria; and the b Department of Anesthesiology, Division of Pain Therapy, University Hospital of Bern, Inselspital, Switzerland.

Ultrasound (US) is a promising imaging technique in interventional pain management. It allows the identification of soft tissues, vessels, and nerves, without exposing patients and personnel to radiation. Imaging can be performed continuously and the fluid injected is visualized in a real-time fashion. Possible applications are nerve blocks of the cervical and lumbar zygapophysial joints, stellate ganglion block, intercostal nerve blocks, peripheral nerve blocks of the extremities, blocks of painful stump neuromas, caudal epidural injections, and injections of tender points. US can be used not only for local anesthetic blocks, but has a potential application for destructive procedures, such as cryoanalgesia, radiofrequency lesions, or chemical neurolysis. The very limited published data available and the clinical experience by the authors suggest that US has a potential usefulness in interventional pain management, but also has limitations. There is a need for clinical trials investigating efficacy and safety of US-guided pain procedures. Until these studies are made, US cannot replace fluoroscopy or computed tomography in routine clinical practice. Rather, only physicians who have been trained appropriately and practice under supervision of an experienced sonographer should use it, until familiarity with the method is gained.

KEYWORDS
Ultrasound; Pain management; Nerve block

Imaging techniques are essential tools in interventional pain management. Many pain procedures cannot be performed with a blind technique, or at cost of high failure rate or unacceptable risks. Fluoroscopy is the standard imaging technique employed by pain physicians. Computed tomography (CT) may also be used in special cases. Recent technological developments in ultrasound (US) imaging has led to an increased interest in this method for interventional pain management.

The present article has the following aims: (1) to highlight the characteristics of US as an imaging technique for pain procedures; (2) to analyze its possible applications in interventional pain management; (3) to provide preliminary data on US-guided pain treatment; and (4) to describe a selection of pain procedures that can be performed with US guidance. The main weight is given to procedures performed on nerves. US-guided injections of joints are not an issue of this review.

The use of US for pain management is in development and there are very few published studies in this field. Efficacy and safety data are not yet available. Therefore, this article should not be seen as a guide for performing pain procedures under US control. Rather, the article presents possible areas of applications and indicates future developments for this promising imaging technique in pain management.

Pain procedures and imaging techniques

Pain procedures

Interventional pain procedures are either diagnostic or therapeutic. Diagnostic techniques aim at identifying the source of pain. They basically consist of injecting a very low dose of a local anesthetic directly near the nerves that supply the assumed anatomical site of the pain origin. A reduction of pain intensity, possibly associated with improvement of function, indicates that the innervated region may be the pain generator. Diagnostic blocks do not allow the identification of the pain mechanism, but only the anatomical source of pain. This practice has been extensively validated for the diagnosis of zygapophysial joint pain, for which neither clinical examination or imaging techniques provide a valid diagnosis. Although diagnostic nerve blocks have not been rigorously validated for other applications, the basic principle has been applied to many other areas of pain medicine. Therefore, diagnostic nerve blocks
are routine practice in many pain clinics. Additional diagnostic pain procedures are intraarticular injections of local anesthetics for a variety of joint pain conditions \(^2\) and disc stimulation (usually called discography) for the diagnosis of internal disc disruption. \(^3\)

There are a variety of therapeutic pain procedures that are used clinically. Listing all of them is beyond the scope of this article. In the authors’ opinion, worthy mentioning are radiofrequency neurotomy for zygapophysial joint pain, \(^4\) transformaminal steroid injections for radicular pain, \(^5\) intraarticular steroid injections, \(^2\) intrasidal electrothermal anuloplasty for internal disc disruption, \(^3\) spinal cord stimulation, \(^6\) intrathecal opioids via implanted pumps, \(^7\) chemical neurolysis, \(^8\) and cryoanalgesia. \(^9\) Some of these treatment modalities have not been investigated in randomized controlled trials and therefore are not supported by strong evidence of efficacy.

