Neuromuscular Ultrasound of Cranial Nerves

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Ultrasound of cranial nerves is a novel subdomain of neuromuscular ultrasound (NMUS) which may provide additional value in the assessment of cranial nerves in different neuromuscular disorders. Whilst NMUS of peripheral nerves has been studied, NMUS of cranial nerves is considered in its initial stage of research, thus, there is a need to summarize the research results achieved to date. Detailed scanning protocols, which assist in mastery of the techniques, are briefly mentioned in the few reference textbooks available in the field. This review article focuses on ultrasound scanning techniques of the 4 accessible cranial nerves: optic, facial, vagus and spinal accessory nerves. The relevant literatures and potential future applications are discussed.

Key Words   neuromuscular ultrasound, cranial nerve, optic, facial, vagus, spinal accessory.

INTRODUCTION

Neuromuscular ultrasound (NMUS) refers to the use of high resolution ultrasound of nerve and muscle to assess primary neuromuscular disorders. Beginning with a few small studies in the 1980s, it has evolved into a growing subspecialty area of clinical and research investigation. Over the last decade, electrodiagnostic laboratories throughout the world have adopted the technique because of its value in peripheral entrapment and traumatic neuropathies. Not yet fully explored, however, are the applications of NMUS for the cranial nerves. Although cranial nerves are commonly involved in neuromuscular disorders, they are not routinely evaluated due to technical limitations of electrodiagnostic techniques. Nerve conduction studies are typically restricted to the blink reflex, and repetitive stimulation studies of the facial and spinal accessory nerves, while needle examination is typically restricted to muscles innervated by facial, trigeminal, hypoglossal, and spinal accessory nerves. Given their sensitive locations, patients often find the studies painful and poorly tolerable, while few electromyographers have acquired a comfort level in performing such studies extensively. Magnetic resonance imaging (MRI) and computed tomography (CT) can also be of diagnostic value in these disorders, but their use is limited by cost, radiation exposure, and limited access. Ultrasound as a safe, inexpensive, rapid, and well-tolerated modality has the potential to complement electrodiagnostic studies in the evaluation of cranial nerves.

Four out of the 12 cranial nerves are accessible by ultrasound and are the focus of our review article. These are the optic, facial, vagus, and spinal accessory nerves. Of possible future interest, indirect evaluation of the occulomotor, trochlear, trigeminal, abducens, and hypoglossal nerves is also possible by ultrasound through examination of the muscles they innervate, but a discussion of muscle ultrasound is beyond the scope of this review.

This review article describes NMUS scanning techniques of four readily accessible cra-

nial nerves and discusses possible clinical applications. The intent is to define what the current best evidence allows us to conclude and to help guide future investigations in this new area.

OPTIC NERVE

Anatomy

The optic nerve carries the sensory impulses generated by stimulation of rods and cons in the retina. It passes posteriorly from the back of the eye through the orbit to enter the optic canal. After exiting the optic canal, the right and left optic nerves join to form the optic chiasm and then the optic tracts. The optic nerve as part of brain is covered by me-

ninges. The dura is continuous with sclera of the eye and the subarachnoid space abuts against the posterior aspect of the retina around the optic disc. Bulging of retina around optic disc creates the sign of papilledema which is characteristic of increased intracranial pressure (ICP).[1]

Optic nerve ultrasound (Table 1)

The optic nerve is most commonly assessed by ophthalmoscopy and MRI but recently ultrasound has emerged as a promising additional assessment tool. Being filled with aqueous fluid, the eye is well suited to ultrasound imaging. Measurement of optic nerve diameter using ultrasound correlates closely with MRI measurement in cadaver and vivo studies[2,3] with high intra- and inter-observer reliability[4-6] and good re-

Table 1. Scanning protocols of cranial nerves

	Optic	Facial	Vagus	Accessory
Technique	Trans-orbital to obtain axial image	Longitudinal (along the nerve)	Axial & longitudinal	Axial & longitudinal
Machine adjustment	- Mode: B-mode - Frequency: 7–15 MHz - Linear probe - Mechanical index ≈0.2 (=power 30%) - Thermal index ≈0.0	- Mode: B-mode - Frequency: >12 MHz - Linear probe - Depth: 2–4 cm	- Mode: B-mode - Frequency: >12 MHz - Linear probe - Depth: 3–4 cm	- Mode: B-mode - Frequency: >12 MHz - Linear probe - Depth: 1–2 cm
Patient position	Supine, eye closed, gaze fixed to midline "closed eye technique"	Side-lying -head on a pillow	Side-lying/supine-head slightly extended	Sitting/supine-head rotated to the opposite side
Probe position	On temporal and superior portion of closed eye-large pad of gel	Transverse just under the ear lobule	Lateral neck at the level of thyroid cartilage	Posterior triangle of the neck behind sternocleidomastoid
Nerve sonographic appearance	Linear structure with hypoechoic center and hyperechoic outer sheath	Linear thin tubular-like structure with hypoechoic center and hyperechoic outer rim	Small round honey-comb/hypoechoic between common carotid artery and internal jugular vein	Small oval hypoechoic lying on top of trapezius or levator scapulae and posterior to sternocleidomastoid
Measurement	- Optic nerve sheath diameter measured at distance 3 mm posterior to eye globe - Inclusion of the outer sheath - Mean of 3 measurements	- At thickest part of the nerve - Inclusion of outer rim - Largest of 2 measurements	Cross sectional area inside hyperechoic rim	Cross sectional area
Tips	- Manipulation of probe to align optic nerve with eye globe - Relaxed environment with head fixation in children - Least pressure by the probe	- Keep probe just under ear to avoid area of confusion with other structures - Use color flow for any suspected vascular structures	Release pressure by the transducer to avoid obliteration of internal jugular vein	Identify the muscles first

producibility.[6]

