Ultrasonography uses high-frequency sound waves (ultrasound) to produce dynamic visual images. For decades, radiologists, or specially trained technicians, have used ultrasonography as a standard imaging tool. Examination of body cavities, glands, blood vessels, and other tissues has been routinely performed, often in conjunction with nerve blocks, fine-needle biopsies, joint injections, or vascular catheterization. Compared to other imaging equipment, ultrasound machines are transportable, free of radiation or magnetization, and relatively inexpensive. Nevertheless, until recently, the images produced have not been detailed enough for ultrasonography to successfully compete with traditional radiological methods.

Compared to other imaging equipment, ultrasound machines are transportable, free of radiation or magnetization, and relatively inexpensive

In the specialty of pain medicine, as well as in orthopedics and spinal and neurological surgery, ultrasonography excited little interest, while other imaging techniques achieved great popularity, particularly in affluent countries. Magnetic resonance imaging (MRI) and positron emission tomography are now widely used to provide precise anatomical diagnoses, producing impressive but costly images of the musculoskeletal system.¹ Yet despite the availability of advanced imaging, millions of injections intended to treat pain are performed with no imaging at all. Advanced pain practices usually use fluoroscopy, which is accurate when bony structures are targeted, but cannot be used to identify soft tissue, including nerves and blood vessels. Bony landmarks are thus used as a surrogate target, assuming the nerves or joint spaces are located nearby. Computed tomography (CT) provides better guidance, but still lacks the ability to identify nuances of anatomy. It is also less available, is time-consuming, and can be problematic in terms of radiation safety. Injections performed without any imaging at all are generally diagnostically inaccurate and often therapeutically ineffective.

Pain researchers have used sophisticated imaging techniques such as functional magnetic resonance and positron emission scanning of the central nervous system (CNS).² For example, thanks to sophisticated CNS imaging, fibromyalgia, literally pain in muscle and fibrous tissue, is now considered a central disorder (a hyperalgesic state). However, the name of the disorder was proposed many years ago on the assumption of ongoing pathology in the periphery. More accessible imaging might have allowed
an earlier understanding that despite clinically appreciated tissue sensitivity, there is no obvious muscle pathology. Myofascial pain is another clinical diagnosis that is traditionally based on identification of pathology in the periphery, called trigger points. Extensive theories were built around these points, but until recently no imaging of the affected muscles was undertaken. Interestingly, it was ultrasound that helped to identify and characterize these pathological foci, which appear as 1–2-mm lesions that can be recognized using vibration sonoelastography and the color variance mode. Another example is a painful neuroma that has traditionally been diagnosed without imaging, with clinicians relying instead on Tinel’s sign as the standard indicative maneuver. While chronic pain can often be managed symptomatically, we should not forget that it can also be a symptom of underlying peripheral pathology (e.g., in nerves, muscles, or tendons). It is important to identify an underlying cause so that it can be directly addressed.

**Does ultrasonography offer hope in terms of expanding the use of imaging for pain diagnosis and treatment, or enhancing knowledge of pain conditions?**

Does ultrasonography offer hope in terms of expanding the use of imaging for pain diagnosis and treatment, or enhancing knowledge of pain conditions? The question arises because as sonographic imaging technology becomes progressively refined, the images produced become easier to interpret, the apparatus becomes increasingly portable, and in terms of its low cost and safety, ultrasonography continues to compete favorably with techniques such as fluoroscopy, CT, and MRI. These considerations may be particularly important for rural areas and the developing countries. “Despite the exponential growth of scientific and technological development, low- and middle-income countries are still largely excluded from access to appropriate and affordable health technologies,” according to the World Health Organization (WHO). The WHO has long recognized the need for cost-effective and readily transportable imaging technology, and portable ultrasonography is particularly suitable for this mission. The WHO published its first manual of ultrasonography in 1995. A new edition dealing with vascular and parenchymal sonography has been posted, and a second volume highlighting musculoskeletal applications is in preparation.

