Evaluation of peripheral nerves of the upper limb with ultrasonography

A COMPARISON OF ULTRASONOGRAPHIC EXAMINATION AND THE INTRA-OPERATIVE FINDINGS

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We prospectively studied 26 consecutive patients with clinically documented sensory or motor deficiency of a peripheral nerve due to trauma or entrapment using ultrasound, and in 19 cases surgical exploration of the nerves was undertaken. The ultrasonographic diagnoses were correlated with neurological examination and the surgical findings. Reliable visualisation of injured nerves on ultrasonography was achieved in all patients. Axonal swelling and hypoechogenicity of the nerve was diagnosed in 15 cases, loss of continuity of a nerve bundle in 17, the formation of a neuroma of a stump in six, and partial laceration of a nerve with loss of the normal fascicular pattern in five. The ultrasonographic findings were confirmed at operation in those who had surgery.

Ultrasound may be used for the evaluation of peripheral nerve injuries in the upper limb. High-resolution ultrasound can show the exact location, extent and type of lesion, yielding important information that might not be obtainable by other diagnostic aids.

Owing to their relatively superficial location, peripheral nerves may be damaged by blunt trauma, fractures and soft-tissue lacerations. The diagnosis of peripheral nerve lesions and decisions regarding their surgical or conservative treatment are normally achieved with the aid of clinical and electrodiagnostic tests. Electrodiagnosis can answer important questions. Persistence of conduction across a lesion will show that some fibres, at least, are intact. Persistence of conduction distal to a lesion after about two weeks from injury, confirms a prolonged conduction block. Loss of conduction and denervation of a muscle confirms a complete degenerative lesion of the nerve. However, such examination does not give sufficient information about the nerve. Any injury may lead to a total lack of motor power and sensory loss of the involved area in the early stages following the trauma.¹

Electrodiagnosis can precisely differentiate low-grade lesions without axonal loss, neurapraxia according to the Seddon classification,² from higher-grade lesions that have axonal loss and damage to elements of the nerve sheath, axonotmesis and neurotmesis. Electromyography and nerve conduction studies may not yield reliable information as to the precise site of nerve damage, thereby giving insufficient help in determining whether to proceed to conservative or surgical treatment. A method of imaging that provides information about the

integrity of the nerve has been lacking.³ This may be accomplished only with direct imaging of the nerve itself. High-resolution ultrasound has been shown to be efficient in the diagnosis of nerve lesions following entrapment, tumours and trauma.⁴⁻⁸ The purpose of this study was to assess the value of ultrasound in determining the presence, localisation and extent of neural damage in patients with clinical evidence of peripheral nerve lesions.

Materials and Methods

High-resolution ultrasonography was performed in 26 patients with peripheral nerve lesions of the upper limb. There were 22 men and four women with a mean age of 26 years (6 to 71). The radial nerve was involved in nine patients, the medial in nine, the ulnar in 11 and the musculocutaneous in one. Some patients had more than one nerve involved.

Ultrasonographic examinations were performed with a Siemens, Sonoline-Siena scanner (Siemens Medical Systems, Erlangen, Germany) with a 7 MHz to 9 MHz changeable transducer by the same radiologist (NK), who had four years of experience with its use. The patients were positioned sitting or supine according to the region to be examined. The examination included the region at the level of suspected damage and at least 10 cm above and below this.

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Fig. 1a

Fig. 1b

Ultrasonographic and intra-operative photograph showing the radial nerve a) with gap formation following transection, the arrows indicate the distal and proximal ends of the severed nerve and b) the repaired nerve, the gap formed after excision of the damaged nerve segment was grafted using autologous sural nerve cable grafts. The ultrasonographic evaluation can detect the cable grafts (small arrows) and the nerve (large arrows).

Results

Radial nerve dysfunction was detected in nine patients, of whom three had a history of soft-tissue laceration without a fracture. Ultrasonographic examination visualised the stump neuroma and the gap between the cut ends of the nerve in one patient, who underwent surgery with direct exploration and repair of the nerve using a sural nerve graft. The intra-operative findings correlated accurately with pre-operative ultrasonographic appearance (Fig. 1). A further five patients had a non-functioning radial nerve following surgery for a fracture of the humerus, including a child aged six years with a supracondylar fracture which had been treated by closed reduction and percutaneous K-wire fixation. On sonographic evaluation, entrapment of the radial nerve at the fracture site was clearly seen (Fig. 2). At operation these findings were confirmed and the nerve was released. The remaining four patients had undergone open reduction and plate fixation of their fractures. Ultrasound detected swollen radial nerves with sharp angulations at the edge of the plate. Another patient had an operation one year previously for fractures and multiple soft-tissue lacerations

of the nerve. Ultrasonographic examination demonstrated swollen nerves in continuity. A tendon transfer was performed aiming to correct an intrinsic minus hand.

