Ulnar Nerve Entrapment at the Wrist

Abstract
Presentation of ulnar nerve entrapment at the wrist varies based on differential anatomy and the site or sites of compression. Therefore, an understanding of the anatomy of the Guyon canal is essential for diagnosis in patients presenting with motor and/or sensory deficits in the hand. The etiologies of ulnar nerve compression include soft-tissue tumors; repetitive or acute trauma; the presence of anomalous muscles and fibrous bands; arthritic, synovial, endocrine, and metabolic conditions; and iatrogenic injury. In addition to a thorough history and physical examination, which includes motor, sensory, and vascular assessments, imaging and electrodiagnostic studies facilitate the diagnosis of ulnar nerve lesions at the wrist. Nonsurgical management is appropriate for a distal compression lesion caused by repetitive activity, but surgical decompression is indicated if symptoms persist or worsen over 2 to 4 months.

Ulnar tunnel (Guyon canal) syndrome is a compressive neuropathy of the ulnar nerve. The site of compression determines whether sensory and/or motor deficits will occur. Motor involvement varies and can include weakness of the hypothenar, interosseous, and thumb adductor musculature.1,2 Sensory involvement most frequently manifests in the hypothenar eminence, little finger, and ulnar portion of the ring finger.3

Anatomy of the Ulnar Nerve

Proximal to the Guyon Canal
The ulnar nerve is derived from the anterior divisions of the eighth cervical and first thoracic spinal nerves. Typically the largest branch of the medial cord of the brachial plexus, the ulnar nerve may also receive fibers from the lateral cord and middle trunk.4 Distal to the axilla, the nerve travels in the anterior compartment of the brachium, pierces the medial intermuscular septum to course through the posterior compartment, and descends along the medial head of the triceps muscle, entering the cubital tunnel posterior to the medial epicondyle.5 Throughout the nerve’s entire course, the most common sites of compression are at the elbow, specifically, the arcade of Struthers, medial intermuscular septal, medial epicondyle, cubital tunnel, and deep flexor pronator aponeurosis.4,6

In the forearm, the ulnar nerve courses between the flexor digitorum profundus and flexor carpi ulnaris muscles, traveling along with and ulnar to the ulnar artery.4 Motor branches of the nerve innervate the flexor carpi ulnaris muscle and, distally, the flexor digitorum profundus muscle to the ulnar two digits.4 The Martin-Gruber anastomosis between the median and ulnar nerves (3 to 10 cm distal to the medial epicondyle) can account for intrinsic function despite the presence of a more proximal ulnar lesion and has been...
reported in 17% of individuals. The dorsal cutaneous branch of the ulnar nerve emerges 6 to 8 cm proximal to the distal ulna and travels dorsally, just distal to the ulnar styloid, to innervate the dorsal ulnar hand. However, this branch of the nerve may be absent.

The palmar cutaneous branch of the ulnar nerve branches 10 to 20 cm distal to the medial epicondyle. The nerve typically courses laterally to the ulnar artery before perforating the antebrachial fascia proximal to the distal wrist crease. It innervates the medial palmar skin and, rarely, the palmaris brevis muscle. However, in a cadaver study, Tubbs et al found that this branch was absent in 10% of hands. The ulnar nerve can be divided into three zones to help identify the site of compression (Figure 1).

At the Guyon Canal

The ulnar nerve and artery pass from the forearm through a narrow interval at the wrist to reach the hand. This interval, typically referred to as either the ulnar tunnel or Guyon canal, is palpably defined ulnarly and proximally by the pisiform and proximally by the pisiform and distally by the hook of the hamate. The ulnar tunnel begins at the proximal-most portion of the palmar carpal ligament, 1 to 2 cm proximal and deep to the distal wrist crease, and continues 4 to 4.5 cm through the palm to end at the fibrous arch that forms the origin of the hypothenar muscles. The entrance of the canal at the proximal wrist flexion crease is triangular, with a radial apex. The triangular, proximal portion of the canal is bounded ulnarly by the pisiform bone, volarly by the volar carpal ligament, and dorsally by the transverse carpal ligament (Figure 2). From proximal to distal, the roof, or volar boundary, consists of the transverse carpal ligament, the palmaris brevis, and the fat and fibrous tissue of the hypothenar eminence. The hypothenar muscles, their fibers of origin, and the flexor retinaculum comprise the floor of the space. The ulnar boundary of the space includes the junctions of the roof with the pisiform proximally and the superficial hypothenar fascia distally.
Distal to the Guyon Canal