**The WHO has long recognized the need for cost-effective and readily transportable imaging technology, and portable ultrasonography is particularly suitable for this mission**

**The Role of Ultrasonography in the Management of Chronic Pain**

Musculoskeletal disorders constitute the majority of the problems pain physicians deal with worldwide. Tendinopathies, arthritis, back and neck pain, nerve injuries and entrapments are examples. A “clinical diagnosis,” based solely on history and physical examination, may be confusing and inaccurate. At the same time, clinicians should not routinely send patients for time-consuming and expensive tests such as MRIs. Moreover, MRI is contraindicated in patients with pacemakers and other metal implants. Up to 9% of patients cannot tolerate MRI owing to claustrophobia and require additional sedation or even general anesthesia. Sonography allows patients to be examined in a more comfortable position, avoiding prolonged and sometimes painful immobilization in the MRI scanner. Patient and practitioner interaction during ultrasound examination is an invaluable addition to the imaging itself. Pressure from the transducer may elicit tenderness, providing information that can be useful to compare with the scan showing the composition of the underlying tissue. Dynamic imaging reveals transient conditions that cannot be visualized by static scanning. Many abnormalities are not detectable when a patient is at rest. The patient may have a swelling, pain, or clicking that occurs only with a certain movement. Examples include shoulder impingement, snapping hip syndrome, subluxations, tendon gliding, ulnar nerve dislocation, and muscle hernia (Fig. 1).

**Patient and practitioner interaction during ultrasound examination is an invaluable addition to the imaging itself**

Ultrasound is an excellent imaging modality to diagnose tendinosis, tendon tears, and bursitis. Accuracy in the diagnosis of rotator cuff tears can reach 100% (full thickness tears) and 91% (partial thickness tears), depending on the experience of the individual performing the examination. With sufficient training

**Fig. 1.** A young athlete complains of excruciating pain in the shin during exercise. Dynamic ultrasound examination reveals a hernia of the tibialis anterior muscle (arrowhead).
and experience, a diagnosis may be established at the point of care during the first encounter with a patient. Even a beginner can diagnose massive fluid collection in a joint or bursa (Fig. 2). More training is required to localize partial rotator cuff tears or peripheral nerve entrapments (Fig. 3). Nonetheless, all physicians have mastered auscultation during their initial medical education and consider it a core of their examination repertoire. Similarly, and thanks to professional societies and learning endeavors, continued education in diagnostic musculoskeletal ultrasound is possible. For example, the European Society of Skeletal Radiology provides excellent imaging tutorials on its website (www.essr.org), and the American Association of Pain Management in Ultrasound (www.aapmu.org) offers practical hands-on courses customized for pain physicians.

**Ultrasound is an excellent imaging modality to diagnose tendinosis, tendon tears, and bursitis**

Procedural ultrasound guidance is another useful and practical application. Real-time control is ideally suited for delivering local anesthetics, corticosteroids, botulinum toxin, and other agents. Detailed description of these techniques is beyond the scope of this article, and the reader is referred to four comprehensive reviews.9-12 Ultrasound guidance is intuitively superior to “blind injections” and has been experimentally confirmed in joint injections.13,14 A comparison with other imaging modalities makes sense when developing standards of care. If ultrasound accuracy compares favorably with fluoroscopy or CT, it should be recommended as a standard, given its cost-effectiveness and radiation sparing. However, contemporary standards were not developed on the basis of scientific data. Only a few validation studies have been published in which cadaver dissection and image-anatomy correlation were performed to confirm the precision of various injections. Nevertheless, a hierarchy of evidence of ultrasound-guided procedures can be formed, as shown in Table I. The following section describes a selection of the most useful and common procedures.