To scan the optic nerve, the most important machine adjustment is to reduce thermal index to 0.0 and mechanical index to 0.2 or lower (can be adjusted by reducing the power output) to avoid thermal and mechanical side effects. Note that color flow and power Doppler imaging significantly increase the insonation energy of ultrasound. The eye is vulnerable to the heat generated by the sound waves, and ultrasound, if done without proper precautions can injure the retina and cause cataract formation in the lens. The earliest optic nerve studies[7,8] used A-mode imaging (amplitude mode); however, B-mode has since become standard. A linear transducer of frequency 7–10 MHz is usually sufficient.

The optic nerve sheath can be visualized using transorbital technique to obtain an axial image. The patient should lie in supine relaxed position and for children, head fixation may be needed. Closed eye technique (Fig. 1A) must be adhered to, in which the patient is instructed to keep both eyes closed and the probe is placed on temporal and superior portion of the eye with large pad of gel and minimal pressure. Some[9] prefer to apply non-adhesive clear dressing on the eye to avoid irritation by gel. The subject should be instructed to maintain his/her gaze at midline to align the optic nerve along the probe. Contraindications of ocular sonography include orbital trauma and ruptured globe.

In the captured image (Fig. 1B), the optic nerve can be seen emerging from the posterior part of the globe. The nerve appears as hypoechoic linear structure with hyperechoic border representing the nerve sheath. For measuring optic nerve sheath diameter, the outer rim should be included. Based on anatomic and histological studies, optimal measures of the diameter of the optic nerve sheath is taken at a distance 3 mm posterior to the posterior rim of the globe. Maximal expansion of the optic nerve sheath predominately occurs in its anterior part and specifically at a distance 3 mm behind the globe, whereas the posterior part shows less dilatation with increased ICP.[10,11] Also, it has been found that measuring the diameter at 3 mm is more reliable and reproducible than measuring it at 5 mm.[6] Three measurements are usually taken and averaged for accuracy.

An alternative technique involves a lateral approach to obtain a coronal image, avoiding the shadowing artifact sometimes encountered with the axial approach.[9] However, further trials are needed to validate pathologic values in patients with elevated ICP before this approach can be more widely used.

Reference data for optic nerve sheath diameter are not yet standardized, although most literature considers diameter >5.7 mm abnormal. The determined cut-off value is proposed mainly for detection of increased ICP and doesn't necessarily apply for diagnosis of other conditions, such as optic neuritis. Moreover, different mean optic nerve sheath diameters have been reported.[5,9] Therefore, as with other reference values, each lab needs to establish its own normative ranges. In children, the diameter increases with age[12] with a mean of 2.9 mm in children <1 year of age and 3.1 mm in children 1 year of age or older.[12]

Review of literature

Most of the published literature on optic nerve ultrasound

Fig. 1. A: Trans-orbital technique to obtain axial image of optic nerve. The subject in supine position, probe is placed on temporal and superior portion of the closed eye using large pad of gel with the subject's gaze at midline. B: Axial image of optic nerve showing the nerve emerging from posterior aspect of eye globe. The nerve aquires hypoechoic center and hyperechoic rim representing the sheath. Diameter is measured 3 mm posterior to eye globe with inclusion of outer sheath.

has focused on its relevance in intracranial hypertension. Sporadic studies have addressed its value in other conditions such as intracranial hypotension and optic neuritis.

Intracranial hypertension in adults

The role of optic nerve ultrasound in detection of increased ICP has been widely investigated[13-24] in brain injuries, intracranial hemorrhage, hydrocephalus, brain tumors, and other conditions. It is usually assessed by brain CT but the definite diagnosis depends on invasive direct measures such as lumbar puncture and intracranial monitoring using intraventricular catheter. Because increased ICP is often an emergency condition, a portable, non-invasive modality such as ultrasound is of particular value. In the early 1960s, Hayreh,[25] in his study of pathogenesis of optic disc oedema, proved that the optic nerve sheath communicates with the cranial cavity, albeit in varying degrees in different individuals. In an elegant cadaveric study by Liu and Khan,[26] the subarachnoid pressure of the optic nerve was found to be directly proportional to ICP, indicating a close relationship between optic nerve sheath and ICP. The optic nerve sheath is sufficiently elastic to reflect pressure changes in subarachnoid space.[27,28] Experimental studies have shown enlargement of optic nerve sheath following intraparenchymal fluid infusion[29] and gelatin-induced widening of the subarachnoid space,[11] it can acutely increase up to 140% of its baseline when subjected to high pressure ($\geq$50 mm Hg).[28] Furthermore, optic nerve sheath diameter measured by ultrasound correlates with direct measures of intracranial preesure.[30,31] The distension in optic nerve sheath occurs early and may even precede development of papilloedema.[25]

The response of the optic nerve to decompression of ICP after intracranial hypertension has also been studied. Hansen et al.[28] found that the optic nerve reacts slowly to ICP decline and doesn't regain its original size immediately, especially when subjected to high pressure loads. The delayed optic nerve response may reflect its limited capability to retract.[28] Also Rajajee et al.[32] found that the percentage of false positive results obtained by ultrasound increases in situations of abrupt change versus steady elevation in ICP; ultrasound may reveal enlarged nerve at the time when the pressure is normal. They suggested the delayed nerve retraction as one possible explanation for their findings. This nonsynchronous decrease in optic nerve diameter and ICP, if substantiated in future studies, may limit the utility of optic nerve sheath diameter measurement in post-treatment ICP monitoring.

