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DIAGNOSTIC IMAGING OF PERIPHERAL NERVES OF UPPER LIMB (INJURIES AND OTHER PATHOLOGIES)

Magdalena Posadzy[1]
Filip Vanhoenacker[2,3,4]
[1]Department of Radiology, W. Dega Orthopaedic and Rehabilitation University Hospital, Poznan University of Medical Sciences, Poznan, Poland
[2]Department of Radiology, Antwerp University Hospital, Edegem, Belgium
[3]Department of Radiology, General Hospital Sint-Maarten, Duffel-Mechelen, Belgium
[4]Faculty of Medicine and Health Sciences, Ghent University, Belgium

SUMMARY

Diagnostic evaluation of upper limb peripheral nerves (PNS) is crucial in case of specific neurologic symptoms. Imaging plays very important role in proper patient management and supporting clinical and/or electrophysiological examination. The article is a short review of preferred imaging modalities emphasizing the role of high-resolution ultrasound (HRUS) and magnetic resonance imaging (MRI) in different neuropathies including posttraumatic, entrapment syndromes and tumours. The aim of this article is to discuss normal appearance and the most frequent pathologies of peripheral nervous system of the upper extremity and to present an overview of currently available imaging methods emphasizing their usefulness, advantages and drawbacks.

Keywords: peripheral nerves (PNS), high-resolution ultrasound (HRUS), magnetic resonance imaging (MRI)

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DIAGNOSTYKA OBRAZOWA NERWÓW OBWODOWYCH KOŃCZYNY GÓRNEJ (URAZY I INNE PATOLOGIE)

Magdalena Posadzy[1]
Filip Vanhoenacker[2,3,4]
[1]Zakład Radiologii, Ortopedyczno-Rehabilitacyjny Szpital Kliniczny im. W. Degi Uniwersytetu Medycznego w Poznaniu

[2]Department of Radiology, Antwerp University Hospital, Edegem, Belgium
[3]Department of Radiology, General Hospital Sint-Maarten, Duffel-Mechelen, Belgium
[4]Faculty of Medicine and Health Sciences, Ghent University, Belgium

STRESZCZENIE

Diagnostyka obrazowa nerwów obwodowych kończyny górnej ma kluczowe znaczenie w przypadku określonych objawów neurologicznych. Odgrywa ona niezwykle istotną rolę w prawidłowym postępowaniu diagnostycznym, wspierając ocenę kliniczną oraz badania elektrofizjologiczne. Artykuł stanowi krótki przegląd preferowanych technik obrazowania podkreślając rolę ultrasonografii wysokiej rozdzielczości i rezonansu magnetycznego w przypadkach neuropatii na różnym tle, w tym pourazowych, zespołów uciskowych oraz zmian nowotworowych. Celem niniejszej pracy jest omówienie prawidłowego obrazu oraz najczęstszych patologii obwodowego układu nerwowego kończyny górnej oraz przegląd dostępnych obecnie metod obrazowania, podkreślając ich użyteczność, zalety i wady.

Słowa kluczowe: nerwy obwodowe, ultrasonografia wysokiej rozdzielczości, obrazowanie metodą rezonansu magnetycznego

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Introduction

Diagnostic evaluation of upper limb peripheral nerves (PNS) is crucial in case of specific neurologic symptoms. Imaging plays very important role in proper patient management and supporting clinical and/or electrophysiological examination. Preferred imaging modalities are high-resolution ultrasound (HRUS) and magnetic resonance imaging (MRI). Computed tomography is less suitable due to inadequate soft tissue contrast resolution for detailed evaluation of neuronal microstructure and because of radiation exposure. Conventional radiography provides only indirect information focusing on potential bone-related entrapment syndromes. The aim of this article is to discuss normal appearance and the most frequent pathologies of peripheral nervous system of the upper extremity and to present an overview currently available of imaging methods emphasizing their usefulness, advantages and drawbacks.