**Useful and Common Ultrasound-Guided Pain Procedures**

**Stellate Ganglion Block (Level II)**

Stellate ganglion block (a sympathetic block of the head, neck, upper extremity, and thorax) was implemented by R. Leriche for management of angina pectoris, and the method has been practiced since 1930 without significant modifications. Currently, it is a common intervention in the diagnosis and management of sympathetically mediated pain and vascular insufficiency of the upper extremities. Both surface anatomy-based and fluoroscopy-guided approaches are insufficiently accurate and may result in complications, such as retropharyngeal hematoma, recurrent laryngeal nerve damage, and infections.15 An anatomically sound sonography-guided method was developed to selectively target the cervical sympathetic trunk and to avoid potential direct damage of the surrounding vascular, neural, and parenchymal organs. The needle is directed from the lateral side to the prevertebral fascia anteriorly to the longus colli muscle, where the lower part of
the sympathetic trunk is located. A typical thickening of the fascia is often sonographically identifiable, serving as a target point. This thickening is none other than a division of the prevertebral fascia containing the traversing sympathetic trunk and, in 30% of individuals, the middle cervical ganglion. Injection of 3–5 mL of local anesthetic will consistently spread over the fascial plane from C3 to T2 vertebrae and will result in reliable blockade of the cervicothoracic ganglion.16

Intercostal Nerve Block (Level III)

This procedure has an important role in the management of acute pain after rib fractures or thoracotomy. It is also valuable as a diagnostic block or in the management of intercostal neuralgia in pain clinics. The routine technique carries a risk of pneumothorax as high as 8%.17 Conventionally, injections are performed distal to the rib angle, and the lateral cutaneous branch may not be anesthetized. Ultrasound guidance provides another option that is safe and efficient. An approach on the medial side of the rib angle allows complete block of the corresponding intercostal nerve while keeping the pleura under direct view, thereby avoiding pneumothorax. In addition, painful needle contact with the rib periosteum, which has been utilized in methods that were not guided by imaging, is no longer required. Surprisingly, in spite of the widespread use of ultrasound guidance for intercostal injections, only case series and retrospective studies have been published. Therefore, the level of evidence is “limited.”

Anesthetic Blockade of Peripheral Nerves (Level I)

Instillation of local anesthetic adjacent to the nerves of the trunk and extremities is within the scope of regional anesthesia. Despite their effectiveness in providing surgical anesthesia and postoperative pain control, these techniques have a role in chronic pain management that is usually limited to diagnosis of a putative source of ongoing pain. When analgesic blocks are used for diagnosis, ultrasound guidance is particularly important because usually small nerves (e.g., the superficial radial, ilioinguinal, lateral femoral cutaneous, saphenous, and plantar nerves) are targeted, and only a minimal amount of anesthetic is injected in order to provide diagnostic precision (Fig. 4). Moreover, often regional anatomy is distorted by previous surgery or trauma, and only real-time ultrasound may help in finding a displaced nerve.

Multiple cadaver and clinical studies have been published in the regional anesthesia literature, with conclusive evidence concerning procedural accuracy of peripheral nerve blocks.

Often regional anatomy is distorted by previous surgery or trauma, and only real-time ultrasound may help in finding a displaced nerve.

Joint and Bursa Injections (Level I)

Steroid injections into the joints and bursae are very commonly utilized in any pain or physical medicine and rehabilitation clinic. Traditionally performed without imaging guidance, these procedures are perceived as minor and harmless. However, this may not be the case. First of all, so-called “blind” injections are inaccurate. Shoulder joint injections performed by orthopedic surgeons may have a 73% failure rate,18 and hip injections are accurate in only 60–80% of cases.19 When patients do not get better after a procedure that was expected to be curative, another procedure is usually offered to make up for the initial technical failure. This process may repeat itself countless times and result in steroid side effects, both local (e.g., liponecrosis) and systemic (e.g., hyperglycemia, hypertension, Cushing syndrome). In addition, mechanical damage of the joint cartilage, tendons, and joint capsule may occur. The benefits of ultrasonography have been reported in multiple clinical studies including randomized controlled trials.
that compared ultrasound guidance to the conventional palpation-guided method. One study showed 43.0% reduction in procedural pain ($P < 0.001$), 58.5% reduction in absolute pain scores at the 2-week follow-up ($P < 0.001$), 75% reduction in significant pain ($P < 0.001$), 25.6% increase in responder rate ($P < 0.01$), and 62.0% reduction in non-responder rate ($P < 0.01$). Sonography also increased detection of effusion by 200% and volume of aspirated fluid by 337%. Another study reported relative 81% reduction in injection pain ($P < 0.001$), 35% reduction in pain scores at outcome ($P < 0.02$), 38% increase in responder rate ($p < 0.003$), 34% reduction in non-responder rate ($P < 0.003$), 32% increase in therapeutic duration ($P = 0.01$), 8% reduction ($\$7$) in cost per patient per year, and 33% ($\$64$) reduction in cost per responder per year for a hospital outpatient ($P < 0.001$).

