# Advanced Ultrasound Imaging in Pain Medicine

**Michael Gofeld, MD**

*Assistant Professor*
*Center for Pain Relief*
*University of Washington*
*Seattle, Washington*

*Dr. Gofeld has a consulting agreement with and provides equipment support for SonoSite and provides equipment support for Philips Healthcare.*

Scientific progress was defined by Boyd as a cyclical process in which development of methods is used to construct scientific theories; these theories lead to more methods, which are then used to develop further theories, and the process continues.[1] In the medical field, the steady development of technology involving ultrasound imaging, and its resulting clinical use, is an outstanding illustration of this process.

**Table.** **Ultrasound-guided Interventional Procedures[4]**

| Procedure | Level of Evidence[a] |
|---|---|
| SPINAL | |
| Interlaminar epidural injection of corticosteroid | IV |
| Caudal epidural injection of corticosteroid | IV |
| Transforaminal lumbar (periradicular) injection | III |
| Transforaminal cervical (periradicular) injection | III |
| Third occipital nerve block | II |
| Cervical medial branch block | IV |
| Cervical zygapophysial joint injection | III |
| Lumbar zygapophysial joint injection | I |
| Lumbar medial branch and dorsal ramus block | I |
| NON-SPINAL | |
| Stellate ganglion block | III |
| Greater occipital nerve block | IV |
| Suprascapular nerve block | IV |
| Intercostal nerve block | IV |
| Celiac plexus block | I |
| Ilioinguinal and iliohypogastric nerve block | II |
| Pudendal nerve block | III |
| Anesthetic blockade and ablation of pure sensory nerves | IV |
| Anesthetic blockade and ablation of painful neuroma | IV |

[a] Level I: Conclusive; Level II: Strong; Level III: Limited; Level IV: Indeterminate

Karl Dussik ingeniously first recognized the potential medical applications of ultrasonography, which he termed "hyperphonography of the brain," in a 1942 paper.[2] Dussik was the first physician to perform a cranial sonogram for the diagnosis of brain tumors and also the first to apply ultrasound in early pregnancy. Furthermore, Dussik performed some of the earliest ultrasound research in painful conditions such as arthritis and multiple sclerosis.[3]

Since the time of Dussik's work, medical ultrasonography has slowly made its way into medical research and clinical practice in several specialty fields. In regional anesthesiology, for example, the use of ultrasound is commonplace, particularly in peripheral nerve blockade and neuraxial structure visualization.[4] However, several major obstacles have slowed the clinical use of this technology in chronic pain medicine. Obstacles include poor image quality, at first;

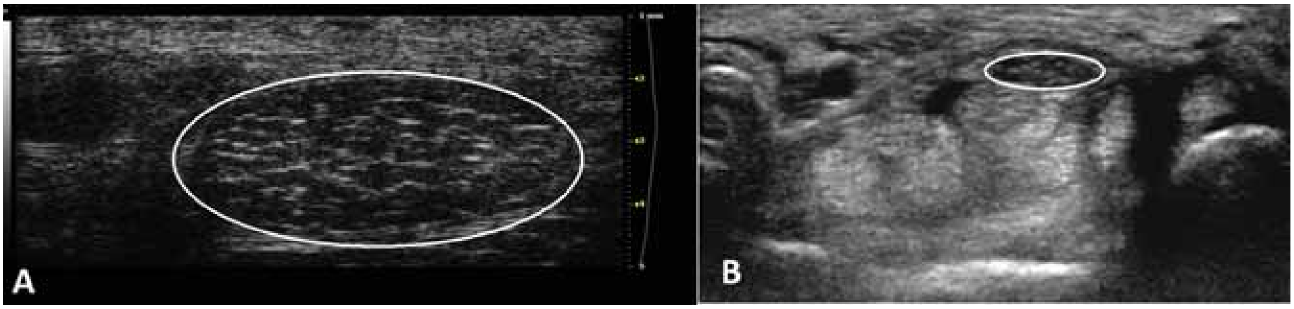

**Figure 1.** **Ultrasonography of the median nerve at wrist. In (A), the nerve is seen with a 50 MHz transducer; in (B), the same nerve is examined under conventional 12 MHz sonogram.**

the need for extensive training due to the many technical demands of ultrasound; a reliance on magnetic resonance imaging (MRI), fluoroscopy, and computed tomography (CT); reluctance on the part of payers and patients; and questionable quality control of ultrasound-guided injections.[4] Until fairly recently, diagnostic and procedural ultrasound remained an interesting "wizard's tool," in the eyes of many.