The clinical application of optic nerve sheath diameter as a screening tool for raised ICP has been validated in adult patients including those with brain injury, in multiple studies,[14-18,23] some with invasive direct measures of ICP as the

gold standard to measure ICP.[16,18,23] In 2008, Geeraerts et al.[16] measured optic nerve sheath diameter in 31 patients with severe traumatic brain injury once admitted to intensive care unit and compared it with invasive ICP recordings. Optic nerve sheath diameter was larger in patients with high ICP compared to those with normal ICP and to control group, and correlated significantly with ICP direct measurement.

In the same year, Soldatos et al.[18] obtained comparable results in their larger study conducted on 50 patients with brain injury and 26 controls. Their control group comprised of critically ill patients who had no evidence of brain injury. Optic nerve sheath diameter was significantly larger in severe cases compared with moderate cases and controls, and was highly correlated with directly measured ICP. Also, optic nerve ultrasound was associated with high inter- and intra-observer reproducibility.

Later in 2011, Širanović et al.[23] compared optic nerve sheath diameter measurement with invasive ICP measurement using intraventricular catheters in 20 patients with traumatic brain injury. Optic nerve sheath diameter was highly sensitive and specific in detection of increased ICP and strongly correlated with direct measures, with an optimal cutoff value of 6.1 mm. The authors attributed their higher cut-off value than that determined by Geeraerts et al.[16] and Soldatos et al.[18] (>5.7 mm) to the difference in the clinical status of their patients.

Other studies were conducted on patients with head injury but used CT scan to validate optic nerve sonography.[15,17] Their key results revealed high sensitivity and specificity of optic nerve ultrasound, despite the fact that CT scan is not considered a gold standard for measuring increased ICP.

The value of optic nerve sonography has also been demonstrated in clinical settings other than traumatic brain injury including spontaneous intracranial hemorrhage,[19,20] idiopathic intracranial hypertension,[21,24] and monitoring ICP changes induced by epidural blood patch for treatment of post dural puncture headache.[33]

Optic nerve ultrasound appears to be a sensitive, specific, and reproducible modality for detection of increased ICP in adults. Its value resides in using it as rapid non-invasive bedside screening tool especially when other measures are unavailable[34] or risky.[35-37]

Intracranial hypertension in children

A study by Ballantyne et al.[12] focused on establishing the normal values of optic nerve sheath diameter in infants and children younger than 15 years. They measured the diameter in 102 healthy children, and it positively correlated with age but no significant difference was noticed between males and females. The authors determined a diameter >4 mm in infants

<1 year and 4.5 mm ≥1 year as abnormal.

A study by Shuper et al.[38] represents some of the earliest work on the clinical application of optic nerve ultrasound in children. In 1997, they investigated it in 10 children with pseudotumor cerberi confirmed by lumbar puncture; optic nerve diameter correlated with opening pressure on lumbar puncture. Additionally, the authors used it to follow their patients, thus sparing them repeat invasive procedures. In 2002, Newman et al.[39] recruited 23 children with shunted hydrocephalus and compared it with 102 controls; optic nerve ultrasound accurately identified the patients with failed shunt; diameter was increased in patients with failed shunt compared to healthy controls. In contrast, diameter values obtained from children with functioning shunt matched those obtained from healthy controls, and interestingly the diameter was also normal in children with temporary manifestations of increased ICP that lasted for only 1 day which may denote that the sheath mainly expands with persistent increase in ICP.

A larger study by Malayeri et al.[40] in 2005 revealed much the same results as that of Newman et al.'s study[39] but in wide spectrum of patients. They recruited 78 children with intracranial hypertension and 78 healthy children. The patient group included cases with hydrocephalus, head trauma, intracranial hemorrhage, intracranial infection, brain tumor, and encephalopathy.

Other investigators have obtained different results in children and cautioned against over-reliance on optic nerve ultrasound because of its low sensitivity and specificity. Le et al.[41] conducted a study on 64 children, 24 of them had confirmed diagnosis of intracranial hypertension, the study showed sensitivity of optic nerve sheath diameter=83% and specificity=38%. Also, a low predictive value and specificity were revealed in a study by Hall et al.[42] performed on 39 children with ventriculoperitoneal shunt, 20 of whom proved to have shunt failure, Hall and his co-workers found no significant difference in diameter in children with shunt failure compared with those with functioning shunt.

The variance in results of studies performed in children may be explained by difference in methodology. In Le et al.'s study,[41] CT scans were used to confirm increased ICP and this was compared to the mean diameter obtained from both eyes (binocular diameter) while Newman et al.[39] depended mainly on direct measurement of cerebrospinal fluid pressure to confirm increased ICP and used the mean of 3 measurements from each eye. In Hall et al.'s study,[42] healthy children were not used as a control group; rather, shunt failures were compared to those with functioning shunt.

Further studies of optic nerve ultrasound are needed in children.

Intracranial hypotension

Currently there is insufficient data to determine the utility of optic nerve ultrasound in intracranial hypotension. However, in a single case report[43] optic nerve ultrasound in a patient with spontaneous intracranial hypotension from cervical cerebrospinal fluid leakage, optic nerve sheath diameter was reduced at the time of presentation and gradually normalized with medical treatment and repeated epidural blood patches.

