Point-of-Care Ultrasound for Outpatient Neurology

Ultrasound is a safe, cost-effective, and easy-to-use tool for real-time in-office imaging of many neurologic conditions.

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Healthcare delivery is rapidly evolving in the US, and significant efforts have been made to expedite the speed and accuracy of diagnostic testing across a variety of healthcare settings. Point-of-care ultrasound (POCUS) has become an increasingly popular diagnostic tool to meet this need.

Ultrasound technology is used in many areas of medicine, including obstetrics, cardiology, critical care, emergency medicine, pediatrics, and primary care. Ultrasound has evolved from large immobile machines to portable devices on wheeled carts, and now, handheld devices that can fit in a clinician’s pocket, making them continuously available at the point of care. POCUS is used primarily to complement the physical exam and is of considerable interest, because it can enable disease screening, accelerate definitive diagnosis, guide clinical decision-making, and decrease overall healthcare costs.

Many different handheld devices are available, and emerging evidence suggests the accuracy of these devices often rivals or surpasses cart-based ultrasound devices and other modalities.

In neurology, there are abundant potential indications, including but not limited to evaluation of extracranial vascular disease, musculoskeletal (MSK) diseases, neuromuscular disorders (NMD), neuro-ophthalmologic conditions, and procedural guidance. The purpose of this article is to provide a background on fundamental ultrasound concepts, review various devices on the market, and discuss the potential uses for POCUS in outpatient neurology.

Fundamentals of Ultrasound Technology

Ultrasound technology uses sound waves with a frequency beyond the threshold of human hearing (>20,000 Hz). Ultrasound images are created by either a silicon chip array of microsensors or a piezoelectric transducer encased in a plastic housing. Differently shaped transducers can emit soundwaves with different foci (Figure 1) to vary the plane of imaging. As sound waves encounter tissues of varying densities (ie, with different acoustic impedances), they are partially scattered, while others return, or “echo,” back to the probe with varying intensity. Tissues such as bone are considered hyper-echoic because they reflect relatively more sound waves than hypoechoic tissues such as blood.

Reflected sound waves that bounce back interact with synthetic compounds in the transducer, (eg, quartz), causing deformations that are converted into electric signals. These signals are interpreted by a computer and displayed as pixels on a digital display. Pixel brightness is determined by the amplitude of the returning echo, which is a function of the tissue density encountered; the number of interfaces encountered by the sound wave; and the wavelength of the transduced sound wave. By measuring the time taken for the sound wave to return to the transducer, the depth of the tissue seen can be determined. Ultrasound frequencies typically vary from 1 to 18 MHz. Higher frequency sounds have smaller wavelengths and can generate very detailed sonographic images; however, high-frequency sound waves attenuate quickly and thus do not penetrate as deeply. Lower frequencies are used to image deeper structures at the cost of resolution.

Ultrasound Probe Array Types

Figure 1. Ultrasound transducers and resulting soundwave arrays.
Ultrasound uses a variety of modes to assess targets of interest. Brightness mode (B-mode) is used for structural imaging and is typically used for image-guided injections (Figure 2A), identification of lesions/cysts/tumors, localizing structural anomalies, and visualizing cardiac and vascular movement across the cardiac cycle (Figure 2B). Motion mode (M-mode) is used mostly to evaluate moving structures (eg, heart valves or cardiac activity; Figure 2B). In M-mode, a plotted waveform depicts the motion of the structure relative to the transducer image plane on the Y-axis and time on the X-axis. This modality is often used in conjunction with B-mode to appreciate the structure of interest visually. Doppler ultrasound can differentiate the movement of reflected ultrasound waves either towards or away from the probe. Doppler ultrasound is used to assess blood flow through vessels or the heart. Flow is color-coded based on the direction the fluid is traveling relative to the probe (Figure 2C).

Available Handheld Ultrasound Devices

Single-Transducer Systems

The Butterfly iQ+ is a handheld, single-probe, whole-body ultrasound scanner powered by a single silicon chip that can be connected to the user’s smartphone. The Butterfly iQ+ is designed to be used in all areas of medicine and comes with 20 imaging presets that can be used to evaluate various organ systems or body regions, including the abdominal cavity and internal organs, heart, lungs, bladder, nerves, blood vessels, muscles, eye, uterus, ovaries, testicles, and the fetus during pregnancy. This transducer is unique in that it uses ultrasound-on-chip technology that can emulate all 3 types of transducers (ie, linear, curvilinear, and phased; Figure 1), eliminating the need for multiple different probes for various applications. A relative disadvantage is that the single probe must be plugged into a mobile device display.

