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Radiologic imaging of the carpal tunnel

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Abstract

Compression neuropathy of the median nerve (carpal tunnel syndrome) is the most common nerve compression syndrome of the extremities. Although the disease is usually diagnosed on the basis of clinical examination and nerve conduction studies, radiologic imaging plays an important role in equivocal cases and especially in the assessment of recurrent or unrelieved symptoms after surgical carpal tunnel release. While plain radiographs and computed tomography are of limited diagnostic value except for the evaluation of osseous carpal stenosis and soft tissue calcifications, high-resolution sonography and magnetic resonance imaging allow for direct visualization of the compressed median nerve and the other soft tissue structures of the carpal tunnel. Due to its excellent contrast resolution, magnetic resonance imaging is superior in detecting mild degrees of median nerve compression and in identifying potential causes of carpal tunnel syndrome, such as tenosynovitis of the flexor tendons or space-occupying lesions. However, the low cost and time requirement favor the use of sonography as the initial imaging study in evaluating the carpal tunnel. © 1997 Elsevier Science Ireland Ltd.

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1. Introduction

1.1. Anatomy of the carpal tunnel

The carpal tunnel is a fibroosseous tunnel on the palmar side of the wrist which contains the flexor tendons of the fingers and the median nerve [1–3] (Fig. 1a,b). Its dorsal and lateral borders are formed by the scaphoid, triquetrum, lunate and pisiform proximally and the trapezium, trapezoid, capitate and hamate distally. It is bordered volarly by the flexor retinaculum (transverse carpal ligament), a broad ligament that extends from the tuberosities of the scaphoid and the trapezium to the pisiform and the hook of the hamate. The flexor digitorum profundus and flexor digitorum superficialis tendons lie within a common tendon sheath separate from the flexor pollicis longus tendon. The tendon of the flexor carpi radialis muscle lies in a

separate fibroosseous tunnel between a deep and a superficial layer of the flexor retinaculum and within a vertical groove of the trapezium. The median nerve is located just beneath the flexor retinaculum and volar to the superficial flexor tendon of the index finger. Occasionally, it may assume a deep position between the superficial flexor tendons perpendicular to the flexor retinaculum. The nerve supplies the abductor pollicis brevis and opponens pollicis muscles, the caput superficiale of the flexor pollicis brevis muscle and the two radial lumbrical muscles and it sends a sensoric branch to the volar side of the wrist.

1.2. Carpal tunnel syndrome

Carpal tunnel syndrome is the most common peripheral nerve compression syndrome and is increasing in frequency with the increasing number of jobs that require repetitive motion of the wrist and fingers, such as typewriting or working with computer keyboards [4]. It is characterized by burning pain, numbness and

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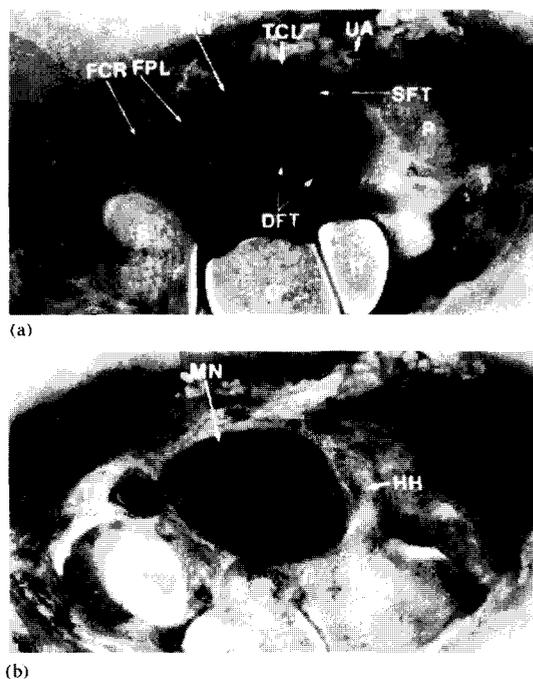


Fig. 1. Cross-sectional anatomy of the carpal tunnel. (a) Cryosection at the level of the pisiform. S, scaphoid; C, capitate; H, proximal part of hamate; T, triquetrum; P, pisiform; TCL, transverse carpal ligament (flexor retinaculum); MN, median nerve; SFT, superficial flexor tendons; DFT, deep flexor tendons; FCR, flexor carpi radialis tendon; FPL, flexor pollicis longus tendon; UA, ulnar artery. (b) Cryosection at the level of the hook of the hamate. TR, trapezium; TO, trapezoidium; C, capitate; H, hamate; HH, hook of the hamate; MN, median nerve.