## A Golden Age of Ultrasound Development

During the past decade, there has been a renaissance for ultrasound in the field of medicine. The pace of evolution of new imaging technology has accelerated, and ultimately has resulted in the development of amazing new ultrasound equipment. This, in turn, has led to the emergence of new scientific breakthroughs, resulting in the implementation of clinical ultrasound in pain medicine—another illustration of Boyd's theory of scientific process. The areas where ultrasound-guided interventions are most commonly being performed are listed in the Table.[4]

Several factors have facilitated this breakthrough in the field of ultrasound pain medicine. First, dramatic improvement in image quality made this imaging modality comparable to magnetic resonance scanning.[5,6] Second, the equipment's portability and versatility increased, and its cost significantly decreased.[7] Third, interventional pain practitioners realized the limitations of fluoroscopy in non-spinal procedure guidance and the drawbacks of "blind injections."[7,8] Fourth and possibly most important, convenient and safe imaging modalities for office-based procedures were needed.[9,10] In addition, regulatory agencies increased awareness of x-ray hazards and raised concerns about radiation safety.[11] Data recently published by the FDA show an alarming increase in radiation-related harm, and researchers thus called for immediate action. In these circumstances, ultrasound imaging appears to be an attractive alternative to ionizing radiation.[12]

## Areas of Research Growth

In the field of interventional pain medicine, visualization of fine structures, such as nerves, fascial planes, and little joints, is imperative for accurate diagnosis and subsequent targeted treatment. There is no clinical tool other than ultrasound that meets this requirement, and there is a growing demand to improve resolution and image quality. Research efforts have resulted in the introduction of real-time compound technology, which is capable of better resolution. More recently, high-frequency ultrasound, which had been used predominantly in research, entered the clinical arena. This technology uses up to 50 MHz transducers and permits tissue visualization in almost microscopic resolution. Such a high-resolution, in vivo micro-imaging system provides clarity down to 30 microns. Soft tissues are seen nearly as histology slices (Figure 1). This may greatly facilitate the diagnosis of peripheral nerve injuries[13] and the assessment and treatment of musculoskeletal disorders.[14-16] This method has just begun to be used in the clinical pain medicine setting, but may