Optic neuritis

The diagnosis of optic neuritis, a common presenting symptom of multiple sclerosis is mainly a clinical one. Visual evoked potentials can detect subclinical cases but can't provide specific diagnosis.[44] MRI of optic nerve is not routinely ordered but can exclude non-demyelinating causes.[44]

Titlić et al.[45] in 2005 were the first group to describe a role for optic nerve ultrasound in optic neuritis of multiple sclerosis. They studied 20 multiple sclerosis patients with clinical diagnosis of acute retrobulbar neuritis and measured their optic nerve diameter using A-mode and 10 MHz probe. The optic nerve diameter of the affected eye was significantly larger than that of the healthy eye (4.2 mm^2 in affected nerve vs. 3.5 mm^2 in healthy nerve). Moreover, it was significantly correlated with number of brain lesions detected by MRI.[45]

Seven years later, Carraro et al.[46] assessed optic nerve diameter and its vascularization using echo-color duplex ultrasound in 29 relapsing-remitting clinical definite MS and 21 healthy volunteers. The study revealed decreased maximum optic nerve diameter measured by ultrasound in patients group (with and without optic neuritis) compared to healthy controls denoting optic nerve atrophy. Their data, didn't reveal any arterial or venous abnormalities.

Although the two mentioned studies[45,46] revealed different results regarding nerve size in multiple sclerosis, they are not totally conflicting; in Titlić et al.'s study,[45] they scanned the patients during the acute stage of retrobulbar neuritis (within 2−3 days of symptoms) and before starting steroid treatment, thus nerve edema is expected to be still present reflected as increased optic nerve diameter in ultrasound. In Carraro et al.'s study,[46] time of scanning is not mentioned but the patients recruited were all having relapsing-remitting definite MS inferring chronicity of the cases, thus finding optic nerve atrophy seems logical.

A recent study by Lochner et al.[47] measured optic nerve sheath diameter and compared it to visual evoked potentials in 21 patients with unilateral optic neuritis resulting in acute visual loss. Their results demonstrated an enlarged optic nerve diameter in the affected eye and measurements from both the affected and unaffected eye were significantly larger compared with controls. No correlation was found between optic

nerve sheath diameter and visual evoked potentials parameters suggesting that the two modalities different aspects of optic neuritis, with visual evoked potentials assessing the functional state of the nerve and ultrasound assessing anatomical enlargement.

The data obtained in Titlić et al.,[45] Carraro et al.,[46] and Lochner et al.[47] studies are promising and suggest a novel indication for optic nerve ultrasound.

Future applications

The majority of ultrasound studies of the optic nerve have been designed to assess ICP as opposed to nerve disease. However, the studies in multiple sclerosis patients suggest a potentially useful role in optic neuritis. Furthermore, optic nerve abnormalities may be seen in a variety of other disorders such as chronic inflammatory demyelinating polyneuropathy (CIDP),[48] sarcoidosis,[49] central nervous system infections,[50] and mitochondrial disorders,[51] and ultrasound could possibly be an attractive screening tool for anatomic assessment of nerve enlargement/atrophy in these disorders.

FACIAL NERVE

Anatomy

The facial nerve, the seventh cranial nerve, consists of motor and sensory parts. It emerges at the lower border of the pons accompanied by the acoustic nerve to the internal acoustic meatus. At the bottom of meatus, the nerve enters and traverses the facial canal to reach the stylomastoid foramen. On emerging from the stylomastoid foramen, it runs forward in the substance of the parotid gland where it gives its terminal branches to different facial muscles.[52] Due to branching and a complex intracranial path after emerging from the stylo-

mastoid foramen, only a portion of the facial nerve is routinely visualized by ultrasound.

Facial nerve ultrasound (Table 1)

The facial nerve can be scanned while the patient is sitting or lying in the lateral decubitus position with head resting on a pillow (opposite the scanned side). Lateral decubitus is the preferred position as it is more comfortable for both the patient and sonographer. It is also the less time consuming technique because the head is fixed and no need to manipulate the transducer frequently with the slightest head movement.

A high frequency linear transducer (>12 MHz) is used and depth is usually adjusted to 2−3 cm. The transducer is placed transversely just under the ear lobule to obtain a longitudinal image of the facial nerve inside the parotid gland (Fig. 2A). Being a tiny nerve in relatively isoechoic salivary gland tissue, an isolated axial view is often technically challenging.

The nerve appears as thin linear tubular-like structure with hypoechoic center and hyperechoic rim running in the middle of the homogenous parotid gland between its superficial and deep parts (Fig. 2B). The most important structure that can be confused with the facial nerve is the parotid duct but the described scanning site is away from it because the duct emerges from anterior border of the parotid gland and runs forward to end in the oral cavity.[52] The duct can be confusing mainly with most anterior part of the facial nerve, specifically its buccal branches below the zygomatic bone. Other less confusing structures are veins and arteries inside the gland, namely the retromanidbular veins and anterior cervical artery which closely relate to facial nerve. They are easily distinguished by using color flow mode. In addition, the artery pulsates and pressure by the probe compresses the
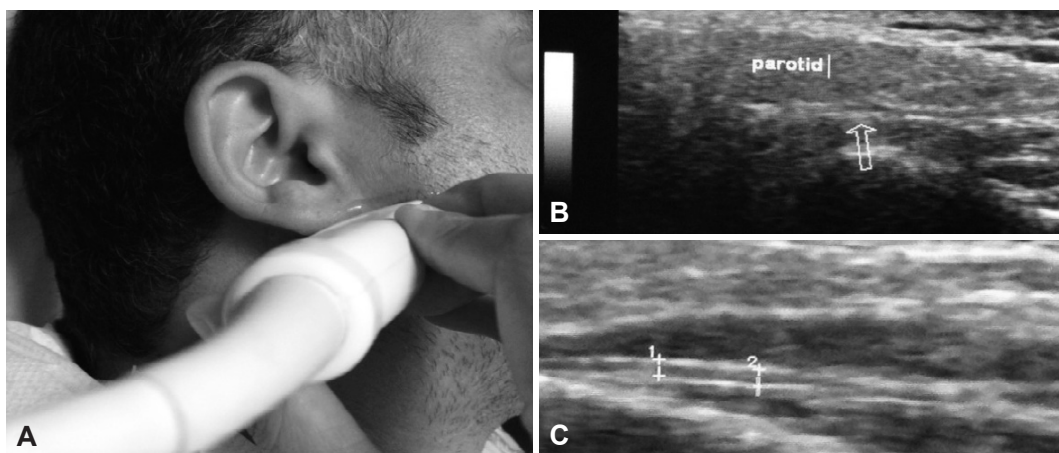