Either upon exiting the canal or in its distal aspect, the motor fibers leaving the trunk of the superficial sensory branch innervate the palmaris brevis muscle. The superficial sensory nerve branch proceeds distally, providing sensory innervation to the palmar hypothenar eminence, little finger, and ulnar aspect of the ring finger (via a radial branch). The deep motor branch typically arises from the dorsal and ulnar side of the nerve trunk and courses distally and radially to the hook of the hamate, innervating the flexor digiti minimi, abductor digiti minimi, and opponens digiti minimi muscles. The nerve continues to course radially parallel to the deep palmar arch, and the deep motor branch terminates, innervating the interosseous, third and fourth lumbrical, and adductor pollicis and flexor pollicis brevis muscles. (The latter muscle also receives innervation from the median nerve.)

Motor innervation of the intrinsic hand musculature varies. Communication between the motor branch of the ulnar nerve and the recurrent branch of the median nerve—described as the Riche-Cannieu anomaly—has been reported in up to 77% of patients and can cause misleading clinical and electrodiagnostic findings. This neuronal communication can account for innervation of the third lumbrical muscle (and, rarely, the fourth lumbrical), by the median nerve, or innervation of the long finger lumbrical and/or the thenar muscles by the ulnar nerve.4

Ulnar sensory innervation also varies. The dorsal cutaneous branch of the ulnar nerve typically provides sensory innervation to the dorsal and radial aspects of the ulnar hand. However, this area may also be innervated by the radial nerve or the posterior cutaneous nerve (as complete absence of the dorsal sensory branch of the ulnar nerve has been reported). Alternatively, the superficial branch of the ulnar nerve can supply sensation to the entire ring finger, the third web space, or the long finger. Communication between the sensory branches of the median and ulnar nerves has been reported in a variety of patterns (albeit with less frequency and emphasis in the literature than the motor communications).

Three-zone Classification

Gross and Gelberman described tripartite zoning of the ulnar nerve within the Guyon canal, which can be useful for identifying the site of compression. This classification corresponds numerically and anatomically to the classification of ulnar nerve injuries in the wrist described by Shea and McClain. Zone 1 includes the ulnar nerve trunk proximal to the superficial sensory and deep motor branches of the nerve (Table 1). Because this zone contains both motor and sensory fascicles, a combined motor and sensory deficit indicates compression in this region (although small lesions in zone 1 can cause isolated sensory or motor deficits). Waugh and Pellegrini reported that ganglia and fractures of the hook of the hamate cause nearly all lesions in zone 1. Zone 2 includes the deep motor branch of the ulnar nerve; compression of this branch manifests as weakness of its innervated muscles. Isolated motor symptoms most likely manifest because of zone 2 compression; ganglia arising from the triquetrohamate joint and fractures of the hamate are the most frequently reported nontraumatic and traumatic causes, respectively. Zone 3 includes the superficial sensory branch of the ulnar nerve. Most pure sensory deficits are caused by compression in this zone; ulnar arterial thrombosis is the most frequently reported cause, followed by abnormal musculature.