paresthesia of the wrist and fingers along the distribution of the median nerve. The disease occurs predominantly in patients in their fourth to sixth decades; women are two to five times more often affected than men. Bilateral involvement of the wrists has been observed in up to 50% of cases [5,6]. Although carpal tunnel syndrome can be generally attributed to a discrepancy between the size of the carpal tunnel and the volume of its contents, with subsequent compression of the median nerve between the flexor tendons and the rigid flexor retinaculum, the exact pathogenesis often remains unknown. Fibrous thickening or tenovaginitis of the flexor tendons, probably resulting from repetitive wrist action, are the most common causes, and have been found intraoperatively in up to 85% of cases [7]. Other possible causes of carpal tunnel syndrome are narrowing of the carpal tunnel as a consequence of fracture, carpal instability or hypertrophic bone changes; space-occupying lesions such as ganglion cysts, hemangioma, or lipoma; deposits of calcium, uric acid crystals, or amyloid; endocrinopathies such as myxedema or acromegaly; and finally venostasis and vasodilatation [7,8]. Congenital abnormalities such as aberrant muscles, excess fat along the dorsal aspect of

the tunnel, or a persistent median artery may also contribute to the pathogenesis of carpal tunnel syndrome [9,10].

1.3. Imaging studies in carpal tunnel syndrome

Imaging studies used for the assessment of carpal tunnel syndrome include plain radiographs, computed tomography (CT), magnetic resonance (MR) imaging and sonography. In the following sections, the usefulness and limitations of these modalities will be briefly discussed.

2. Plain radiographs

Plain radiographs of the wrist and carpal tunnel views are of limited value, as the soft tissue contents of the tunnel cannot be visualized. However, they may reveal osseous carpal stenosis due to displaced fractures, malalignment of the carpal bones, hypertrophic changes in osteoarthritis, or carpal instability [11]. Soft tissue calcifications, such as calcium pyrophosphate or hydroxylapatite depositions, or calcified tophi, can also be detected on plain radiographs (Fig. 2).

3. Computed tomography

Although the flexor tendons of the fingers can be regularly identified on axial CT scans, contrast resolution is not sufficient for evaluating soft tissue changes within the carpal tunnel. However, as compared to plain radiographs, CT offers various significant advantages [11,12]. The etiology, localization, and extent of osseous carpal stenosis can be exactly determined on axial thin-section images and on multiplanar or three-dimensional reconstructed images (Fig. 3a,b). CT is also more sensitive in detecting soft tissue calcifications and

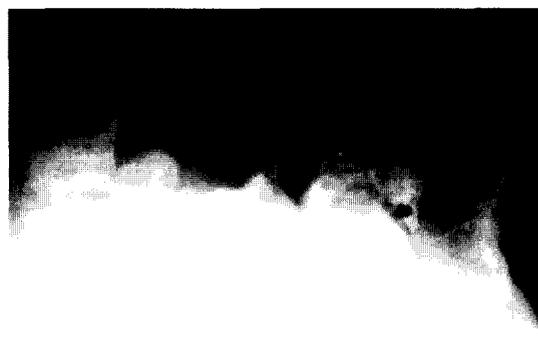


Fig. 2. Soft tissue calcification in carpal tunnel syndrome. Carpal tunnel view shows amorphous hydroxyapatite depositions within the carpal tunnel.

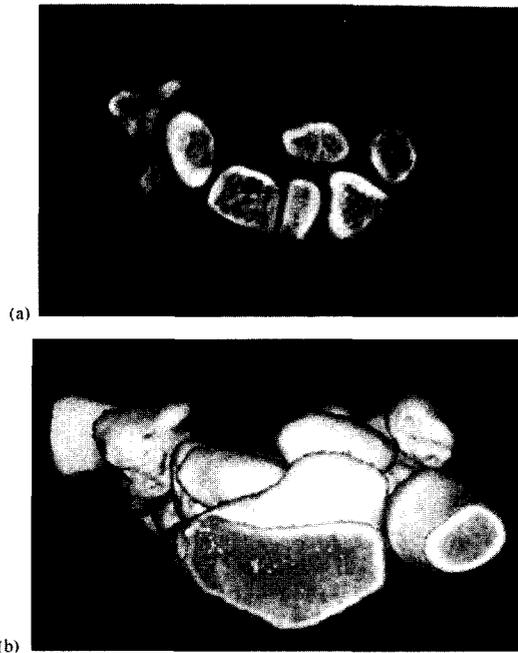


Fig. 3. Carpal tunnel syndrome due to transscaphoidal luxation of the lunate. (a) Axial CT scan through the proximal part of the carpal tunnel shows significant narrowing by the volarly displaced lunate. (b) Corresponding three-dimensional reconstructed image.

space-occupying lesions within the carpal tunnel, although, in non-calcified lesions, it is inferior to MR imaging.

