Review Article

The Application of Ultrasound Guidance in Electrodiagnostic Studies – A Narrative Review

CME Credits

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Abstract

Electrodiagnostic studies, including nerve conduction study and electromyography, were conducted based on surface anatomy in a conventional manner. However, the anatomical variations and difficulty in the identification of target nerves or muscles render the accuracy of electrodiagnostic studies questionable. In recent years, high-resolution ultrasound (US) has been used to scan both the peripheral nerves and musculoskeletal system. Furthermore, an increasing number of clinicians have incorporated US into electrodiagnostic studies to achieve accurate sampling and prevent potential unwanted tissue injuries. In this review article, we present summarized information about the utility of US in assisting electrodiagnostic studies.

Keywords: Electromyography, nerve conduction study, ultrasonography-guided

Introduction

The realm of peripheral nerve injuries is a critical and relatively common challenge faced by physiatrists, neurologists, and neurosurgeons. An early and accurate diagnosis provides important information about the severity and prognosis of nerve injuries. More importantly, this diagnostic information should be timely to decide further treatment plan to avoid complications, including muscle atrophy, joint contracture, and neuropathic pain.[1]

Electrodiagnostic studies, including nerve conduction studies (NCS) and electromyography (EMG), are crucial for clinicians to achieve accurate diagnoses of peripheral nerve injuries.[2] Conventionally, the positions of electrical stimulation and recording electrodes were decided based on anatomical landmarks. However, previously published studies have revealed multiple anatomical variations of both upper and lower limbs.[3-5] In addition, nerve injury-related denervation might lead to prominent muscle atrophy, which would alter the relative positions of the target nerves and muscles.[6] Furthermore, it is difficult to conduct electrodiagnostic studies when the examined participants have obesity or when the sampled nerves or muscles are deeply seated.[2] This renders the accuracy of conventional landmark-based electrodiagnostic studies questionable.

Electrodiagnostic studies could assess the functional integrity of a peripheral nerve. On the other hand, high-resolution ultrasound (US) could provide morphological information while diagnosing peripheral neuropathies.[6-12] In previous years, the utility of US in assisting NCS or EMG has been discussed. Stimulation or recording electrodes could be more accurately placed along the traveling path of the nerves, and the required stimulation level could be decreased to lessen the discomfort of the recruited participants.[11,13-17] Furthermore, the amplitude of acquired compound muscle action potentials (CMAPs) and sensory nerve action potentials (SNAPs) using US-guided NCS is larger than the conventional method.[13,15,17] In addition, the application of real-time US guidance while performing EMG on a patient with significant muscle atrophy could prevent unwanted neurovascular injuries.[6]

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In this review article, we aimed to sum up the available results from studies investigating the value of employing US to assist NCS and EMG.

Applying Ultrasound in the Nerve Conduction Studies of the Upper Limbs

NCSs of the upper limbs are usually considered less difficult to conduct than NCSs of the lower limbs because the distance of the target nerves from the stimulation and recording electrodes is shorter in the upper limbs. At present, studies investigating the utility of US are scarce. One study employed US to determine the optimal stimulation and recording sites for proximal radial motor studies, whereas Wei *et al*. found that US guidance could improve the precision of radial and ulnar NCSs.[16,17] The summarized information about the role of US in the NCSs of the upper limbs is presented in Table 1.

In clinical practice, proximal motor NCS of UE might be challenging as it is difficult to accurately place the stimulation electrode on the traveling path of the target nerves. In addition, the examined participants might not tolerate the electrical stimulation due to the relatively intense electrical current required to reach supramaximal stimulation. Thus, few studies employed US to determine the positions of the nerves and muscles for accurate placement of stimulation and recording electrodes. In 2017, Yeo *et al*. presented a standardized method and possible reference value for radial motor NCS employing US to determine the most optimal stimulation site at spiral groove (SG) and the best recording site, the location with the largest cross-sectional area (CSA) of the extensor indicis proprius (EIP).[16] In this study, 55 healthy controls were recruited, and each participant was scanned with US along the line between the lateral edge of the acromion and the lateral epicondyle of the humerus to find the site, where the radial nerve (RN) was most superficial at the SG level. This site was then deemed as the optimal stimulation site, and the surface distance between this site and the lateral epicondyle of the humerus was measured. Furthermore, the CSA of the EIP was evaluated via US, and the level with the largest CSA of the EIP was labeled as the optimal recording site. The distance between the optimal recording site and the ulnar styloid process was also measured. Furthermore, the authors proposed two indices, the SG and EIP ratios, to establish a normalization method and reference value after considering the arm length of each individual. The value calculated using the distance between the optimal stimulation site and the lateral epicondyle of the humerus divided by the upper arm length was defined as the "SG ratio." On the other hand, the value calculated using the distance between the optimal recording site and the ulnar styloid process divided by the forearm length was defined as the "EIP ratio." The mean values of the SG and EIP ratios were 0.338 and 0.201, respectively. The SG and EIP ratios were not significantly