Aim

The aim of this article is to discuss normal appearance and the most frequent pathologies of peripheral nervous system of the upper extremity and to present an overview currently available of imaging methods emphasizing their usefulness, advantages and drawbacks.

Results

Anatomy

Peripheral nerves are rope-shaped structures composed of multiple neuronal fibres surrounded by endoneurium, bound together by perineurium to form internal fascicles. The outer sheath consists of epineurium, which encompasses the entire nerve (Figure 1). Knowledge of this anatomical structure is a prerequisite for understanding the imaging appearance of nerves.

Reliable PNS evaluation on ultrasound requires use of high-frequency linear probes (12 to 18 MHz) with dedicated musculoskeletal presets adjusted to precise neural visualization. On axial cross-section HRUS images a normal nerve is rounded or oval-shaped structure formed by cluster of regular hypoechoic fascicles framed by hyperechoic septa of connective tissue (Figure 2A). On longitudinal HRUS images, a nerve appears as parallel orientated hypoechoic bands surrounded by thin linear layers of perineurium (Figure 2B).

High resolution ultrasound

Nerves abnormalities detected on HRUS include: discontinuity, changes in nerve calibre or shape, loss of fascicular pattern and changes in echogenicity. The cause of extrinsic nerve compression may vary including soft tissue tumours, foreign bodies, misplacement or migration of implants or osteoarticular abnormalities like osteophytes or supracondylar process. The main advantages of HRUS are excellent spatial resolution followed by lack of contraindications, possibility of evaluation the nerve at long distance, dynamic and functional investigation during exercise, ease of side-to-side comparison, wide availability and low costs. Limitations include poor contrast resolution, operator dependence with long learning curve, and difficulties in visualisation of deep located nerves with restrictions to access some anatomical areas. Anterior interosseous nerve is relatively small and deep located thus HRUS evaluation is limited, however secondary changes in denervated muscles can be detected.

Magnetic resonance imaging

High-resolution MRI with augmentation of 3D nerve-selective techniques or MR-neurography are particularly performed to gain maximum of high soft-tissue contrast and spatial resolution (Mitchell *et al.* 2014). Axial plane is crucial, supported by perpendicular planes if needed. Normal nerve on axial T1-weighted images (WI) has a honeycomb pattern, is isointense to muscles and is surrounded by hyperintense epineural fat (Figure 3).

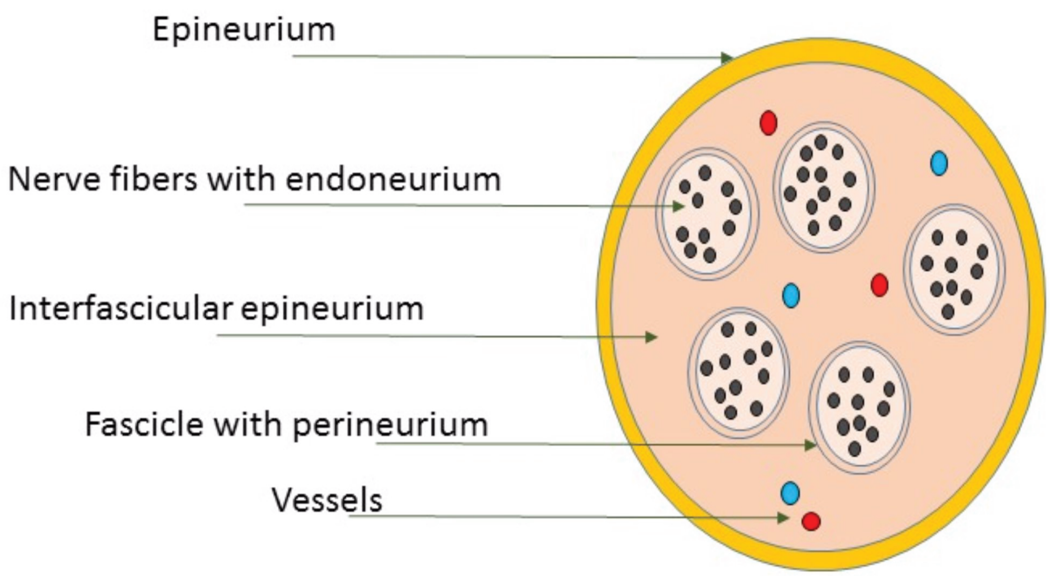

Figure 1. Axial cross-section anatomy of the nerve: nerve trunk with five fascicles in group arrangement.