Both diagnostic and therapeutic procedures require a high precision of instrumental positioning. For diagnostic nerve blocks, it is essential that the needle be placed as close as possible to the targeted neural structures and the smallest possible amount of local anesthetic be injected. Failure to do so results in lack of selectivity with a consequent high rate of false positive responses. The same principle applies to the use of chemical neurolytic agents, such as alcohol or phenol: inaccurate needle placement or excessive spread of the injected solution may result in neurolysis of other structures with possible complications. For radiofrequency or cryoanalgesia procedures, the probe must be placed very close to the target nerve, as the lesion is localized around the active tip of the probe. An inaccurate placement invariably results in an unsuccessful treatment or may produce severe complications.

From the above considerations, it is evident that many pain procedures should not be performed using a blind technique, ie, merely based on external anatomical landmarks. While such an approach may be used for some regional anesthetic techniques, it is unacceptable for most pain procedures. The use of nerve stimulation in a blind approach is infrequently helpful for pain management and may be considered at best as an additional tool. Thus, the pain physician can perform most interventional procedures effectively and safely with only the aid of imaging techniques.

**Fluoroscopy and computed tomography**

Fluoroscopy allows only the visualization of bones. Nerves and soft tissues are not visible. Vessels can be seen only when they are punctured and contrast medium is injected. Thus, neither the target nerves nor other relevant structures can be displayed. Despite these limitations, fluoroscopy is the standard method for pain procedures, mainly for the following reasons: (1) both the target and other important structures can mostly be identified based on the bony landmarks; (2) the whole field is visualized on the same image; (3) imaging is very rapidly obtained, which allows multiple needle repositioning in a short time; and (4) the apparatus is not excessively expensive, which keeps the costs of the procedures at acceptable levels.

Although fluoroscopy remains the standard imaging technique for different pain procedures, it cannot be employed in all situations. For instance, fluoroscopy has no value for interventions at the upper or lower extremity.

CT provides more information than fluoroscopy. For instance, muscles, viscera, big vessels, nerve roots, the intervertebral discs (including herniations and protrusions), and the dural sac are visualized. The images of each slice can be reconstructed in a three-dimensional picture. The opening of joints is easily displayed, \(^10\) which may make intraarticular puncture of difficult joints, such as the sacroiliac joints of some patients, easier than by fluoroscopy. Thus, CT may theoretically allow a more accurate and safer instrumental positioning than fluoroscopy.

The main disadvantage of CT is the high cost of the apparatus and therefore of the performed procedures. Furthermore, imaging is not as rapidly obtained as with fluoroscopy. Therefore, multiple needle repositioning, which is frequently necessary, usually results in relatively long procedural times. CT does not allow a real-time visualization of contrast medium injection, which is a useful characteristic of fluoroscopy. The authors are not aware of studies that have compared fluoroscopy with CT with regard to clinically significant outcomes. The large experience with fluoroscopy, extensively documented by published works, attests its usefulness for precise and safe performance of pain procedures. Thus, although CT is a useful tool for pain physicians for selected cases, its routine use is hardly justified.

**Ultrasound**

US can identify muscles, ligaments, vessels, joints, and bony surfaces. Importantly, thin nerves can be visualized, provided that high-resolution transducers are employed. This characteristic is not shared by any other imaging technique and is the major reason for the great potential usefulness of US in interventional pain management. Unlike fluoroscopy and CT, US does not expose patients and personnel to radiation. Imaging can be performed continuously. The fluid injected is easily visualized in a real-time fashion. Therefore, if the target nerve is identified, US provides the unique opportunity to assure spread of the injected solution at the site of block during administration, without radiation exposure. Vessels are visualized, most clearly when Doppler sonography is available. Thus, the risk of intravascular injection of local anesthetics or injury of vessels during destructive procedures is minimized. US is much less expensive than CT and, depending on the type of device, may be less expensive than fluoroscopy.

A limitation of US is the poor visualization of thin needles. However, the movements of the tissues while advancing the needle provides experienced practitioners with reliable information on the needle position. Some structures, ie, bones, produce an US shadow behind them, which makes the identification of structures in this area impossible. As mentioned above, the use of high-frequency transducers is mandatory to achieve the appropriate resolution to identify small nerves. However, the higher the resolution, the lower the working depth (tissue penetration).
Pain procedures under ultrasound guidance

This section will present some examples of pain procedures that can be performed under US guidance. Not all the diagnostic and therapeutic modalities described, independent of the imaging technique employed, are supported by strong evidence of validity and efficacy. Deliberately, this review will not exclude those pain procedures that have not yet been subjected to rigorous scientific scrutiny.