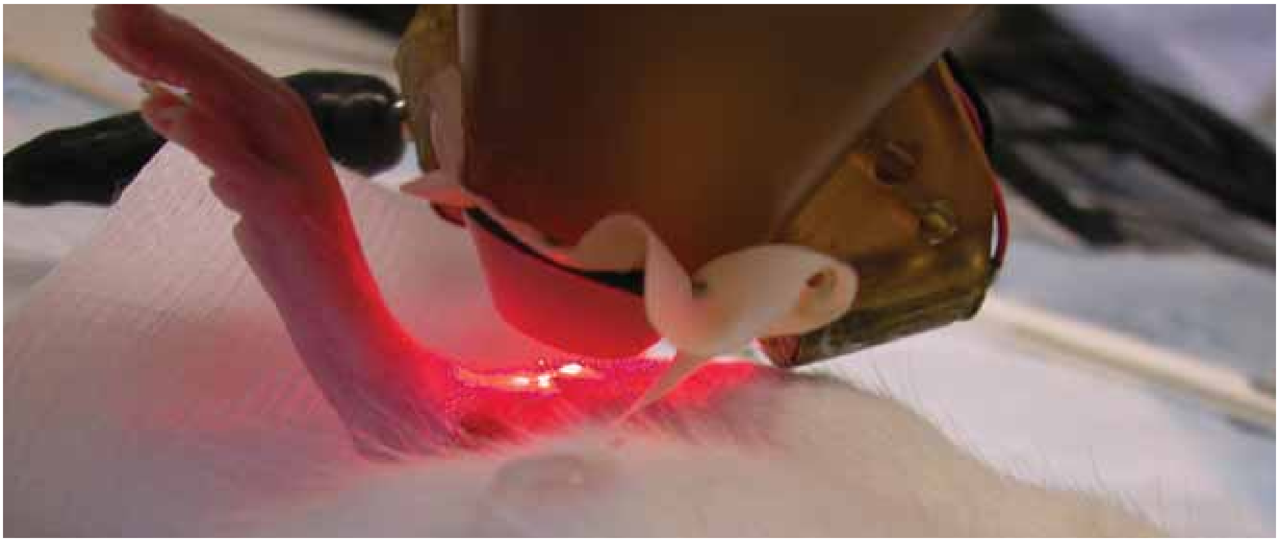

**Figure 2.** **Intense focused ultrasound of rat paw to study physiologic responses to thermal and mechanical irritation.**

**Courtesy** of Pierre Mourad, PhD

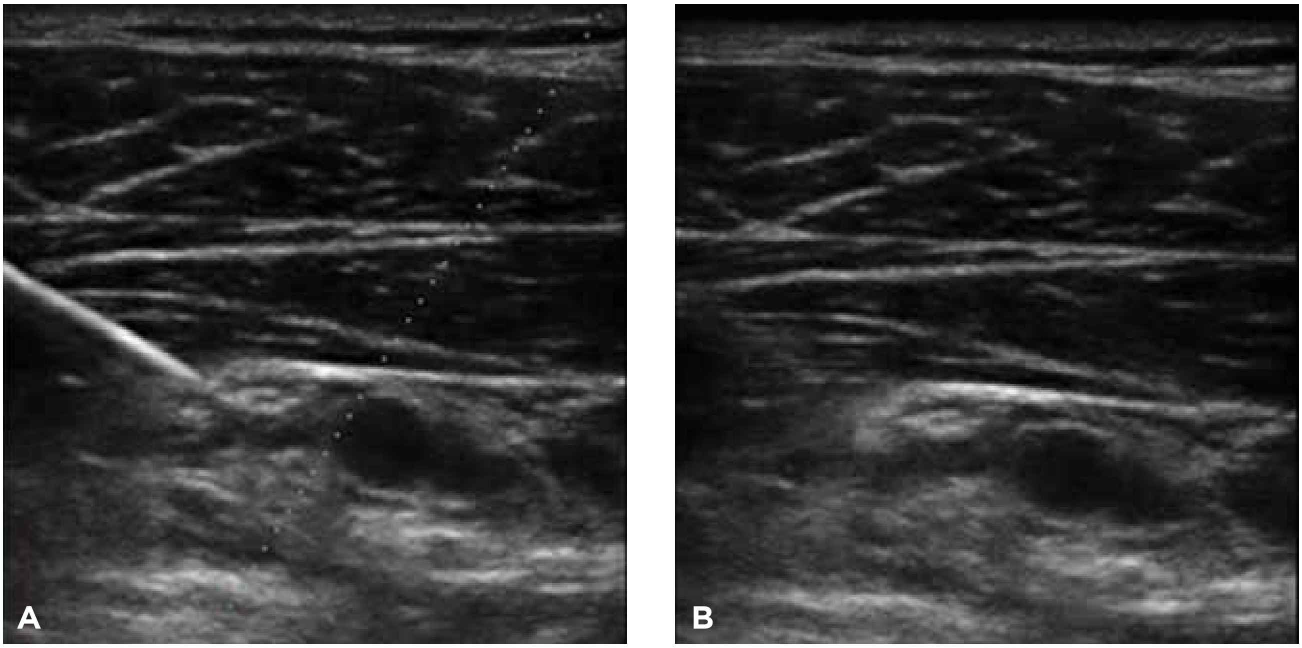

**Figure 3.** **Enhanced Needle Visualization (ENV; SonoSite). In (A), ENV is on; in (B), ENV is off.**

**ENV,** enhanced needle visualization

be accepted into routine practice in the near future. The University of Washington Imaging and Anatomy research laboratory is the first to implement high-resolution ultrasound in neuroimaging.[17,18]