Limitations of the three-zone classification scheme include anatomic variation and the possibility of multiple sites of compression. For example, although frequently reported as the proximal boundary of zone 2, the pisohamate hiatus was present in 57% and 80% of hands in two studies. In addition, although bifurcation of the ulnar nerve into superficial (sensory) and deep (motor) branches

Table 1

| Table 1 | Ulnar Tunnel Zones, Associated Ulnar Nerve Branches, and Common Causes and Symptoms of Compression |
|---------|-------------------------------------------------------------------------------------------------|
| Zone | Associated Ulnar Nerve Branch | Common Causes | Common Symptoms |
| 1 | Ulnar nerve trunk proximal to the superficial sensory and deep motor branches of the nerve | Ganglia, fracture of the hook of the hamate | Combined motor and sensory deficit |
| 2 | Deep motor branch of the ulnar nerve | Repetitive trauma, ganglia of the triquetrohamate, fracture of the hook of the hamate | Isolated motor deficits |
| 3 | Superficial sensory branch of the ulnar nerve | Abnormal musculature, ulnar arterial thrombosis | Isolated sensory deficits |

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In an cadaver study has been reported to
Burns can result and have been found
chronic renal

In this
Dorsally displaced fractures of
f o u n da nu l n a r
Prolonged
Soft-tissue masses may
have been found originating

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can
28
In addition to occupationally
du-
the most commonly reported
activities involving prolonged
Patients with other sys-
alcoholism, and hypothy-
can be seen originating

Copyright
Soft-tissue Tumors
702
Figure 3

Coronal T2-weighted magnetic
resonance image demonstrating
a ganglion cyst within the distal ulnar
tunnel. The abductor digitii minimi
muscle—the most commonly reported
anomalous muscle related to distal ulnar
compression—can be seen originating
at the ulnar aspect of the pisiform.

typically defines the start of zone 2, both
the location and number of branches
vary considerably. In an cadaver study
of 31 upper extremity specimens, Lind-
sey and Watumull, found an ulnar
trifurcation pattern in 6 hands (19%).

Although the three-zone scheme will
be referred to herein, a five-zone scheme
in which lesions of the deep motor
branch have been classified into three
types has been described. In this
scheme, zone 2 includes the superficial
ersory sensory branch, and zone 3 compres-

sion results in deep motor neuropathy
that affects the hypothenar muscles
and the intrinsic muscles. Zone 4 compres-
cion causes deep motor neu-
ropathy, with the hypothenar muscles
spared. Zone 5 compression results in
depth motor neuropathy that strictly
affects the ulnarly innervated interossei
of the middle and index fingers as well as
the adductor muscle.

Etiology

Soft-tissue Tumors
Ganglia are the most commonly re-
ported cause of ulnar tunnel syn-
drome and have been found emanating from the triquetromhamate,
piotrigueal, un nocarpal, and mid-
carpal joints. Soft-tissue masses may
impinge upon the ulnar nerve within
the small confines of the ulnar tunnel
and, in order of decreasing frequency,
the following masses may also be
encountered: lipomas, giant cell tu-
mors, and intraneural cysts. Du-
puytren nodules and cords that
impinge on the ulnar tunnel also have
been reported.

Trauma
Repetitive vibratory trauma or pro-
longed compression of the ulnar palm
has been described as the second most
common cause of ulnar tunnel syn-
drome. In addition to occupationally
related activities such as jackhammer-
ing, activities involving prolonged
dorsiflexion of the wrist are associated
with distal ulnar lesions. Prolonged
pressure on the ulnar palm associated
with cycling and weightlifting can
also cause ulnar tunnel syndrome.

Aneurysms related to blunt vessel
trauma are a frequently reported cause
of ulnar tunnel syndrome. For ulnar
lesions related to occupation or avo-
cation, many authors recommend
onsurgical management with activity
modification.

Fractures of the hook of the hamate
are the most commonly reported tra-
matic cause of ulnar tunnel syndrome;
other causes include fractures of the
trapezium, pisiform, and the base of the
metacarpals of the little and ring
fingers. Dorsally displaced fractures of
the distal radius can be associated with
traction neuropathy, but fractures of
the ulnar head are more likely to cause
direct compression. Burns can result
in direct damage to the nerve or nerve
compression through contractures.