Fig. 2. A: Facial nerve scanning technique. The subject is in lateral decubitus position with the head resting on a pillow. The probe is placed transversly just below the ear lobule along the longitutdenal course of facial nerve. B: Longitutdinal image of facial nerve. The nerve (arrow) appears as linear tubular-like hypoechoic structure with hyperechoic rim inside the homogenous relatively hyperechoic parotid gland. C: Enlarged image of facial nerve showing diameter measurment at the nerve's thickest part with inlcusion of its hyeprechoic border.

vein. The main facial artery and vein run close to the mandibular branch of the facial nerve near the inferior border of the mandible and therefore they are not sources of confusion.

The facial nerve can be assessed for size, echogenicity and vascularity. Diameter is measured at the thickest part of the nerve with inclusion of the outer rim (Fig. 2C). More than one measurement can be taken and the largest is chosen. Change in echogenicity is expected in facial nerve lesions, for example, the outer rim of the nerve and/or its lumen may be hyperechoic in chronic lesions due to adhesions or fibrosis. In contrast, edema of acute lesions could blur the outer border or mask it.

Review of literature

Only one study has evaluated the diagnostic role of facial nerve ultrasound. In this study, Lo et al.[53] investigated its value in prognosis of Bell's palsy. They recruited acute Bell's palsy patients and scanned them twice-during 1st week and after 3 months from disease onset. They then correlated facial nerve diameter with clinical grading, nerve conduction studies and blink reflex. The study revealed high correlation between facial nerve diameter and clinical grade outcomes. In contrary to electrodiagnostic studies, ultrasound predicted good and poor recovery at 3 months (100% positive predictive value, 77% negative predictive values). They attributed the poor outcome of the patients having enlarged facial nerve in ultrasound to perineural edema which may have deprived the nerve from its nutrients and delayed its regeneration. These initial findings, if confirmed, may help decision making of optimal treatment according to the expected prognosis.

Future applications

Bell's palsy is the most common lesion affecting the facial nerve and is expected to be important target for future studies. It is an acute facial neuropathy of unknown etiology affecting its peripheral part. It is thought that the nerve swells and is compressed within the facial canal at the stylomastoid foramen. This leads to thickened edematous perineurium, axon and myelin degeneration with intra-neural inflammatory cells infilteration.[54-56] As such, it may be potentially considered as a form of entrapment neuropathy.[54] Future studies of the nerve, at different stages of idiopathic Bell's palsy may possibly be informative in diagnosis, prognosis and follow up of the patients and perhaps as a guide for interventions such as systemic or local steroids.

In addition, work is needed to explore role of ultrasound in assessment of diseases with predilection to affect facial nerve, such as Guillain-Barré syndrome, CIDP and hereditary neuropathies. The natural history of traumatic facial nerve lesions, and the role of intraneural blood flow in health and disease may also be useful subjects of future investigation.

VAGUS NERVE

Anatomy

The fibers of the vagus nerve, the tenth cranial nerve leave the medulla below the glossopharyngeal nerve between the olive and inferior cerebellar peduncle, then these fibers unite into single nerve that enters the jugular foramen. The nerve has a small superior ganglion and long inferior ganglion which lies in the jugular fossa below the skull base. In the neck, the nerve lies in the carotid sheath in the space between
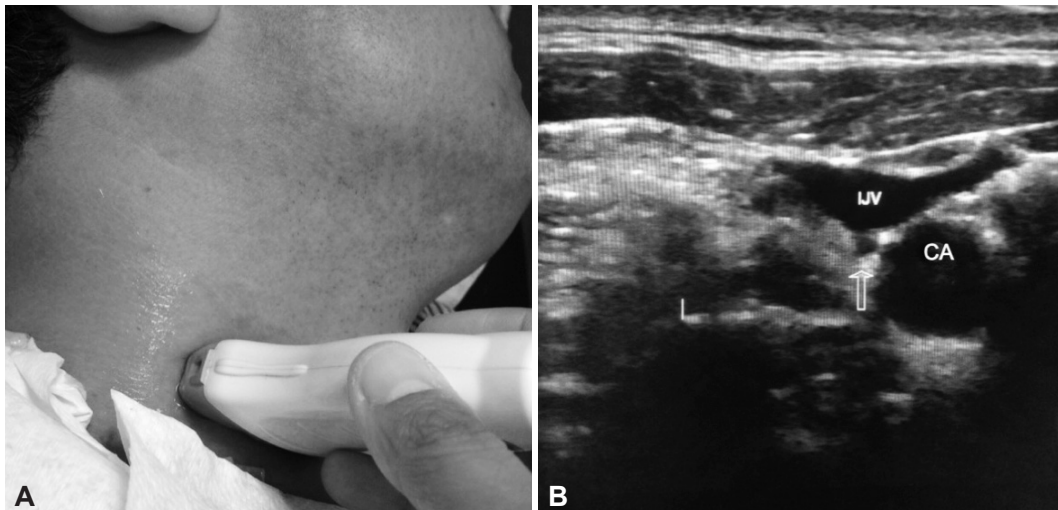