Table 1: Summary of studies of ultrasound-guided nerve conduction studies

Author, year	Study groups	Study design	Main results
US-guided NCSs of upper limb			
Yeo *et al*., 2017[16]	55 healthy controls	US-guided NCS of RN at radial groove; US measurement of CSA of EIP	Spiral groove ratio 0.338 and EIP ratio 0.201 as the indexes for best stimulating and recording sites
Wei *et al*., 2021[17]	30 healthy controls	US-guided NCSs of UN, RN, SRN, and DUCN	Less stimulation intensity was required for RN and UN motor studies with the use of US-guidance
			Larger CMAP amplitude of RN and UN motor studies was noted with use of US-guidance
			Onset latency of DUCN NCS was shorter under US-guidance
US-guided NCSs of lower limb			
Kamm *et al*., 2009[21]	44 patients with suspected polyneuropathy	US-guided NCS of SN (needle recording electrode)	SN SNAP amplitude recorded under US-guidance was significantly larger than blind technique
Boon *et al*., 2011[14]	25 obese participants	US-guided NCS of LFCN for stimulation near ASIS and recording site at thigh	Reproducibility increased while between-side variability decreased under US-guidance
Scheidegger *et al*., 2011[22]	20 healthy controls	US-guided NCS of SN (needle recording electrode)	Larger SN SNAP amplitude was recorded using US-guided placement of the needle-recoding electrode
			Consistent between-test results were obtained from US-guided needle recording electrode
Park *et al*., 2015[13]	29 healthy controls	US-guided NCS of LFCN for stimulation near ASIS	Larger LFCN SNAP amplitude was recorded using US-guided NCS compared with conventional technique
Kim *et al*., 2018[15]	32 healthy subjects	US-guided NCS of SPN	Larger SPN SNAP amp was recorded using US-guided NCS compared with conventional technique.
Choi *et al*., 2019[20]	40 healthy controls	US-guided NCS of SN (surface-stimulating electrode)	SNAP amplitude of type 1 SN was significantly larger under US-guidance

ASIS: Anterior superior iliac spine, CMAP: Compound muscle action potential, CSA: Cross-sectional area, DUCN: Dorsal ulnar cutaneous nerve, EIP: Extensor indicis proprius, LFCN: Lateral femoral cutaneous nerve, NCSs: Nerve conduction studies, RN: Radial nerve, SN: Sural nerve, SPN: Superficial peroneal nerve, SRN: Superficial radial nerve, UN: Ulnar nerve, US: Ultrasound, SNAP: Sensory nerve action potential correlated with personal data, including age, sex, height, arm length, and CSA of the EIP muscle, indicating that these two indices were already standardized. Based on the SG and EIP ratios, the optimal stimulation site of the RN was at 34% of the humerus length from the lateral epicondyle of the humerus, whereas the optimal recording site was at 20% of the forearm length from the ulnar styloid process.[16]

Although it was intuitive to think that the stimulation level required for US-guided NCS would be lower than that for conventional surface anatomy-guided NCS, comparison of the stimulation levels required between these two techniques was not conducted until 2021 by Wei *et al*.[17] In this study, 30 normal healthy controls were included, and they all underwent both conventional surface anatomy and US-guided NCSs. The nerves assessed using NCS included the RN crossing the SG, ulnar nerve (UN) crossing the cubital tunnel (CT), superficial RN, and dorsal ulnar cutaneous nerve (DUCN). The NCS parameters, including the CMAP and SNAP amplitudes, and onset latencies were recorded. These parameters obtained from the US- and landmark-based techniques were compared. The results indicated that the CMAP amplitudes of the UN above and below the CT and the RN below the SG were significantly larger when obtained using the US-guided NCS. The onset latency of the DUCN was significantly shorter using the US-guided NCS. Another major finding of this research was that the stimulation level used for US-guided motor NCSs of the RN and UN was significantly lower than that used for landmark-based radial and ulnar motor NCSs. Furthermore, the authors recorded the time needed for US scanning of the target nerves. It was found that nerve scanning could be finished within 1 min, indicating that US scanning is feasible in routine clinical practice.