Anomalous Muscles and
Fibrous Bands
Anomalous hypothenar musculature,
which has been reported in 16% to
25% of hands, has been reported to
cause 16% of distal ulnar lesions.
The number of abductor digitii minimi
muscles (the hypothenar muscle with
the most variability) and where
they originate commonly varies
(Figure 3). Variation in insertion site
(always at the proximal phalanx of the
little finger, with an additional reported
insertion at the extensor aponeurosis in
83% of hands) has been reported less
often. Alteration in the origin of the
flexor digitii minimi (or the muscle’s
absence) and unusual orientation or
additional anomalous hypothenar
muscles have also been reported.

Anomalous or hypertrophied ulnar
musculature (including the palmaris
longus and/or palmaris brevis) can
contribute to distal ulnar lesions by
impinging on the Guyon canal.

Arthritic, Synovial,
Endocrine, and Metabolic
Conditions
Conditions related to osteoarthritis
and rheumatoid arthritis, including
tenosynovitis, exuberant pannus
formation, edema, and bony defor-
mity, have been linked to compres-
sion of the ulnar nerve in the ulnar
tunnel. Patients with other sys-
temic neuropathies associated with
diabetes mellitus, chronic renal
failure, alcoholism, and hypothy-
roidism are highly susceptible to
peripheral neuropathy. Periarticular
calcium deposits have also been
linked to acute compression of the
ulnar nerve at the Guyon canal.
The patient’s history and electro-
diagnostic studies can help the cli-
nician distinguish between these
conditions and isolated distal ulnar
dysfunction.

Iatrogenic Injury
Laceration of the ulnar nerve has been
reported in the course of tendon
transfers and carpal tunnel releases.
In addition to the potential for direct
injury to the nerve during surgery,
carpal tunnel release alters the anatomy of the tunnel. Although this commonly results in decreased pressure and increased volume of the ulnar tunnel as well as improved distal ulnar conductivity, postoperative ulnar neuropathy related to ulnar translocation of the contents of the carpal tunnel has also been reported. 

Controversy exists regarding if and when exploration of the Guyon canal is appropriate when a carpal tunnel release is performed. Silver et al reported that a “very small percentage of patients” had residual symptoms of ulnar nerve compression after carpal tunnel release was performed and noted that routine decompression of the Guyon canal performed at the time of carpal tunnel release may not be indicated. Murata et al recommended exploration of the Guyon canal as an adjunct procedure when a distal ulnar lesion is identified or the surgeon suspects multiple sites of nerve compression.

**Diagnosis**

Distal ulnar neuropathy presents with an isolated or mixed sensorimotor deficit that is typically localized to the ulnar hand. When determining a diagnosis, clinicians should attempt to rule out more prevalent causes of neuropathy (eg, carpal tunnel syndrome, cubital tunnel syndrome, cervical nerve root compression) while gathering additional information that may indicate ulnar tunnel syndrome. It should be noted that ulnar motor and sensory findings may be the hallmark presentation for a variety of conditions, including other peripheral, proximal (eg, cubital tunnel syndrome), and infectious (eg, poliomyelitis) neuropathies; brachial plexopathy or central nervous system lesions; malignant peripheral nerve sheath tumors; and neuromuscular disorders (eg, Charcot-Marie-Tooth disease, amyotrophic lateral sclerosis).

**History**

To rule out the presence of more proximal nerve compression, clinicians should inquire about the duration and severity of symptoms related to the ulnar hand, brachial plexus, the remainder of the arm, and the cervical spine. As the clinician obtains an inability to perform specific movements of the hand, particular attention should be focused on findings that may be indicative of ulnar neuropathy. These findings may include decreased strength and atrophy of the hypothenar muscles; atrophy; or subjective sensory changes. Nerve pathology may be localized with sensory and motor testing in the context of the three-zone scheme described previously (Table 1).

**Motor Examination**

To differentiate neuropathy caused by a lesion at the Guyon canal from other peripheral neuropathies, the motor function of the intrinsic and extrinsic musculature in both the median and ulnar distributions should be examined. The palmaris brevis sign may help the clinician to distinguish ulnar compression at the cubital tunnel from that at the Guyon canal; abduction of the little finger coincides with palmaris brevis contraction in the latter case but not in the former. Impaired palmaris brevis function may strengthen the impression of a zone 3 lesion because the superficial sensory branch of the ulnar nerve provides the relevant motor innervation. This is in contrast with other motor tests that focus on the musculature innervated by the deep motor branch of the nerve.