Wireless Multiple-Transducer Systems

Clarius offers the largest selection of handheld transducers for different applications and provides different probes and imaging sets for different medical specialties, although neurology is not yet among these. Clarius software and imaging sets also include artificial intelligence-assisted imaging algorithms. Clarius handheld transducers have the advantage of transmitting images to the chosen display wirelessly via Bluetooth technology. The VScan Extend from GE Healthcare also uses traditional piezoelectric sensing and has 2 available corded transducers; 1 is phased for deep tissue imaging and the other provides an array on each side of the transducer (dual head) for curvilinear or linear arrays. The VScan Air is a wireless version of the dual head transducer.

Other Systems and Considerations

The Philips Lumify uses all 3 types of transducers with traditional piezoelectric sensing and is connected to the user’s tablet with a cord. Lumify is also sold with Philips telehealth application, Reacts, which allows real-time image sharing with simultaneous voice communications capabilities. The Kosmos system offers 3 different transducers and comes with its own small tablet display, but also works with Android devices. Kosmos also offers an image storage platform, artificial intelligence-assisted imaging algorithms, and telehealth capabilities. Other considerations when choosing a handheld POCUS device include image storage capabilities and whether these require a cloud-based subscription, are Digital Imaging and Communications in Medicine (DICOM) compatible, and comply with Health Insurance Portability and Accountability Act (HIPAA) regulations.

Outpatient Neurology POCUS Uses

Extracranial Vascular Disease

Extracranial internal carotid artery stenosis (CAS) is a systemic atherosclerotic disease, defined as the presence of stenosis in individuals without a history of ischemic stroke, transient ischemic attack, or other neurologic signs or symptoms. Clinically significant CAS is defined by the United States Preventive Services Task Force (USPSTF) as 60% to 99% stenosis and is strongly associated with ipsilateral strokes. Screening
for internal CAS can be accomplished using Doppler ultrasound, MR angiography (MRA), and CT angiography (CTA). Auscultation for carotid stenosis has been shown to be a poor predictor of underlying internal CAS and is therefore not recommended as an appropriate screening tool.\textsuperscript{11}

Currently, screening for asymptomatic internal CAS is not guideline recommended; however, with widespread use of POCUS, high-risk individuals may be screened in an outpatient setting. Early detection of high-risk individuals would allow for the initiation of risk factor modification and optimal medical therapy, including controlling cholesterol, blood pressure, and diabetes. In addition, those found to have severe narrowing can be referred to surgery for further evaluation and potentially help prevent fatalities such as stroke. Currently, the USPSTF concludes that screening for asymptomatic CAS in the general population has no benefit and may be harmful because studies comparing surgical procedures to optimal medical therapy for CAS management have not been shown to improve survival or reduce stroke incidence.\textsuperscript{12} False positives may expose patients to unnecessary additional testing or treatment. Despite this recommendation, to date there have been no dedicated studies evaluating whether screening for CAS decreases the rates of stroke or death. We suggest the use of POCUS detection in patients with asymptomatic disease may lead to earlier implementation of optimal medical therapy and delay disease progression, prevent stroke, or even death in the long run.

**Transcranial Doppler**

Ultrasound has also been used to detect intracranial blood flow with transcranial Doppler ultrasound (TCD; Figure 2C). With this technique, ultrasound waves are sent through tissues of the skull and reflect off blood cells in vessels allowing the interpreter to detect the speed and direction of blood flow. By measuring this flow velocity, the clinician assesses for changes in flow that could indicate areas of stenosis or potential acute ischemia, vasospasm, or subarachnoid hemorrhages. TCD can also be used to assess physiologic health by detecting changes in blood pressure related to cerebral autoregulation, changes in end-tidal CO\textsubscript{2} reflecting cerebral vasoreactivity, or areas of hyperemia, which plays roles in cognition and motor activation.

**NMD**

Neuromuscular ultrasound (NMUS) can be used as an adjunct to EMG and the neurologic examination for evaluation of NMD, including myopathies, muscular dystrophy, entrapment neuropathies, and polyneuropathy. Current research is focused on developing reliable protocols for the evaluation of scapular winging, diaphragmatic weakness, and brachial plexus pathology.\textsuperscript{13-15} Ultrasound characteristics of normal skeletal muscle include heterogeneous hypoechoic areas interspersed with hyperechoic areas, which represent the normal fibrous connective tissues. When viewed in the transverse plane, this forms a “starry-sky” appearance and a “streaking” pattern when viewed in the longitudinal plane (Figure 3; Table).\textsuperscript{16} Nerve pathology can be diagnosed sonographically by measuring cross-sectional area, echogenicity, vascularity, and nerve mobility (Table). Ultrasound characteristics of normal nerve tissue include discrete “honeycomb” fascicles encased within a relatively hyperechoic epineurium.\textsuperscript{16,17}

**MSK**

Ultrasound has been used as a diagnostic and therapeutic modality when evaluating the MSK system. Therapeutically, ultrasound uses wave technology to generate a current that subsequently relaxes muscles and eases pain. Diagnostically, MSK ultrasound is used as a tool to assess soft tissues by evaluating the movement of joints, ligaments, and tendons; detecting fluid collections; and visualizing structural landmarks to aid in procedures such as joint or fluid aspirations, injections, and biopsies.