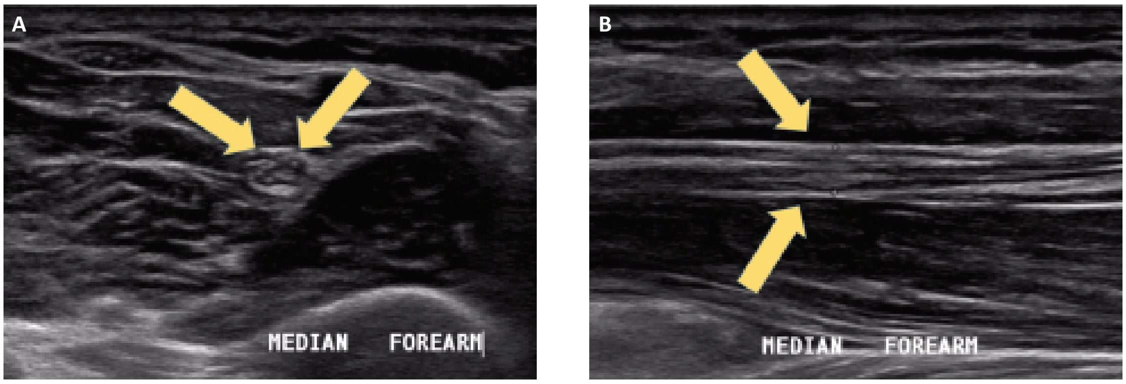

Figure 2. HRUS images of median nerve at the level of middle forearm, A – axial, B – longitudinal planes.

On T2-WI PNS is usually of intermediate signal, with sometimes seen hyperintense areas representing slight amount of endoneural fluid in larger trunks. After intravenous contrast administration, a normal nerve does not enhance due to presence of blood-neuronal barrier (Ohana *et al.* 2014).

MRI in comparison to HRUS is recognized as representing a better contrast with superior tissue characterisation and is preferred in deep seated structures. Examination is less operator depended and muscle denervation can be noticed earlier than on HRUS. On the other hand, MRI fails to evaluate multifocal nerve pathology because of limited field of view (Zaidman *et al.* 2013), is less available and more time consuming and has a higher cost. HRUS can easily adapt to oblique nerve course and it is possible to apply a local compression with the transducer and produce Tinel sign.

Neuropathies

Neuropathies can be divided into three groups: posttraumatic or postsurgical, entrapment syndromes and tumours. Other conditions such as polyneuropathies and inflammatory changes are beyond the scope of this short article.

Traumatic neuroma is a known response to peripheral nerve injury, which can be result of trauma or surgery and is a form of disorganised fibroinflammatory regeneration. It can be classified as two types: end-bulb neuroma or neuroma in continuity. The latter can be spindle-type with intact