Nerve blocks for cervical zygapophysial joint pain

Chronic neck pain following whiplash injury is the result of lesions of the cervical zygapophysial joints in 50% of patients. Diagnosis is made by blocking the nerves supplying the joints using a small amount of local anesthetic. After identification of the involved joints, the nerves may be destroyed using a percutaneous radiofrequency neurotomy technique. This method is well validated and can provide lasting pain relief.

Typically, the diagnostic blocks are performed under fluoroscopic control. However, either fluoroscopy or CT does not visualize the nerves. Because several injections are frequently needed to identify the involved joint or until zygapophysial joint pain is ruled out, the procedure may expose patients and personnel to considerable radiation doses.

In a pilot study we tested the hypothesis that the 3rd occipital nerve, which innervates the C2 to 3 zygapophysial joint and a small skin area, can be visualized by US and also blocked by injecting local anesthetic under US control (Eichenberger and coworkers, unpublished data). The region of the C2 to 3 joint was investigated by US in 10 healthy volunteers, using a 15-MHz transducer. The injection of saline or local anesthetic was performed in a double-blind, randomized fashion. Anesthesia at the innervated skin area was tested by pinprick and cold. The 3rd occipital nerve could be visualized in all 10 subjects and displayed a mean diameter of 2.1 mm (standard deviation, 0.5). Anesthesia of the skin was found in 9 of 10 local anesthetic injections, whereas no anesthesia was observed after the 10 saline injections. However, radiological control revealed no appropriate needle positioning according to the standard fluoroscopy technique in 50% of cases. Thus, while this result is encouraging, further work has still to be done to clarify whether US-guided block of these nerves can be reliably and safely performed. So far, we cannot yet recommend US as an alternative to fluoroscopy for performing nerve blocks for zygapophysial joint pain. Perhaps, US examination can provide important information on the anatomical position of the nerve before performing fluoroscopy-guided nerve block or radiofrequency lesion.

Nerve blocks for lumbar zygapophysial joint pain

Zygapophysial joint pain is also a common cause of chronic low back pain. To date, the only validated test to reliably diagnose lumbar zygapophysial joint pain is to block the nerves supplying the target joint with a local anesthetic (medial branch blocks). Fluoroscopy is the standard method to control needle placement. Recently, an US-guided methodology to block these nerves has been developed. The technique does not necessarily imply expensive equipment, since high resolution is not required. Indeed, any US device cannot visualize the medial branches, and the bony landmarks of the spine are the target structures of the procedure. For this purpose, a curved array US transducer with a frequency between 2 and 6 MHz (commonly used for diagnostic examination of the abdomen), connected to a small portable US machine at the size of a portable computer, is sufficient.

This recently published three-part study in cadavers, volunteers, and patients identified the necessary US landmarks and described a paravertebral cross- and long-axis view to reliably guide the needle to the L2 to L4 medial branches. Sonographic measurements revealed a significant increase in skin-to-target distances from the third to the fifth lumbar vertebra. A documented and fluoroscopy-controlled clinical case series of 28 US-guided blocks underlined the principal clinical feasibility of the technique. Accuracy of US-guided Th12 to L4 medial branch blocks was recently confirmed in a cadaver study by CT control: these preliminary data showed a rate of over 90% of successful needle placements. Large-scale clinical studies are planned to support these findings.

Despite the aforementioned encouraging results, the procedure has limitations. Obesity may result in poor US image quality. Furthermore, it is difficult to identify the bony landmarks to block the dorsal ramus of L5 at the junction between the ala and the superior articular process of the sacrum. This nerve provides, together with the medial branch of L4, the nerve supply to the L5 to S1 zygapophysial joint, which is a frequent source of low back pain.

In conclusion, US guidance is a promising technique for nerve blocks of the lumbar zygapophysial joints. Further studies are needed before this method can be presented as an alternative option to fluoroscopy.