Another exciting area in diagnostic sonography is the growing use of intense focused ultrasound (iFU). It seemed plausible that iFU would form the basis of a diagnostic test (Figure 2) producing discernible nonpainful sensations in a reliable fashion. Experiments in the University of Washington neurosurgery research laboratory found consistently high sensitivity and specificity for the ultrasound-induced perception in human volunteers.[17,18] Preliminary work indicates that iFU could act as a novel tool for inducing quantitative noninvasive deep focal stimulation of tissue. If so, iFU could become a useful technology for studying and diagnosing chronic painful conditions, such as fibromyalgia and arthritis. In addition, a noninvasive method for peripheral nerve stimulation might allow sensory and motor testing in regional anesthesia. Anesthesiologists would be able to localize a nerve using ultrasonography and then perform nerve testing prior to needle insertion. Future studies will assess the ability of this method to stimulate deep discrete sensations—similar to electrical stimulation—to facilitate ultrasound-guided nerve blocks and diagnose peripheral pain generators.

## The Growing Role of the Interventionalist

Another potential development in pain medicine is the imaging-guided interventional practice. In interventional pain medicine, needles and catheters must be positioned precisely to ensure efficacy and avoid complications. Here too, ultrasound technology has made significant progress. Enhanced visualization makes it possible to see the needle clearly when placing it in the plane approach. Previously, it was not possible to achieve this goal with angles steeper than 45 degrees (Figure 3). When the needle is inserted at a steep angle, the needle reflection essentially vanishes from the ultrasound image, and surrogate markers such as tissue motion and fluid injection must be used to identify the position of the needle shaft and tip on the ultrasound image. There are also echogenic needles that are specially coated or etched to make them more clearly visible on the ultrasound monitor.

Currently, special software manages the problem of ultrasound needle visualization when steep angles are formed between the needle and the ultrasound transducer. This technology consists of proprietary algorithms that enable clear ultrasound visualization of the needle even at steep angles. Unfortunately, it does not eliminate difficulties in keeping the needle steady under the ultrasound beam while progressing to the target.

**Figure 4. Guidance positioning system. The projection of the needle path is indicated by the green dotted line, the actual needle position is shown by the red figure, and the tibial nerve is denoted by white arrows.**

Recently, several ultrasound systems were introduced enabling real-time needle tracking. As the user moves the needle and the ultrasound probe to perform an interventional procedure, graphics in the ultrasound system indicate the position and orientation of the needle in relation to the ultrasound probe, and the intersection of the needle path with the ultrasound image. Based on these graphics, the user can decide how to move the needle or the ultrasound probe to align the needle with the ultrasound plane and reach a particular anatomic target. Needle tracking systems can show the position and orientation of the needle shaft and tip regardless of whether the needle is kept within the ultrasound plane or not. These systems allow the free-hand operation of the needle without cumbersome needle guide devices, although they do require the use of specialized sensors, which are mounted on the needle and ultrasound probe to track motion. Essentially, the system signals that the cannula is advanced at a particular angle and will meet the target that is seen on the monitor (Figure 4).

In contrast, when the object is deep or bone is acoustically sheltering it, real-time navigation is impossible. This particularly is true in the area of spinal