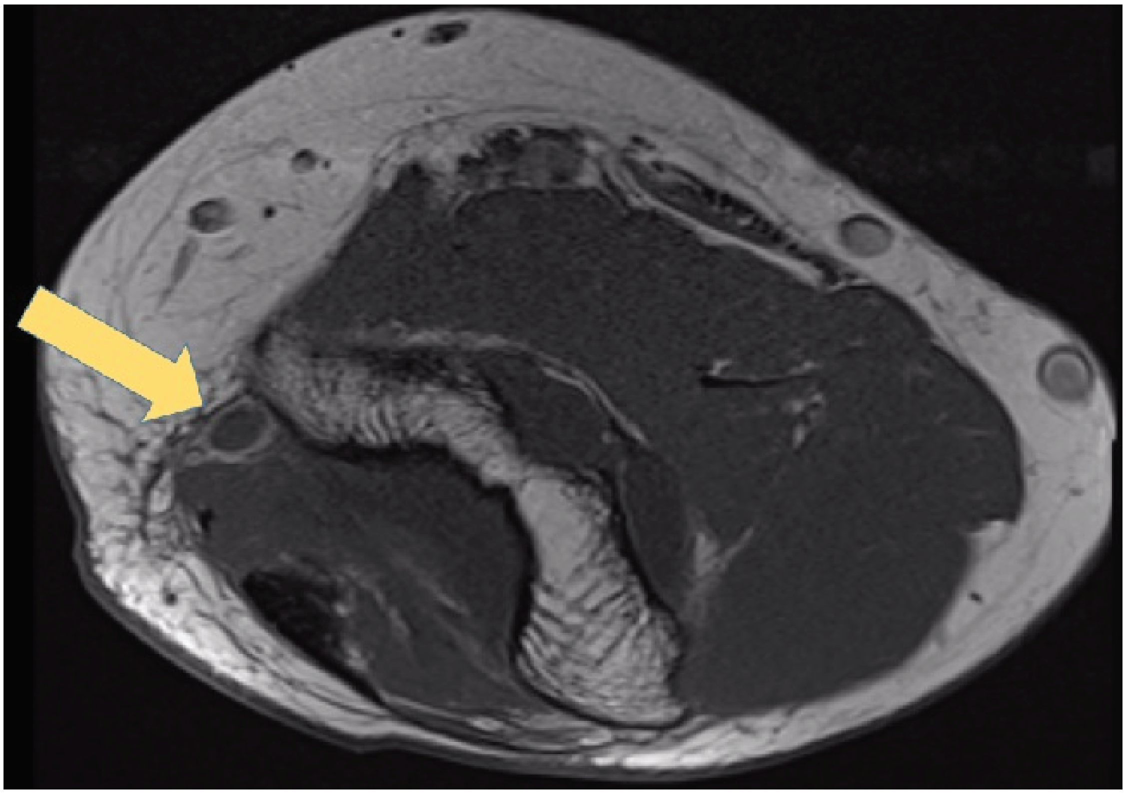

Figure 3. Axial T1-WI of the elbow, showing the ulnar nerve, as a hypointense structure surrounded by a rim of fat (arrow).

perineurium or lateral neuroma occurring after partial disruption of the perineum or nerve repairs (Chhabra *et al.* 2010). End-bulb neuromas can be result of amputation or complete discontinuity of the nerve.

On imaging, injured nerves are swollen, with loss of anatomical fascicular pattern, more precisely appreciated on HRUS than on MRI. On MRI, bulbous neuroma formation may be seen at the ends of injured nerve on T2-WI as hyperintense nerve termination.

The most common entrapment syndrome affects median nerve at carpal tunnel. Other nerve entrapment syndromes of upper limb are posterior interosseous syndrome at the level of arcade of Frohse, cubital tunnel syndrome, Guyon canal syndrome (with frequent cause of repetitive trauma in cyclist named handlebar palsy), supracondylar process syndrome, pronator syndrome, anterior interosseous nerve syndrome (Kiloh-Nevin syndrome). Less often seen is handcuff neuropathy of superficial branch of the radial nerve. Predisposed anatomical locations, such as course of the nerve through the fibro-osseous or fibro-muscular tunnels or penetration of the muscle are potential risk sites for compression. Typical MRI manifestation of compressed nerve is hyperintense signal changes on T2-weighted images. In long-standing process, fatty infiltration and atrophy of denervated muscles occur. HRUS detects nerve calibre changes with focal flattening at the level of compression followed by proximal swelling and hypoechogenicity.