Stellate ganglion block

Stellate ganglion block is a possible intervention in patients suffering from vascular diseases or sympathetically maintained pain of the head or the upper extremity. The most commonly performed technique is to palpate the Chassaignac tubercle at the base of the C6 transverse process while simultaneously shifting the carotid artery laterally. Then a needle is inserted beside the palpating finger and directed vertically toward the target point in a blind way without any radiological visualization. At that level, the middle cervical ganglion is located, while the stellate ganglion is situated more caudally and posteriorly in the chest on the head of the first rib. To decrease the high risk of pneumothorax, the blind technique is restricted to C6. However, with the blind technique several side effects or complications can occur, such as recurrent-, phrenic nerve- or nerve root block, epidural or intrathecal injection of local anesthetic, puncture of the thyroid gland or of a large vessel leading to hematoma formation and/or intravascular injection. Even a puncture of the esophagus (at the left side of the neck) leading to mediastinal infection may occur.
Different imaging techniques like fluoroscopy, CT, and magnetic resonance imaging for stellate ganglion block have been proposed. However, they are not routinely employed because of time consumption, costs, and availability of the equipment.

US allows the visualization of all relevant anatomical structures of the stellate ganglion region (Figure 1) and has first been described in 1995 as a useful guidance tool for stellate ganglion block. Direct visualization of the target, all nearby structures, the needle, and local anesthetic spread enabled a safe and effective sympathetic block. Compared with the blind-puncture group in this study, a reduction in the amount of local anesthetic to 5 mL was achieved. Moreover, the block onset was hastened by using US. There was no hematoma in the US group, but 3 of 12 in the group were treated by the blind approach.

Since then, progresses in transducer and imaging technology have further improved the accuracy to exactly identify the individual anatomy during US-guided stellate ganglion block. US-guided stellate ganglion block is now the standard procedure performed by the authors. Although clinical studies are lacking, it seems reasonable that a puncture under direct US vision has the potential to decrease the rate of complications and to improve the reliability of stellate ganglion block compared with a blind technique, provided that the practitioner has gained appropriate instruction and experience with the procedure.

Intercostal nerve blocks

Intercostal nerve blocks are performed for a variety of pain conditions, ranging from acute postoperative pain to chronic pain syndromes. Following thoracotomy, about 50% of patients develop chronic pain. In those patients who do not respond to conservative treatment, intercostal blocks may be performed for diagnostic purposes, for instance, to predict the effect of cryoanalgesia of the intercostal nerves. Anecdotic reports suggest that repeated blocks with local anesthetics may provide long-lasting pain relief. The validity of diagnostic blocks, as well the efficacy of therapeutic local anesthetic blocks and cryoanalgesia, has not yet be proven by appropriate controlled trials, but these procedures are still used by pain physicians.

Using the standard technique, the lower edge of the rib is palpated and the needle is first advanced until bone is contacted at this location. Thereafter the needle is moved caudally and advanced 2 to 5 mm further into the intercostal space and up to 5 mL of local anesthetic is injected. This procedure may produce high blood levels of local anesthetic, especially if several intercostal spaces are injected.

There are no published data on US-guided intercostal nerve blocks. Thus, the following technique is based on

Figure 1  Ultrasound anatomy of the neck for stellate ganglion block. T: trachea. Th: Thyroid gland. CA: carotid artery. J: jugular vein. TP: transverse process of C6. O: Esophagus. Note that the traditional blind technique, implying an anterio-posterior needle direction perpendicular to the frontal plane, would invariably injure either the thyroid gland, the carotid artery, or even the esophagus. A possible approach in this patient under ultrasound guidance would be an oblique needle direction, by which the needle is advanced laterally to the great vessels toward the transverse process of C6.
the personal experience of the authors. Using US, the nerves are rarely seen because they lie close to or are covered by the caudal edge of the rib. In contrast, the spread of the injected solution can mostly be seen clearly by US during the injection. Usually 2 mL of local anesthetic is sufficient to fill the intercostal space, which allows the block of several intercostal nerves with minimal risk of local anesthetic toxicity. Interindividually, the width of the intercostal space may vary and sometimes more volume has to be applied to fill the intercostal space. Thus, the use of US allows an appropriate dosage based on the individual anatomy.