![Figure 3](image_url)

Figure 3. Transverse (A) and longitudinal (B) ultrasound of normal biceps muscle. Transverse ultrasound of myopathic biceps muscle (homogeneous, hyperechoic) in acid maltase deficiency (Pompe disease) (C). Reproduced with permission from Penny VB, Hollinger J. Ultrasound in neuromuscular medicine. Pract Neurol (US). 2019;(20):51-55.
Neuro-Ophthalmologic Uses
Transorbital sonography can be used to view the optic nerve and evaluate possible neuropathy as with any nerve (see NMD) and for diagnosis and follow up of acute optic neuritis. Ultrasound imaging measurement of the optic nerve diameter and optic nerve sheath diameter (ONSD) are being evaluated as a means of evaluating intracranial pressure (ICP) in the context of subarachnoid hemorrhage, intracranial hemorrhage, and traumatic brain injury (Figure 4). There is no definitive cut off value for ONSD to suggest an ICP over 20 mm Hg yet, but some studies have suggested 5 to 6.2 mm.18-21

POCUS-Guided Procedures
Ultrasound can also be used as a mapping tool to define anatomic landmarks when performing procedures such as lumbar puncture or botulinum toxin injections. In lumbar puncture, POCUS helps determine the depth of ligamentum flavum, the width of interspinous spaces, and any vertebral abnormalities. POCUS can help guide the placement of needles by allowing the clinician to pick the widest interspinous space and monitor a needle tip during the procedure.

Botulinum toxin injections, used to treat muscle spasticity, sialorrhea, and migraine, can also be guided by POCUS. Structural landmarks can be identified for needle placement and advancement of the needle tip can be monitored (Figure 2A). The relatively easy use, noninvasiveness, and cost-effectiveness make POCUS an excellent tool for outpatient injections that rely upon proper injection technique to avoid adverse events. In this regard, POCUS can help increase healthcare delivery to patients with chronic headaches or neuropathic pain and improve their overall quality of life.

Conclusions
In conclusion, POCUS is a readily available tool that can be used as a screening, diagnostic, and even therapeutic modality in specific clinical situations. It provides accurate real-time information, is portable, low-cost, and noninvasive without use of ionizing radiation or high-intensity electromagnetic fields. Disadvantages include but are not restricted to limitations on

### TABLE. ULTRASOUND CHARACTERISTICS OF NEUROMUSCULAR DISORDERS.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Characteristic ultrasound finding(s)</th>
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<tbody>
<tr>
<td>Muscular dystrophies and myopathies</td>
<td>Replacement of normal muscle cells with fibrous tissue creates a bright hyperechoic appearance; loss of deep tissue reflections can help differentiate muscular dystrophy from inflammatory myopathies; distribution of specific findings may also help to identify specific forms of neuromuscular disease</td>
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<tr>
<td>Diaphragmatic paralysis</td>
<td>Side-by-side comparison of diaphragmatic thickness and change in thickness during the respiratory cycle</td>
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<tr>
<td>Motor neuron disease</td>
<td>The presence of fasciculations identified on ultrasound is more sensitive than with EMG</td>
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<tr>
<td>Amyotrophic lateral sclerosis (ALS)</td>
<td>Increased echogenicity in denervated muscle mixed with hypoechoic areas of preserved motor units creates a nonspecific “moth-eaten” appearance in end-stage ALS</td>
</tr>
<tr>
<td>Entrapment neuropathy</td>
<td>Increased cross sectional area and decreased echogenicity occur with progression; Doppler ultrasound may show increased vascularity due to inflammation, and changes in nerve mobility can be seen</td>
</tr>
<tr>
<td>Acquired polyneuropathy</td>
<td>Multifocal nerve enlargement in noncompressible sites; multifocal ulnar and median nerve enlargement may help to differentiate between multifocal motor neuropathy and ALS; axonal polyneuropathies may demonstrate mild enlargement</td>
</tr>
<tr>
<td>Hereditary hypertrophic polineuropathies</td>
<td>Diffuse enlargement along the entire course of an affected nerve.</td>
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field of view; difficulty acquiring images of tissue obscured by bone, air, or gas; dependency on operator skill; and relatively low image resolution. With proper training and use, POCUS can help deliver effective healthcare in both outpatient and inpatient settings. The technology can increase access to medical care, especially in areas where medical care is less accessible. To expand its use as a screening, diagnostic, and therapeutic tool in neurology, further studies and education are needed.