Peripheral nerve tumours originate from the nerve sheath. Benign neoplasm include schwannoma and neurofibroma. The main goal of imaging is to differentiate benign from malignant peripheral nerve sheath tumours (MPNST) including: malignant schwannoma, malignant neurofibroma, nerve sheath fibrosarcoma, neurogenic sarcoma, neurofibrosarcoma.

Schwannomas usually affects major nerve trunks, more often are seen at the level of elbow or wrist and at the flexor surface. Typically, they are fusiform or nodular in shape, well-circumscribed, encapsulated with entering and exiting nerve (Figure 4).

Figure 4. Neurogenic tumour at the forearm on a coronal T1-WI. Note a fusiform lesion surrounded by split-fat sign with an exiting and entering nerve.

On HRUS a homogeneous, hypoechogenic mass on the course of the nerve can be seen, in ancient tumour cystic degeneration may occur, resulting in intralesional anechoic areas. On T1-WI MRI images they are iso- or hypointense, hyperintense on T2-WI and after gadolinium administration marked enhancement is characteristic (Figure 5).

The target sign appearance refers to central area of low-signal fibrocollagenous tissue surrounded by high-signal rim seen on T2-WI images and is most common in neurofibromas. The typical split fat sign on MRI is best seen on T1-weighted sequences as a rim of fat around the lesion. MRI imaging features are not specific for any subtypes of malignant tumours and histopathology is required for definitive diagnosis.

Discussion

The decision which imaging method is the most appropriate for evaluation of upper limb peripheral nerves pathology should be always based on the clinical presentation in each individual patient and the local availability of each modality. Meticulous correlation with clinical history

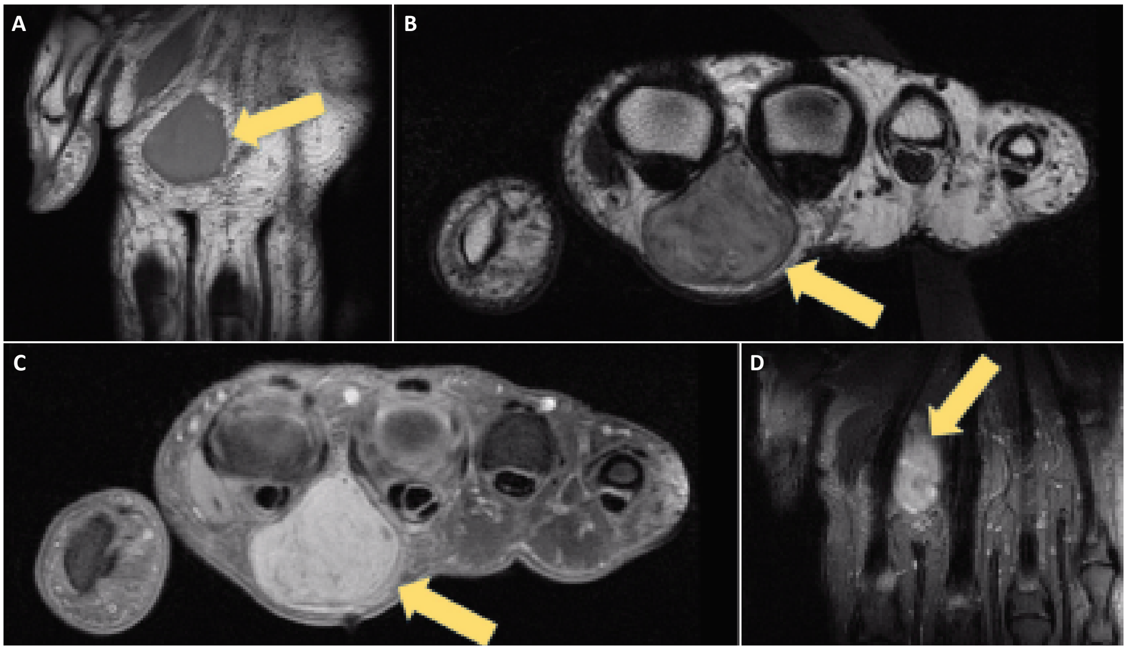

Figure 5. Schwannoma of the interdigitial nerve : A – Axial T2-WI, B – Coronal T1-WI, C – Axial FS T1-WI after gadolinium contrast administration, D – Coronal FS T1-WI after gadolinium contrast administration. The lesion is of intermediate signal on T2-WI with some intralesional areas of higher signal. There is marked enhancement.