4. Magnetic resonance

MR imaging is widely accepted as a useful method for the assessment of carpal tunnel syndrome [13–15]. The normal and pathological anatomy of the carpal tunnel and its surroundings is best displayed on axial T1-weighted and T2-weighted images. Additional images in the sagittal and coronal planes may be required for evaluating carpal bone anomalies or soft tissue tumors. MR imaging of the carpal tunnel is best done with a surface coil, with the arm at the side of the patient. Larger patients may need to have the arm placed above the head.

The flexor retinaculum and flexor tendons appear as low signal-intensity structures on all imaging sequences (Fig. 4). The tendon sheaths are of intermediate signal intensity and are only a few millimeters thick. The median nerve, of low signal intensity in T1 weighted and T2-weighted images, is round or ovoid in cross section, usually with its long axis orientated parallel to the flexor retinaculum. The size and shape of the nerve are relatively constant at the level of the radioulnar joint, pisiform and hook of the hamate (Table 1). General findings in patients with carpal tunnel syn-

drome include swelling, flattening and increased signal intensity of the median nerve, and increased palmar bowing of the flexor retinaculum [14,15] (Fig. 5). Swelling of the median nerve may be either diffuse or bulbous shaped, suggesting pseudoneuroma. It is usually most pronounced at the level of the pisiform. Flattening or attenuation of the nerve due to external compression is usually marked in the narrow distal part of the carpal tunnel. Elevated signal intensity of the median nerve on T2-weighted images, presumably from compression-induced edema, is an almost constant finding. However, fibrosis in long-standing compression neuropathy may also result in low signal intensity of the nerve. Palmar bowing of the flexor retinaculum is best identified at the level of the hook of the hamate. It can be quantified by measuring the distance from the volar apex of the ligament to its attachments to the trapezium and the hook of the hamate (palmar displacement). In normals, palmar displacement of the flexor retinaculum does not exceed 4 mm (Table 1). In tenosynovitis of the flexor tendons, the tendon sheaths appear distended and of increased signal intensity on T2-weighted images (Fig. 5). However, mild degrees of chronic fibrous thickening of the tendon sheaths may remain undetected [15]. Other findings possibly related to the cause of carpal tunnel syndrome, such as ganglion cysts, rare soft tissue tumors, or aberrant muscles, are readily identified by MR imaging.

5. Sonography

High-resolution sonography with near field probes working at frequencies of 7–10 MHz or even higher is able to display the carpal tunnel and its contents similar to MR imaging [16,17] (Figs. 6 and 7). The median nerve is best identified on axial imaging planes. The superficial flexor tendon of the index finger can be used as a landmark, as it lies just deep to the median nerve.

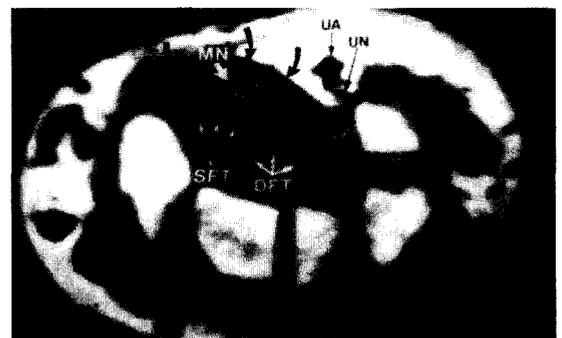


Fig. 4. MR imaging: normal findings. Axial T1-weighted MR image at the level of the pisiform. Flexor retinaculum (curved arrows); SFT, superficial flexor tendons; DFT, deep flexor tendons; MN, median nerve; UA, ulnar artery; UN, ulnar nerve.

Table 1
Normal range of measurements in the carpal tunnel

Measurement	Calculation	At radio-ulnar joint	At pisiform	At hamate
Cross-sectional area of median nerve	$1/4 \times a \times b \times \pi$	6–10 mm ²	6–11 mm ²	6–10 mm ²
Flattening ratio of median nerve	a/b	2.0–4.0	2.0–4.0	2.2–4.2
Palmar displacement of flexor retinaculum ^a				0–4 mm

For calculations of the cross-sectional area of the median nerve, an elliptic shape of the area is assumed. a, long axis of the median nerve; b, short axis of the median nerve.