Applying Ultrasound in the Nerve Conduction Studies of the Lower Limbs

Compared with the upper extremity, the limb volume of the lower extremity is usually greater. Moreover, anatomical variations of the sural nerve (SN) and superficial peroneal nerve (SPN) were reported, which rendered the accuracy of conventional NCSs questionable.[18,19] Therefore, identifying the target nerves can be more difficult, and the examination may be longer. In addition, reliable results of the NCS of certain nerves, such as the lateral femoral cutaneous nerve (LFCN), are difficult to obtain due to poor reproducibility.[2] As a result, several studies have been conducted to prove the utility of US in assisting NCSs of the SN, SPN, and LFCN.[13-15,20-23] Although such studies were scarce, they demonstrated that the CMAP and SNAP amplitudes acquired from US-guided NCS were larger than those acquired from conventional landmark-based NCS. Furthermore, more reliable NCS parameters could be obtained with US-guided NCS.[13-15] The summarized information about the role of US in the NCSs of the lower limbs is presented in Table 1.

Ultrasound-guided nerve conduction studies of the sural nerve

The utility of US in the NCS of the SN was the most widely discussed among the NCSs of the lower limbs. The SN was known to have several types of anatomical variations at the calf area, which makes it difficult for clinicians to locate the best stimulation site.[4] In 2014, Kim *et al*. clearly depicted four types of anatomical variations of the SN using US scanning and proposed that the best stimulation point for the NCS of the SN was at 1 cm lateral to the midline of the calf at the level 14 cm proximal to the lateral malleolus.[21] US has also been incorporated in the placement of both needle and surface electrodes for SN NCSs.[20-23] Kamm *et al*. first employed US to guide the placement of the needle recording electrode in SN NCS.[21] The study result indicated that the SNAP amplitude recorded using the US-guided technique was greater than that using the blind technique.[21] Furthermore, later in 2011, Scheidegger *et al*. compared the between-test reproducibility between the US-guided placement of the needle electrode and the landmark-based placement of the surface electrode. More consistent between-test NCS parameters were obtained from the needle electrode group.[22] Although US-guided placement of the needle electrode was proven to be feasible and accurate in the NCS of the SN, surface electrode is more widely used in clinical practice for easier application and prevention of painful sensation caused by needling. The question of whether US could guide the placement of surface recording electrodes for SN NCS was first addressed by Choi *et al*. in 2019.[20] They employed US to scan the SN of the enrolled healthy controls. The SN was classified into four types based on the study results from Kim *et al*.[18] Every participant underwent both conventional surface anatomy- and US-guided NCS. The position of the surface stimulating electrode was determined via US scanning in the US-guided NCS group. The recorded SNAP amplitude in Type 1 SN, of which the SN was formed by the fusion of medial and lateral sural cutaneous nerves, was significantly larger with the US-guided technique.[20]

Ultrasound-guided nerve conduction studies of the lateral femoral cutaneous nerve

A reliable and accurate NCS result of the LFCN is difficult to obtain due to its low reproducibility, anatomical variations, high between-side difference, and absent response even in asymptomatic participants, especially among participants with obesity.[24,25] In 2011, Boon *et al*. employed US to localize the LFCNs of 25 obese normal participants at sites near the anterior superior iliac spine (ASIS) and inguinal ligament for surface stimulation and along the proximal thigh for the placement of the recording electrode.[14] All participants underwent both surface anatomy landmark-based technique and US-guided NCS. The SNAP of the LFCN was obtained in 49 of 50 trials using the US-guided technique but in only 46 of 50 trials using the conventional technique, indicating that the reproducibility was increased using the former.[14] Later in 2015, Park *et al*. again employed US to identify the LFCN near the ASIS at the space between the fascia lata and fascia iliaca and adjust the surface stimulation point under echo guidance to conduct US-guided NCS of the LFCN.[13] The study results indicated that the SNAP amplitude was significantly larger in the US-guided group than in the conventional NCS group, whereas there was no significant between-group difference in the SNAP latency.[13]