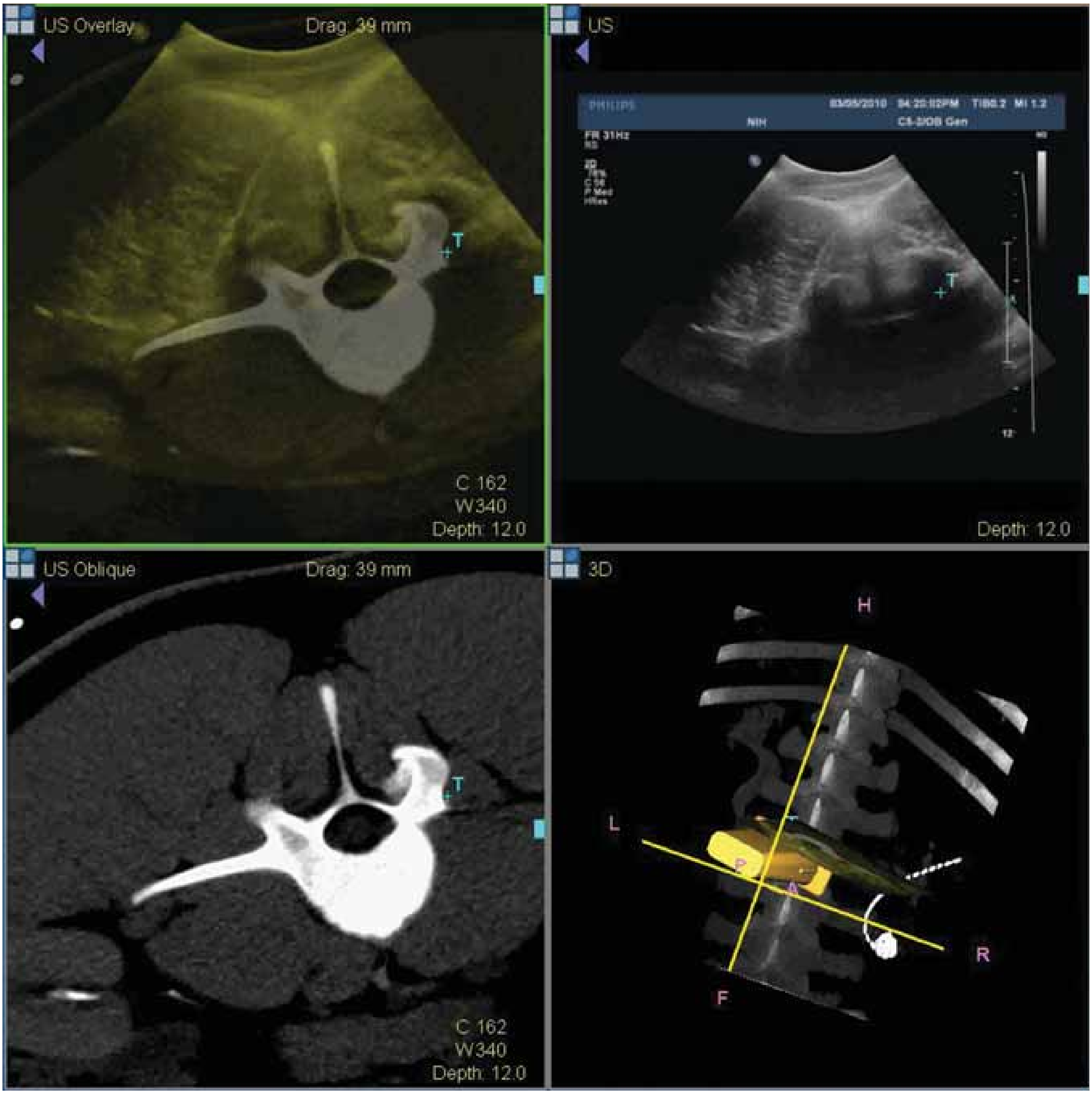

**Figure 5.** **Interventional fusion technology using CT and ultrasound on swine spine. Clockwise from upper left: overlaid ultrasound on CT image, ultrasound image, transducer position, and CT image.**

**CT,** computed tomography

**Courtesy** of Andrew Mannes, MD, William Pritchard, MD, PhD, Neil Glossop, PhD, Laura Glynn, Bradford Wood, MD, and Carey Buckner, BS, RDMS, RVT, RDCS procedures. Fusion imaging offers a technical solution for this problem. The fusion technology provides real-time, 3-dimensional visualization and navigation tools for all stages of diagnosis and intervention, including pre-procedure planning and intra-procedure navigation. It transforms 2-dimensional patient image sets (derived from CT, positron emission tomography with CT, and MRI) into dynamic maps on which a tool can be navigated. The system performs spatial mapping from one image space to another image space or from image space to physical space (registration), allowing the physician to correlate scan sets with live ultrasound of the patient. After completing ultrasound registration of definite anatomic structures (eg, spinous process), this mapping is overlaid (fused) with the pre-procedural images. This makes some structures, otherwise invisible on plain ultrasound images (such as bones), recognizable. Ultimately, complex interventions can be accomplished without use of ionizing radiation. First preclinical and clinical studies have been done on spinal injections, the major anatomic target in interventional pain management[8] (Figure 5).

## Conclusion

Much work has been done in the field of ultrasound-guided interventional pain medicine since the days of Dussik. Much more work lies ahead, however, as efforts proceed to develop new imaging techniques to improve the diagnosis and treatment of chronic pain conditions. Nevertheless, great technological progress makes further achievements possible and creates endless opportunities in clinical research and for the advancement of patient care.

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