^a Palmar displacement of the flexor retinaculum is defined as the distance from its palmar apex to a straight line between the attachments of the ligament to the trapezium and the hook of the hamate.

It can be easily distinguished from the other flexor tendons by moving the fingers. Another guiding structure is the tendon of the palmaris longus muscle which lies just volar to the median nerve, superficial to the flexor retinaculum. On sagittal scans, the median nerve can be distinguished from the flexor tendons by watching the tendons gliding within their sheaths during flexion and extension of the fingers, while the nerve remains stable. Echogenicity of the tendons and the nerve depends on the angle of the ultrasound beam. They appear both echogenic when the ultrasound beam is perpendicular to their surface, and echo-poor when it is oblique [16]. On axial scans, the median nerve seems to be surrounded by a narrow echogenic rim possibly representing the perineural fibrous tissue. With the exception of signal alterations, all diagnostic criteria which have been described for MR imaging, are also valid for sonography (Figs. 6 and 7). Comparative studies showed good correlation for measurements of the cross-sectional area and of the flattening ratio of the median nerve obtained with sonography and MR imaging (Table 1) [17]. Measurements of the palmar bowing of the flexor retinaculum were less accurate with sonography than with MR imaging. This is probably due to poor visualization of the carpal bones on sonograms, which makes identification of the measuring points

difficult. In addition, due to its better contrast resolution, MR imaging is superior in detecting mild degrees of median nerve compression [17]. Although acute tenovaginitis and extensive thickening of the flexor tendon sheaths are visible on sonograms, MR imaging is generally superior in detecting possible causes of carpal tunnel syndrome. A major advantage of sonography lies in the possibility of real-time assessment of dynamic changes in the carpal tunnel during flexion and extension of the wrist and fingers. Flexion of the wrist produces anatomic crowding in the carpal tunnel, which often results in flattening or interposition of the median nerve between the tendons, while the carpal tunnel may appear completely normal during wrist extension. Anatomic variations possibly related to the etiology of carpal tunnel syndrome, such as distal prolongation of the lumbrical muscles, are also easier to detect with a dynamic ultrasound examination. Finally, the low cost and moderate time requirement favor the use of sonography as the initial study in evaluating the carpal tunnel.

6. Imaging after carpal tunnel release

Carpal tunnel syndrome can be treated conservatively by splinting of the wrist, injection of steroids into the carpal tunnel and administration of nonsteroidal anti-

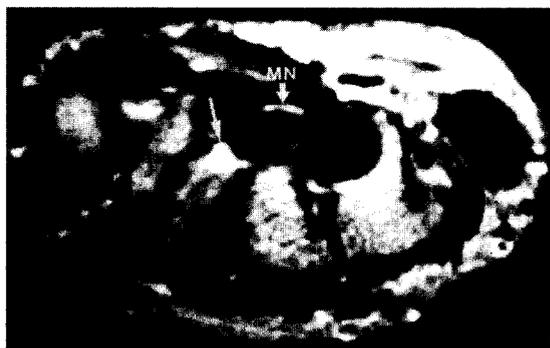


Fig. 5. MR findings in carpal tunnel syndrome. Axial T2-weighted image at the level of the hook of the hamate shows high signal intensity and extensive flattening of the median nerve (MN). Note increased signal intensity of the flexor tendon sheaths and a small ganglion cyst (arrow).

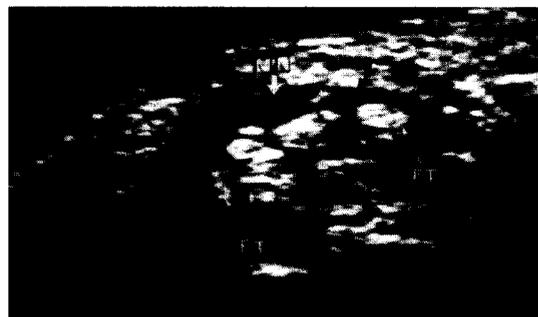


Fig. 6. Sonography: normal findings. Axial sonogram at the pisiform level. Flexor retinaculum (curved arrows); FT, flexor tendons; MN, median nerve.