One of the main advantages of performing intraarticular injections under ultrasound is that the joints are accessed via the synovial recesses, which prevents painful needle contact with bone or cartilage (Fig. 5).

**Spine Injections (Level I)**

Perhaps the major advantage in ultrasound-guided spine interventions is the lack of radiation exposure. Spine procedures constitute the vast majority of specialty pain medicine invasive methods, and the annual dose of ionizing radiation can be significant for both patients and personnel. On the other hand, given the significant attenuation of an acoustic signal by bone structures and the considerable depth of the intervention, these procedures are challenging for sonographers.

Epidural interlaminar steroid injection is the most commonly performed pain management intervention. The main limitation in implementing ultrasound guidance is the acoustic sheltering and thus the inability to confirm the spread of the injectate, which may be particularly important if a specific spinal level or root is targeted. Nevertheless, since the procedure is still performed in an office setting in a majority of pain clinics worldwide without imaging, ultrasound can effectively facilitate localization of precise spinal level and help decrease procedure time and number of attempts by identification of bony landmarks to assist with needle placement. It may be particularly helpful in patients with difficult surface anatomy because of obesity, previous lumbar surgery, or scoliosis. Ultrasound-guided subarachnoid injections of opioids and baclofen can easily be performed at the bedside in the context of an intrathecal trial, thus eliminating cumbersome arrangements with the fluoroscopy department and assuring technical accuracy.

As in the case of interlaminar epidural steroid injections, ultrasound is helpful in identification of bony landmarks during a caudal epidural steroid injection; as much as a 10% variation in sacral anatomy has been reported. Up to 25.9% of caudal epidural placements, performed without image guidance, were misplaced. In a study by Chen et al., placement of ultrasound-guided caudal epidural was confirmed by fluoroscopy with a 100% success rate; however, once the needle was advanced into the sacral hiatus it could no longer be visualized as it was obscured by bony landmarks.

Lumbar zygapophysial (facet) intraarticular joint injections were most likely the first ultrasound-guided spine injections to be validated against CT-guided injections. The cleft of the zygapophysial joint is usually visualized utilizing the transverse view of the lumbar vertebra. A recently completed cadaver study confirmed the feasibility of the ultrasound-guided injections as compared with standard imaging (Fig. 6). The contrast was seen

![Fig. 5. Intraarticular hip joint injection. The needle tip (arrowhead) is placed into the distended by effusion anterior synovial recess (black). Notably, the needle cannot be seen completely—a typical appearance when a curvilinear transducer is used. IP, iliopsoas muscle; FH, femoral head; FN, femoral neck.](image)

![Fig. 6. Lumbar zygapophyseal joint injection. The needle (arrowheads) is inserted into the joint. ES, erector spinae muscle; QL, quadratus lumborum muscle.](image)
in the joint in 88% of cases. If “invisible” joints were excluded, the success rate would be as high as 96%.26

Sacroiliac joint injections can technically be done under ultrasound guidance. Two approaches, superior and inferior, were recently described. A cadaver study by Klauser et al.27 investigated the feasibility of the injections in two different locations, the first at the level of the first posterior sacral foramen and the second at the level of the second posterior sacral foramen. When these techniques were applied in 10 patients, CT verification showed an 80% success rate of the intraarticular contrast spread.28 Another study by Pekkaiahli et al.29 showed a 76.7% success rate, with a steep learning curve.

Spinal injections under ultrasound have triggered the most intensive debates concerning procedural accuracy compared with X-ray-based techniques. However, ultrasound techniques have been extensively evaluated in both the preclinical setting, utilizing imaging with anatomical correlation, and in clinical comparative experimental work. Evidence is therefore considered conclusive.

**Ultrasound-Guided Intrathecal Drug Delivery Pump Refill (Level II)**

Intrathecal pump drug refill may result in so-called “pocket fill” that subsequently may lead to significant adverse outcomes. A recently published report of 351 complications, including 8 lethal events, alarmed the Food and Drug Administration (FDA), which subsequently published a Class I recall on the agency website.