Fig. 3. A: Vagus nerve scanning technique. The subject in lateral decubitus position with head slightly extended. The probe is placed on lateral neck at level of thyroid cartialge. B: Axial image of vagus nerve. The nerve (arrow) appears as hypoechoic oval structure wedged posteriorly between common carotid artery (CA) and internal jugular vein (IJV).

the internal carotid/common carotid artery and internal jugular vein.[57] The vagus nerve maintains voluntary motor control over the anterior cervical skeletal muscles and involuntary control of the heart and smooth muscle and secretory organs in the intestines. Its more superior branches innervate voluntary muscles of the palate, pharynx, and larynx. Its lower cervical, thoracic, and abdominal branches are autonomic parasympathetic fibers. It also has sensory fibers to the visceral mucosa of gastrointestinal and respiratory systems.[58]

Vagus nerve ultrasound (Table 1)

The vagus nerve is best scanned at the lateral neck (Fig. 3A) where it lies inside the carotid sheath. The patient can lie in the lateral decubitus or supine position with neck slightly extended. To obtain an axial image the depth is adjusted to 3−4 cm and scanning starts by placing the transducer in the midline of the anterior neck at the level of cricoid cartilage moved superiorly to the level of thyroid cartilage, and then in this plane the transducer is moved laterally until visualizing the carotid artery and jugular vein. The vagus nerve appears as a small round honeycomb structure; sometimes relatively hypoechoic situated posteriorly inside the carotid sheath and wedged between the common carotid artery and internal jugular vein (Fig. 3B). Cross sectional area is measured by tracing the border just inside the hyperechoic rim using. The longitudinal image can be easily obtained by rotating the transducer at this site. The internal and external jugular branches are usually difficult to visualize.

Review of literature

Few studies have targeted vagus nerve ultrasound, but those available yield valuable information. Sample et al.[59] were the first to delineate neurovascular bundle during neck ultrasound scanning. In their study, they identified linear hypoechoic structure in the tracheoesophageal groove while they were evaluating parathyroid gland using grey-scale ultrasound. Later in 1985, Solbiati et al.[60] confirmed in part of their study that the linear hypoechoic structure described by Sample et al.[59] is in fact the recurrent laryngeal nerve. They performed sonographic studies of the neck in three cadavers, identified neurovascular bundle, and then injected it with ink. Subsequent dissection and histologic examination demonstrated the ink within the injected structure which they identified as recurrent laryngeal branch of the vagus based on its position, course and anatomical relations.[60]

In 1998, Knappertz et al.[61] were concerned with anatomic and *in vivo* validation of vagus nerve imaging using B-mode ultrasound. In a cadaver they used ultrasound to identify the nerve as a centrally hypoechoic and peripherally hyperechoic structure between the common carotid artery and internal

jugular vein inside carotid sheath, and then they marked it with a hypodermic needle using a transdermal approach. Neck dissection confirmed accurate identification of vagus nerve by ultrasound. Additionally, they performed 100 ultrasound scans in healthy individuals and successfully identified the vagus nerve with high reproducibility in 97%.[61]

Only one study reported normal values of cross sectional area of the vagus nerve.[62] In this large-scale study, Cartwright et al.[62] determined the reference values of the vagus nerve in addition to other upper and lower extremity nerves in 60 healthy volunteers. They scanned the vagus at the level of carotid bifurcation and located it in the carotid sheath posterior to the carotid artery and jugular vein. The authors measured the cross sectional area by tracing the nerve just inside the hyperechoic rim and obtained values ranging from 1−9 mm^2 with a mean of 5±2 mm^2. The upper limit of side-to-side difference in cross sectional area was 3.1 mm^2.

Different specialists share interest in clinical applications of vagus nerve ultrasound, including radiologists, otolaryngologists and neurologists. The radiologists and otolaryngologists are typically interested in its use in imaging nerve tumors, neck masses and vocal fold paralysis. These applications are out the scope of our review and interested readers are referred to relevant resources for more information.[63-65]

Two groups of neurologists have evaluated vagus nerve ultrasound in neurological disorders.[66,67] The first group, Cartwright et al.[66] studied the sonographic changes of nerves in Charcot-Marie-Tooth (CMT) type 1B. They measured cross sectional area of vagus nerve in addition to median and sural nerves in 12 members of a single large family with CMT 1B and compared it with 24 healthy controls. They also searched for any difference in vagus nerve size between CMT patients with and without cranial neuropathies. They found increased cross sectional area of vagus and median nerves in patients with CMT 1B compared with healthy controls; mean vagus nerve cross sectional area was 8.50 mm^2 in patients vs. 5.88 mm^2 in controls. However, there was no significant difference in vagus cross sectional area between patients with cranial neuropathies and those without cranial neuropathies[66] which may denote subclinical cranial neuropathy in asymptomatic patients, subclinical affection of cranial nerves in the form of slowed conduction has been demonstrated previously in patients with type I and type II hereditary motor and sensory neuropathy.[68]

The second research group, Jang et al.[67] assessed the pattern of nerve enlargement in 10 patients with CIDP compared to 18 healthy controls. They scanned multiple peripheral nerves in upper and lower limbs in addition to the vagus nerve. The study revealed significantly larger cross sectional area of studied nerves in CIDP patients compared to the con-

trols.[67] The preliminary results provided by the two cited articles may help in evaluation of those types of polyneuropathy having the tendency to affect cranial nerves and detection of subclinical cases.