Ultrasound-guided nerve conduction studies of the superficial peroneal nerve

In clinical practice, it is often difficult for physicians to adjust the positions of both surface stimulation and recording electrode of the SPN NCS.[2] At present, there is only one available research investigating the importance of US in deciding the optimal recording site for SPN NCS.[15] In this study, 32 healthy controls were recruited, and each of them underwent both conventional and US-guided NCS. The SNAP amplitudes of both intermediate dorsal cutaneous nerve and medial dorsal cutaneous nerve were recorded. The SNAP amplitude recorded using the US-guided technique was significantly larger than that using the conventional technique.

Ultrasound-Guided Electromyography

Under certain circumstances, including obesity or atrophied muscles due to denervation, conventional landmark-based EMG studies may not be accurate, and potential injuries might occur, especially when performing EMG on the diaphragm.[26] In such situations, US guidance may provide additional assistance to achieve more accurate sampling and avoid unintended neurovascular injuries.[6,27]

EMG of the diaphragm could lead to potential injuries to the internal organs. Chiodo *et al*. considered needle insertion at the anterior axillary line above the 8th rib was the safest technique.[28] However, accurate sampling or localization might not be feasible under circumstances of obesity and altered anatomy caused by atrophic muscle or hyperinflated lungs due to chronic obstructive lung disease.[27,28] In 2008, Boon *et al*. presented how to visualize the diaphragm and adjacent tissues as well as the ribs, intercostal muscles, pleura, liver, and spleen under real-time US guidance.[27] The scanned area included the 7th–9th intercostal spaces at the midaxillary line. US probe was put vertical to the ribs initially, and the diaphragm could be identified beneath the intercostal muscles.[27] After the initial localization of the diaphragm, the probe was then rotated parallel to the long axis of the ribs at the intercostal spaces.[27] To further confirm the location of the diaphragm, the examiners could ask the examined participants to take a breath as the diaphragm would thicken with inspiration. Finally, the needle was inserted under US guidance, and the in-plane approach was favored for the complete visualization of the needle, including the needling tip and needle shaft.[27] The authors assumed that this technique could improve the accuracy and safety of EMG of the diaphragm, especially when the diaphragm was severely atrophic or paralyzed.[27]

Another case report article presenting the use of real-time US guidance in clinical practice was published in 2022.[6] A patient with suspected left proximal median neuropathy underwent electrodiagnostic study and US median nerve tracking to confirm the level of nerve injury. The physical examinations before the electrodiagnostic study was conducted demonstrated atrophic left forearm and thenar muscles. According to the authors' description, it was difficult at first to identify the flexor pollicis longus (FPL) muscle using surface anatomy during EMG. Thus, real-time US guidance was then applied, and precise EMG sampling of the FPL was successfully completed. Furthermore, adjacency of the radial artery and atrophic FPL muscle was observed during US scanning. Therefore, the use of US avoided accidental radial artery punctures.

Future Scope – Expanding the Application of Ultrasound Guidance in Electrodiagnostic Studies

Certain NCS including facial NCS and blink reflex study and proximal stimulation of brachial plexus at Erb's point is difficult to be tolerated owing to the inevitable pain caused by electrical stimulation.[2] Nonetheless, no studies have investigated the value of US guidance in these NCSs. Few studies have used US to investigate the morphological features of the facial nerve in the healthy population and in patients with idiopathic facial nerve palsy and brachial plexus at supraclavicular fossa could be clearly identified using US.[29-34] Therefore, the application of US guidance in these NCSs should be feasible and the applied electrical stimulation amount is expected to be less under US guidance.

Now only two case reports showing the value of US guidance in EMG studies were published now.[6,27] However, in our laboratory at the NTUH, we also conducted US-guided EMG for selected patients. Similar to Boon *et al*. and Huang *et al*., we also believe that US-guided EMG is relatively easy to learn and should be employed when precise sampling is difficult or when risky sampling is expected.[6,27]

Conclusion

The application of US guidance in NCSs could potentially improve both accuracy and yield rate. Furthermore, the stimulation level required for some NCSs might be lower under US guidance. As for EMG, the incorporation of US guidance could help achieve precise sampling and avoid unintended tissue injuries.

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Conflicts of interest

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