Nine patients presented with median nerve dysfunction, of whom eight had a history of lacerations to the volar side of the forearm. Ultrasonography revealed partial or total transection of the nerve. Exploration was undertaken in four cases, in which the intra-operative findings correlated with the ultrasound images. Nerve repair was performed in all cases, in one of which an autologous sural nerve graft was used. After operation the cable grafts and their anatomical continuity were demonstrated by ultrasound. Another patient had loss of function of the median nerve following a soft-tissue interposition arthroplasty for arthrosis of the first carpometacarpal joint. Ultrasound studies demonstrated segmental loss of continuity of the nerve, which was confirmed at operation.

Of the 11 ulnar nerve lesions that were detected on clinical examination, nine had been sustained as a result of a sharp laceration on the volar side of the forearm. Total or partial transection of the nerve was shown by ultrasonography

Fig. 2

Ultrasonographic and intra-operative photograph showing entrapment of the radial nerve at the fracture site. The nerve is pulled towards the bone, forming a steep angle (arrows).

Fig. 3

Ultrasonographic and intra-operative photograph showing the ulnar nerve following total transection with fusiform swelling at the cut ends. The arrows indicate the neuroma formation.

(Fig. 3). Operation was undertaken on eight and the ultrasonographic findings correlated perfectly with the appearance at operation. The other had dysfunction of both the ulnar and median nerves following operation for a supracondylar fracture. Ultrasonography revealed lacerations of both nerves at the fracture site.

The patient with injury to the musculocutaneous nerve had sustained a penetrating injury to the posterior aspect of the axilla. There was wasting of the biceps muscle and weakness of active elbow flexion. A laceration to the nerve was demonstrated by ultrasonography and these findings were confirmed at operation.

In all of the patients involved in this study, high-resolution ultrasound clearly visualised the affected nerve, giving detailed information about the cause of dysfunction and the anatomical integrity of the nerve. The information obtained fell into four groups:

1. Loss of continuity of the nerve bundle where the severed nerve ends were clearly seen with or without a gap.
2. A fusiform swelling or formation of a stump neuroma was visible at the site of transection. In chronic partial

lesions a fusiform swelling was seen, demonstrating a chronic partial laceration with a neuroma in continuity. In total transections the ends were separated with fusiform swellings at each end showing formation of a stump neuroma.

3. Disintegration or loss of the normal fascicular pattern was visible in acute, partial lacerations. The outer lining of the nerve (the epineurium) was interrupted on one side, with evidence of partial fascicular discontinuity.

4. Swelling and hypoechogenicity without a fusiform swelling was seen in nerves that were not severed but injured by the impact of fracture fragments, by prolonged traction at the operative site, or possibly by impingement between fracture fragments.

Discussion

In spite of clinical and electrodiagnostic examination the precise localisation of the site and extent of injury of a nerve may remain uncertain. Before planning definitive treatment, the surgeon should be aware of the type of injury, the position of the proximal and distal stumps, and

the presence or absence of a neuroma and excessive perilesional scar tissue. The advent of high-resolution ultrasound scanners has enabled successful demonstration of peripheral nerves.^{4,7-13} Following trauma, high-resolution ultrasound can differentiate between rupture of a nerve bundle and fibroblast infiltration which results in the formation of a traumatic neuroma. It can demonstrate the location and cause of inflammation or compression.⁵ This study has shown that ultrasonography can be helpful in the determination of the type of injury, the localisation of proximal and distal nerve stumps, and in diagnosing a neuroma.

One of the limitations of ultrasonographic nerve assessment is that the peripheral nerves of the upper limb cannot be traced clearly throughout their entire paths. This is especially true when the nerve lies deeper than 3 cm and a linear array transducer of < 7 MHz is used.¹⁴ Recently, Gruber et al¹⁵ observed that with the use of more powerful 5 MHz to 12 MHz and 9 MHz to 17 MHz broadband linear-array transducers, injuries of the supraclavicular brachial plexus can be assessed. A limiting factor is that it requires an experienced operator with a thorough knowledge of the ultrasonographic appearance of different soft-tissue structures.⁵ We have found that the radial nerve can best be traced in the middle and distal thirds of the upper arm, where it courses around the humerus in a relatively superficial path. More proximally, it lies deep to the muscles of the pectoral girdle and cannot be well visualised. Distally, the nerve pierces the extensor muscle mass and divides into its terminal branches, and owing to its deep location and diversion it cannot be visualised. The ulnar and median nerves can be followed throughout the arm from the axilla to the hand. Thin limbs with little subcutaneous fat give the best results.

High-frequency transducers are required for detailed resolution. In one study⁵ it was noted that the frequency of the transducer should be > 7 MHz in superficial locations and at least 5 MHz in deeper locations, with a linear array to diminish distortion.

Compared to MRI, high-resolution ultrasound is faster and more cost-effective, non-invasive and safe. It offers superior spatial resolution and a more dynamic study while avoiding the possibility of claustrophobia in patients.^{5,12} It

gives effective imaging for capturing morphological changes in the peripheral nerves, and may be used both as an aid to diagnosis and to follow-up the results of treatment.

Supplementary material

A table showing details of the patients is available with the electronic version of this article on our website at www.jbjs.org.uk

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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