(i.e. previous trauma or placement of osteosynthesis, soft tissue lump, viral infection) and electromyographic studies is mandatory. The strength and disadvantages of ultrasound and MRI are summarized in Table 1. Close cooperation of referring physician with radiologist or sonographer is the key to accurate diagnosis and optimising the use of healthcare resources including imaging. Currently, HRUS is regarded as the first-line imaging modality for evaluation of upper limb peripheral nerve pathology (Klauser *et al.* 2012; Zaidman *et al.* 2013), including masses, dynamic evaluation of entrapment syndromes or traumatic nerve lesions (Toia *et al.* 2016). If further tissue characterization of a mass lesion is required, subsequent MRI with a body marker placed at the level of the suspected lesion is mandatory (Zaidman *et al.* 2013).

MRI is particularly useful for evaluation of muscle denervation in the acute and subacute phase by demonstration of muscle edema on fluid-sensitive sequences (STIR or fast suppressed T2-weigthed images). Although ultrasound maybe used for the evaluation of fatty infiltration and muscle atrophy in chronic denervation, MRI is much more suitable for precise evaluation of the degree of fatty infiltration and the topography of the involved muscles. In daily practise upper limb peripheral nerve pathologies located distal to the level of brachial plexus are easily evaluated in ultrasound. Although the brachial plexus may be evaluated by a highly experienced sonographer (Lapegue *et al.* 2014), due to its complex anatomy and relation to other structures, MRI remains the preferred imaging method for evaluation of the brachial plexus.

Table 1. Summary of main advantages and drawbacks of US and MRI in the evaluation of peripheral nerves pathology.

MODALITY	ADVANTAGES	DISADVANTAGES
ULTRASOUND	No medical contraindications Excellent spatial resolution Evaluation of the nerve at long distance Dynamic evaluation Easy side-to-side comparison Low cost Easy adaptation to oblique nerve course Local compression (Tinel sign) Readily available	Operator dependence (long learning process) Less contrast resolution Limited access to deeply located nerves or hidden by other structures *High-frequency linear probes (12 to 18 MHz) are required
MAGNETIC RESONANCE IMAGING	Better contrast resolution Preferred for deeply located structures Less operator-dependent Early muscle denervation changes Characterization of mass lesions	Medical contra-indications for MRI (most pacemaker, ….) Metal artifacts after previous osteosynthesis. Limited Field of View (FOV) Less available More time consuming Higher cost

Conclusions

Diagnostic imaging of the peripheral nerves pathology provides valuable information on the status of the affected nerve itself but also evaluation of the perineural environment and innervated muscles. This is clinically relevant and affects patient management. Ultrasound is recommended as the initial examination in most scenario's, although subsequent MRI may be needed for more precise cartography and timing of muscle denervation and for characterization of soft tissue tumors.

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Author responsible for correspondence :
Magdalena Posadzy
Department of Radiology, W. Dega Orthopaedic and Rehabilitation University Hospital, Poznan University of Medical Sciences, Poznan, Poland
magdalenaposadzy@gmail.com

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Autor odpowiedzialny za korespondencję:
Magdalena Posadzy
Zakład Radiologii, Ortopedyczno-Rehabilitacyjny Szpital Kliniczny
im. W. Degi Uniwersytetu Medycznego w Poznaniu
magdalenaposadzy@gmail.com