When performing cryoanalgesia using US guidance, the formation of the ice ball around the tip of the cooled probe may be seen directly by high-resolution US (Figure 2). The probe can be redirected if the ice ball does not reach the anatomical site where the nerve is supposed to be located. Direct visualization allows the production of a matrix of lesions at different sites in the intercostal space to account for possible anatomical variations and enhance the chance of freezing the nerve. An important advantage of the method is the minimal risk of pleura injury, which is particularly important when thick probes are used and the procedure is performed on an outpatient basis.

**Block of inguinal nerves**

In anesthesiological practice, the ilioinguinal and the iliohypogastric nerve are often blocked without the use of an imaging technique. A well-known indication is postoperative pain relief in children after hernia repair. However, complications, such as femoral nerve palsy or even a small-bowel perforation, are described with this blind technique.

Chronic pain after inguinal hernia repair represents an important problem. A systematic review found that chronic postherniotomy pain occurs in 15 to 53% of cases, with about one-third of patients reporting moderate to unbearable pain. Considering the very high number of operations performed, this pain syndrome probably affects the quality of life of many patients and causes high social costs. The mechanisms responsible for the pain complaints are unclear. A possible explanation is neuropathic pain due to damage of the genitofemoral, ilioinguinal, or iliohypogastric nerves.

In patients with chronic pain that is unresponsive to conservative treatment, diagnostic blocks of these nerves may be performed to predict the effect of cryoanalgesia. A case series on 10 patients undergoing cryoanalgesia showed encouraging results, but in this study the nerves were isolated surgically under local analgesia and the follow-up data were partly lacking. US offers a perspective of precise percutaneous approach to these nerves, but cryoanalgesia remains a poorly documented treatment modality, independent of the imaging technique.

Again, the following section is not based on published evidence, but rather on personal experience. The ilioinguinal and the iliohypogastric nerve may be visualized using...
high-resolution US. Just medial and cranial to the superior iliac crest, they are lying between the external and internal oblique or the internal oblique and transverse abdominal muscles. Important anatomical variations on the location of the nerves exist. Usually, 1 to 2 mL of local anesthetic is enough to see fluid completely surrounding the nerves after the injection. Unfortunately, the ilioinguinal and iliohypogastric nerves cannot be visualized in all subjects. Moreover, the genitofemoral nerve is important for the innervation of the inguinal region and is unlikely displayed by US, probably because of its deep course. Thus, important limitations apply to US-guided blocks of the inguinal region, but this issue has never been subjected to scientific investigation.

Block of other nerves, stump neuroma, ganglia, and caudal injections

In contrast to the peripheral nerve blocks performed for anesthesiological purposes, only nerves without motor function are possible targets for pain therapists. The pure sensitive nerves may be treated by either radiofrequency neurectomy, cryoanalgiesia, or chemical neurolysis, provided that diagnostic blocks reduce pain significantly and consistently after at least two diagnostic sessions. Again, the evidence supporting this practice is very weak. Therefore, these destructive procedures are confined to very selected cases, in the hands of experienced practitioners and with a mandatory long-term follow-up. In these cases, US may offer an additional tool to increase efficacy and safety, despite the absence of published data.

Examples of nerves that are of potential interest for the pain physician are the superficial radial nerve, the sural nerve, and the saphenous nerve. The latter two nerves may be sonographically well identified because the greater or small saphenous vein accompanies them. These veins are easily visualized directly under the skin. The superficial radial nerve may be seen a few centimeters distal to the elbow just after the division of the radial nerve into its deep and superficial branch. At this place, the superficial radial nerve lies directly between the brachioradial and the supinator muscle and meets the radial artery a few centimeters more distally.

Stump neuroma after amputation of a limb may be a cause of persistent pain. US may be useful in the diagnosis of such stump neuroma. Diagnostic blocks of the neuroma using US help to identify the pain generator, eg, the anatomical source of pain in these patients. Following positive local anesthetic blocks, US-guided intraneuronal injection of phenol may be a therapeutic option. A special case is represented by celiac plexus block.

Neurolytic celiac plexus block is superior to placebo in relieving pain in patients with inoperable pancreatic cancer. In this respect, this procedure is one of the few interventional pain techniques that have been subjected to a double-blind randomized controlled trial. US has been employed to perform this block using an anterior approach. However, retroperitoneal abscess has been reported after US-guided celiac plexus block, suggesting that the traditional posterior approach under fluoroscopy may still be the safest choice.