Future applications

Vagal nerve dysfunction has been implicated in a number of peripheral nervous system disorders such as CIDP, laryngeal nerve palsies, Guillain-Barré syndrome, sarcoidosis, and Lyme diseases. Moreover, the vagus may be involved in a variety of poorly understood autonomic disorders including cardiac dysrhythmias, orthostatic hypotension, and gastroparesis. Studies have shown vagal pathology in diabetes, chronic alcoholism and in experimental models of Guillain-Barré syndrome.[69-71] The extent to which these changes are reflected in vagus nerve size or echogenicity as detected by ultrasound remains to be discovered.

SPINAL ACCESSORY NERVE

Anatomy

The accessory or eleventh cranial nerve is composed of two roots; spinal and cranial. The spinal root is formed by fibers from cell bodies in the anterior horn of upper five or six segments of the cervical cord; its rootlets arise from the lateral surface of the cord to join the cranial root. The cranial root emerges from medulla below the vagus nerve. The spinal and cranial parts unite and pass through the jugular foramen. Outside the skull, the accessory nerve donates its cranial part to the vagus and these are distributed to striated muscles of soft palate and larynx.[72] The spinal part after its exit from the jugular foramen runs backward in front of the internal jugu-

lar vein in 66.6% of cases and behind it in 33.3%.[72] The nerve then descends to the upper part of sternocleidomastoid muscle. It pierces the muscle and courses obliquely across the posterior triangle of the neck to end in the deep surface of the Trapezius muscle.[72]

Accessory nerve ultrasound (Table 1)

The posterior triangle of the neck is the best accessible site for scanning of accessory nerve. A high frequency probe is needed to obtain high resolution as it is small tiny nerve. The scanning can be done with the patient in sitting or preferably supine position with head tilted or rotated to the opposite side. The depth is adjusted to 1−2 cm and to obtain the axial view of the nerve, the transducer is placed transversely in the posterior triangle of the neck just behind the sternocleidomastoid muscle between it and trapezius muscle (Fig. 4A). It can also be visualized more distally toward the root of the neck between sternocleidomastoid and levator scapulae muscles. To distinguish the nerve, it can be easier to first identify the sternocleidomastoid and trapezius/levator scapulae muscles in the image. The sternocleidomastoid muscle is broad relatively hypoechoic muscle situated just under the skin and subcutaneous tissue. After identifying the muscles, the accessory nerve will appear more clearly as small oval hypoechoic structure with monofasicular pattern on top of trapezius/levator scapulae and posterior to sternocleidomastoid muscle (Fig. 4B).

Review of literature

Most of the published literatures on spinal accessory nerve ultrasound are case reports of pathological conditions. This is due to its low prevalence. Few researches have studied its
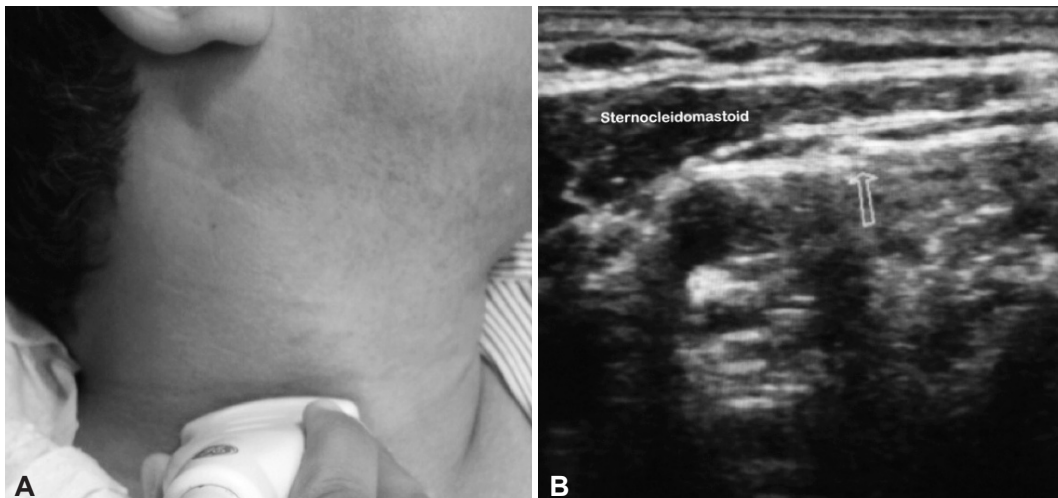

Fig. 4. A: Spinal accessory nerve scanning technique. The subject is in lateral decubitus position with head rotated to the side opposite the scanned side. Probe is placed on posterior triangle of the neck just behind the sternocleidomastoid muscle. B: Axial image of spinal accessory nerve. The nerve appears as small rounded hypoechoic structure (arrow) superficial to trapezius muscle and deep to sternocleidomastoid muscle.

anatomical variation and ease of visualization in healthy volunteers. Bodner et al.[73] in 2002 verified sonographic localization of accessory nerve in 3 fresh cadavers. They injected blue ink around the nerve guided by ultrasound. On dissection, they found the ink stained the nerve denoting accurate localization by ultrasound. Likewise, Canella et al.[74] scanned the accessory nerve in 7 cadavers and demonstrated that the best site for nerve identification is between latero-posterior border of sterncleidomastoid and anterior border of trapezius muscle. A recent large-scale study by Mirjalili et al.[75] focused on scanning of the nerve in 50 healthy subjects. The investigators provided detailed sonographic description of the accessory nerve which can be of relevance to preoperative mapping. They found the nerve running superficial in posterior triangle of the neck with straight or tortuous course at a depth of 3 mm from skin with mean diameter of 0.76±0.12 mm.