An ultrasound-guided technique of the pump access and control of the refill procedure has been published and validated. Direct visualization of the needle entry into the reservoir and monitoring of the drug instillation using Color Doppler may effectively prevent erroneous pocket injection.30 In addition, ultrasound can be used in diagnosis of the infrequent but serious problem of an inverted or “flipped” pump, or it can help in differential diagnosis of reactive effusion versus infection.

**Emerging Techniques**

Preoperative neuroimaging may be used to optimize surgical planning and facilitate access to anatomically challenging nerve structures. Operative access to a target nerve can sometimes be challenging, making the operation more extensive. Individual variations of human anatomy are common and unpredictable, especially regarding small branches of distal nerves. The application of ultrasound in the surgical environment—intraoperative ultrasound—could therefore be of great benefit in guiding the surgeon to the targeted nerve through a more direct pathway, and in a more rapid manner. Cokluk et al.31 showed the value of ultrasound in making pathological diagnosis preoperatively. Koenig et al.32 demonstrated the accuracy of high-resolution intraoperative ultrasound in grading of peripheral nerve injuries, as confirmed by intraoperative electrophysiological recording. This technique was particularly useful for identification of reversible versus irreversible nerve lesions. Correlation between sonographic nerve appearance and the compound nerve action potential was tremendously accurate.

**The application of ultrasound in the surgical environment, intraoperative ultrasound, could therefore be of great benefit in guiding the surgeon to the targeted nerve through smaller incisions, via a more direct pathway, and in a more rapid manner**

Another interesting development is a magnetic positioning system that may be used as an enhancement for procedural accuracy. Addition of this navigation system makes it possible to approach a desired target without using traditional in-plane and out-of-plane techniques. Early results in both the laboratory and clinical setting are encouraging. The navigation system may be used with a portable ultrasound machine or may be part of more sophisticated “fusion” methodology, when a second imaging modality (e.g., CT or MRI) is used to “overlay” preprocedural study on real-time ultrasonography and guide the needle or other device using a virtual reality animation.

**Three-dimensional imaging is another new advance in ultrasonography**

Three-dimensional imaging is another new advance in ultrasonography. This technology provides fascinating pictures in cardiac and obstetric imaging, but it is less useful for diagnostics of the spine or extremities. The reason is the purely physical properties of sound wave speed in the human body. While the sound wave is sharply different between liquid and solid organs (i.e., fetus face and amniotic fluid), it has only vague variations in speed when passing through other tissues. More research and development are needed to see, for instance, the rotator cuff complex as a three-dimensional anatomy class model.

One of the fundamental limitations of the ultrasound-guided injections is the inability to reliably diagnose intravascular injection, which makes it potentially unsafe, especially when large volumes of local anesthetics, insoluble corticosteroids, or neurolytic agents are injected. Development of “smart needles” using either photonic emission or computed coherence tomography may solve this difficult problem. A recent study showed promising results in identification of the intravascular position of the needle tip using optical reflectance spectroscopy.33

**Conclusion**

Ultrasonography opens a new, albeit two-dimensional and grayscale, window into the fascinating world of human anatomy. Bedside point-of-care sonographic imaging is an invaluable clinical tool in diagnosis of musculoskeletal and neurological pathology. Procedural ultrasound effectively provides guidance to ensure precise targeted delivery of drugs and to avoid complications associated with surface anatomy-based injections.
Ultrasoundography opens a new, albeit two-dimensional and gray-scaled, window into the fascinating world of human anatomy

New developments are under way, such as needle navigation systems, optical recognition of different tissues, photonic needles, and ultra-high-definition ultrasound. Validation studies comparing ultrasound with other traditional radiological methods are necessary to prove the comparability and in many cases the superiority of this rapidly progressing field of medical imaging. As ultrasoundography becomes increasingly accessible and easier to use, it opens up many treatment and research opportunities. Importantly, assuming that cost and practicality continue to compare favorably, diagnostic sonography and ultrasound-guided interventions could become routine, especially as the technology improves and the images become easier to interpret.

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