Epidural injection of steroids is frequently performed to treat radicular pain. The transforaminal approach with fluoroscopic guidance allows a selective injection at the target nerve root and its efficacy is supported by randomized controlled trials. To date, this procedure cannot be performed with US guidance because of the depth of the target structures. The caudal injection of steroids via the sacral hiatus is less selective, because only a small part of the injected solution reaches the nerve root that is supposed to cause the symptoms. The published literature is weak and shows, at best, short-term benefits. Nevertheless, injections of steroids via the caudal route are easy to perform and are widely used by practitioners without imaging techniques. However, the sacral hiatus may be difficult to identify and US may be a useful tool for appropriate caudal needle placement.

Trigger/tender point injections

Trigger and tender points are commonly identified in pain patients. However, there is no valid diagnostic tool to detect these points, nor there is agreement on the definition and meaning of trigger and tender points in chronic pain conditions. A trigger point may be defined as a focal, hyperirritable spot located in a taut band of skeletal muscle. The spot is painful on compression and can produce referred pain (ie, pain at a distance to the site of stimulation), motor dysfunction, and autonomic phenomena. In patients with painful muscle spots, the above criteria for the definition of a trigger point are often not fulfilled and therefore it may be better to call them tender points. Tender points are associated with pain at the site of palpation without necessarily evoking referred pain and associated phenomena. It is unclear whether a painful spot is the result of pathological changes at the site of pain, or rather a referred pain area. In the latter case, the primary nociceptive focus would be localized at another anatomical structure.

There is very weak scientific evidence that trigger/tender point injections with saline, local anesthetic or dry needling are effective. Nevertheless, they are widely used for the treatment of patients with musculoskeletal pain conditions. Recently, unspecific injections have produced impressive results in chronic low back pain, suggesting that unspecific treatment effects may have a value in those pain conditions.

One of the possible explanations for the low effect of trigger/tender point infiltrations may be the fact that it is difficult to inject the target spots selectively. The accurate localization and injection of deep structures may be problematic. It is also difficult to inject all the muscle layers and fasciae corresponding to the painful spot. A possible approach is to inject a high volume of solution during withdrawal of the needle, which may increase the risk of local anesthetic toxicity, especially when multiple points are injected.

An alternative approach is to perform trigger/tender point infiltrations under US visualization. In some cases it is possible to see a muscle twitch when the needle is entering the trigger point in the target muscle. Different muscles and
fascia planes may be infiltrated selectively. A further advantage of the method is the avoidance of inadvertently entering deep structures. Particularly in the thoracic and lower cervical region, US visualization may prevent the puncture of the pleura, which may be situated only some millimeters deep to the target muscles (Figure 3).

As for the previous indications, US is not a means to justify the use of a treatment modality that is still controversial, but rather an additional tool for those practitioners who believe in the efficacy of trigger/tender point injections.

Conclusions

US is a promising imaging technique in interventional pain management. This review identified potential applications of US for which there is no alternative imaging technique. This is mostly the result of the unique ability of US to visualize nerves of small size. For other applications, US could be seen as a potential competitor of fluoroscopy, CT, or blind approaches. However, US has limitations that preclude its use for several currently performed pain procedures. For instance, at present there is no way to perform effectively and safely transforaminal steroid injection or disc stimulation (discography) using US guidance. For these and other applications, fluoroscopy has still no competition.

Reading a review or a book chapter cannot learn US-guided pain procedures. Nerve sonography requires excellent anatomical knowledge and experience. The identification of the nerves is frequently difficult. Because US-guided pain management is a new field, there is a lack of research. Future clinical studies should focus not only on developing techniques of US-guided procedures, but should also compare the effectiveness and safety of US with the already available imaging techniques or blind approaches. Until these studies are made, US cannot replace fluoroscopy or CT in routine clinical practice. Rather, only physicians who have been trained appropriately and practice under supervision of an experienced sonographer should use it, until familiarity with the method is gained.

Independent of the imaging technique, too many pain procedures are still supported by very little research attesting their efficacy and safety.

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