The most common cause of spinal accessory neuropathy is iatrogenic lesion following neck surgery especially lymph node dissection and biopsy. Other infrequent causes have been described for instance: stretch injury,[76,77] carrying heavy objects,[78] vigorous exercise,[79] and idiopathic conditions.[78] The iatrogenic cases are easily diagnosed because of the clear history of surgery and symptoms onset following neck procedures. In the absence of apparent cause, it is easy to miss it because symptoms of shoulder pain and inability to elevate the arm are not specific and occurs in other musculoskeletal conditions. Moreover, trapezius muscle atrophy, which is a characteristic sign of the nerve palsy, can be missed during examination.

Multiple case reports exist. In the first report published in 2002, Bodner et al.[73] scanned 4 patients with accessory nerve palsy confirmed by electrodiagnostic studies. Two patients had lymph node biopsy, 1 underwent surgical neck dissection and 1 patient experienced whiplash trauma. Ultrasound detected nerve dissection in 3 patients and revealed scar tissue in which the nerve was embedded.

The second report by Lucchetta et al.[78] in 2014 described two cases with accessory palsy. One patient complained of shoulder pain after carrying heavy bag but their second patient had irrelevant history. Ultrasound scanning of the first patient showed enlarged cross sectional area implicating acute lesion. On the contrary, ultrasound of the second patient showed reduced cross sectional area and didn't reveal any nearby mass, thus he was diagnosed as having idiopathic spinal accessory nerve palsy.

Also this year, Seok et al.[79] presented accessory palsy case. Their patient was healthy 32 years old male presented by neck and shoulder pain with drooped shoulder. The patient was assessed by nerve conduction studies, electromyogra-

phy, ultrasound, and MRI. Electrodiagnostic studies demonstrated spinal accessory nerve lesion. Ultrasound scanning showed focal swelling of the nerve under the sternocleidomastoid muscle with increase in cross sectional area from 1 to 3 mm^2 at site of maximal enlargement. MRI, on the other hand was normal except for trapezius muscle atrophy suggesting superiority of ultrasound over MRI.[79]

Recently, Güven et al.[80] presented an interesting case of accessory nerve palsy in a patient with thrombocytopenic purpura. A 43-year-old man with a previous diagnosis of thrombotic thrombocytopenic purpura and known history of polyneuropathy developed shoulder weakness after a prolonged stay in the intensive care unit. Examination showed trapezius atrophy and weakness of shoulder abductors on the left side in addition to the typical signs of polyneuropathy. Ultrasound revealed a swollen left accessory nerve and electrodiagnostic tests confirmed nerve injury. The cause was not clear but the authors linked it to patient's stay in the intensive care unit and suggested that malposition and central venous catheterization might have been contributing factors.

This case demonstrates the additional value of ultrasound in superimposed nerve lesions which has been pointed out by other investigators.[81,82] Focal neuropathies superimposed on polyneuropathy can create a diagnostic challenge and require extensive electrodiagnostic testing.[81] Ultrasound evaluation in such cases may save time and spare the patient the pain of electrodiagnostic studies.

It is evident from the case reports that ultrasound is sometimes able to provide valuable information in addition to that obtained by electrodiagnostic studies: It can localize focal swelling, confirm or exclude extrinsic causes of compression thus differentiating traumatic conditions from idiopathic ones, and can help in serial follow-up.

Future applications

The wide variability of the anatomical course and relations of the accessory nerve[83] contribute to its risk of iatrogenic injury during surgical procedures. A prior proof of principle study has shown that ultrasound can be successfully used to map the course of superficial nerves in cadavers[84] and showed that preoperative sonographic tracking facilitated surgical access of the nerves and reduced dissection time. As such, pre-operative mapping of the accessory nerve may be an area where ultrasound can be used, not just as a diagnostic tool in nerve injury, but also as an interventional technique to potentially help avoid iatrogenic nerve transections in explorations of the posterior triangle of the neck.

CONCLUSION

Ultrasound can reliably image 4 cranial nerves: the optic, facial, spinal accessory, and vagus nerves. They are sometimes involved in more generalized or multi-focal neuropathies, but the extent to which this occurs has yet to be rigorously evaluated. These nerves are also susceptible to focal dysfunction which may reflect either central or peripheral nervous system pathology. Although electrodiagnostic studies are available to evaluate different functions of these nerves (visual evoked potentials, cardiac autonomic reflexes, blink reflex studies, and spinal accessory compound motor action potentials), few diagnostic laboratories use any combination of techniques routinely. Ultrasound offers an inexpensive, portable, non-invasive tool for rapid and reliable evaluation of the morphology of these nerves which has already been shown to be informative in a number of pathologic conditions. Further investigation may find additional uses for ultrasound which include pre-operative mapping of nerves to avoid surgical injury, detection of intraneural blood flow in inflammatory disorders, and guidance of needle placement for diagnostic or interventional purposes. Because of their knowledge of anatomy, physiology, and comfort level with new technology, physicians with experience in electrodiagnostic medicine are well suited to incorporating cranial nerve ultrasound into their practices.

Conflicts of Interest

The authors have no financial conflicts of interest.

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