Fig. 7. Ultrasound findings in carpal tunnel syndrome. Axial sonogram at the hamate level shows abnormal flattening of the median nerve (MN).

inflammatory drugs. If conservative treatment fails, surgical decompression of the median nerve by sectioning the flexor retinaculum is performed [4,5]. Carpal tunnel release can be done by open surgery or by endoscopic retinacular release and results in a high rate of success. However, not all patients respond well after surgical treatment [18]. In these cases, exact determination of the underlying pathology is necessary for selecting treatment, especially for indicating surgical re-exploration. The patient's history and physical examination are often equivocal and the value of electrodiagnostic studies is also limited. For these reasons, imaging studies play a crucial role in the assessment of recurrent or unrelieved carpal tunnel syndrome. Due to its superior contrast resolution, MR imaging is usually favored above sonography, which is additionally hampered by acoustic shadowing resulting from the surgical scar [15]. A successfully released flexor retinaculum is seen as an incomplete low-signal-intensity band, with the contents of the carpal tunnel displaced volarly and the fat stripe at the bottom of the carpal tunnel thickened, as compared to the preoperative examination (Fig. 8). Comparative pre- and postoperative studies with sonography and MR imaging showed that the flatten-

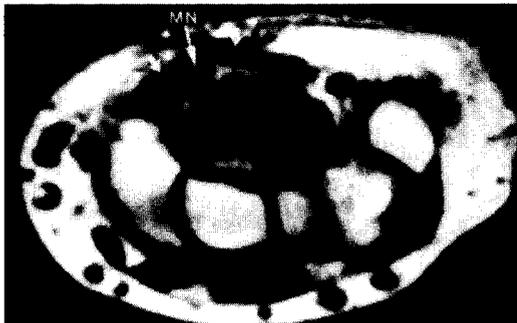


Fig. 8. Normal post-operative findings. Axial T1-weighted MR image shows complete transection of the flexor retinaculum (arrows) and normal shape of the volarly displaced median nerve (MN).

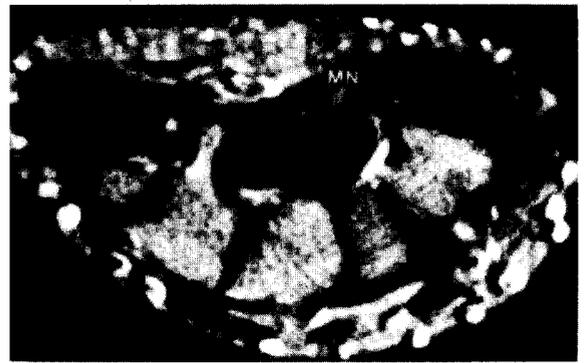


Fig. 9. Persistent compression of the median nerve after incomplete transection of the flexor retinaculum. T2-weighted axial MR image shows abnormal flattening and high signal intensity of the median nerve (MN).

ing ratio of the median nerve returned to normal in all patients with completely or partially relieved symptoms, whereas swelling persisted in the majority of cases [15]. Persistent flattening of the median nerve after carpal tunnel release is a reliable sign of persistent or recurrent compression [15]. The most common causes for failure of surgical decompression are incomplete incision of the flexor retinaculum, especially in its distal part, extensive scarring and chronic exsudative flexor tenovaginitis [15,18] (Fig. 9). Persistence of high signal intensity changes on T2-weighted images within a normally flattened median nerve suggests chronic neuritis (Fig. 10). This finding obviates surgical exploration, while re-surgery is necessary in most other cases.

7. Summary

The diagnosis of carpal tunnel syndrome can usually be made based on clinical findings, electromyography and nerve conduction studies. However, distinguishing



Fig. 10. Chronic neuritis of the median nerve after complete carpal tunnel release. T2-weighted axial MR image shows persistently increased signal intensity within a normally flattened median nerve.

carpal tunnel syndrome from other nerve entrapments, such as cervical root compression, thoracic outlet syndrome, or nerve entrapment at the forearm (anterior interosseous nerve syndrome), is not always possible on the basis of clinical findings alone and electrodiagnostic measurements may also be equivocal. In addition, selecting treatment may require identification of the exact cause of median nerve compression. Finally, preoperative assessment of the position of the median nerve is useful in patients who are scheduled for endoscopic retinacular release. For these reasons, plain radiographs of the wrist and the carpal tunnel, and an ultrasound examination are usually required. A CT examination should be performed, whenever the plain radiographs give evidence of osseous carpal stenosis or soft tissue calcifications. MR imaging is the modality of choice for the evaluation of soft tissue tumors within the carpal tunnel, for the assessment of therapy failure after surgery, and whenever findings on conventional imaging are equivocal.

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