Grip and pinch strength measurements should always be compared with those of the contralateral extremity. Decreased key pinch strength can indicate weakness of the adductor pollicis and first dorsal interosseous muscles caused by a deep motor lesion. A positive Froment sign, characterized by interphalangeal flexion when a patient attempts to pinch a thin object, also demonstrates weakness in these muscles, and the flexor pollicis longus compensates for the weakened muscles. Inability to cross the index and middle fingers may indicate deficient deep ulnar motor innervation of the first palmar and second dorsal interossei. Because the hypothenar muscles receive motor innervation at the origin of the deep motor branch of the ulnar nerve, intact function in these muscles combined with weakness of the
interosseous and adductor pollicis muscles indicates a lesion distal to the deep motor branch. Inability to adduct the little finger, known as Wartenburg sign, indicates paralysis of the third palmar interosseous muscle.14

Sensory Examination
The presence or absence of sensation at the palmar and dorsal aspects of the ulnar hand can indicate the site of an ulnar lesion. A dorsoulnar sensory deficit indicates the presence of a lesion25 proximal to the dorsal cutaneous branch, whereas retained sensation in the little and ring fingers combined with intrinsic weakness suggests the presence of a lesion at the deep motor branch of the ulnar nerve. Two-point discrimination, light touch, and monofilament pressure testing (if available) of all dermatomes can help determine sensory deficit patterns. Manual pressure applied over the distal ulnar tunnel can help confirm a distal ulnar lesion by provoking numbness or paresthesias in the ulnar nerve distribution.14

Regardless of sensory findings in the hand, percussion over the ulnar nerve to elicit a Tinel sign should be performed throughout the nerve’s course—beginning at the brachial plexus, through the elbow and forearm, across the wrist, and into the hand—because multiple levels of compression may be present.6 The elbow flexion test can aid the clinician in localizing the site of nerve entrapment at the cubital tunnel; pain, numbness, or paresthesia in the ulnar sensory distribution of the hand following 1 minute of maximal elbow flexion is a positive sign for ulnar entrapment at the cubital tunnel.

Vascular Examination
Because distal ulnar nerve compression is frequently associated with arterial thromboses and aneurysms, a detailed vascular examination is warranted.8,14 The clinician should confirm an ulnar arterial pulse while palpating for a thrill or pulsatile mass. Additionally, an Allen test performed at the wrist can help the clinician assess patency of the arterial arch system in the hand; normal capillary refill should occur in ≤2 seconds, with >5 seconds being abnormal.8 Pallor and coolness of the ulnar digits are additional signs of arterial insufficiency. Doppler examination or arteriography may aid in localizing a lesion of the ulnar artery.33

Imaging
Radiography (specifically, the carpal tunnel view) and CT can reveal fractures of the hook of the hamate, ectopic calcification, and displacement associated with distal ulnar lesions.21 In addition to identifying peripheral nerve lesions, an MRI of the hand at the level of the hook of the hamate can depict the branching pattern of the ulnar nerve in the Guyon canal; anomalous musculature; and ganglia, which are a commonly reported cause of distal ulnar neuropathy3,5 (Figures 2 and 3). Advances in high-resolution ultrasonography over the past two decades have enabled better visualization of soft-tissue, vascular, and nerve structures.36

Electrodiagnostic Studies
Electrodiagnostic evaluation of the ulnar nerve can help the clinician confirm or rule out nerve entrapment.37 Ulnar nerve segments at the elbow, forearm, and hand are commonly evaluated. In addition to localizing lesions, nerve conduction velocity studies and electromyography can help the clinician rule out motor neuron disease or peripheral neuropathy associated with diabetes mellitus and alcoholism by comparing sensory conduction studies of the sural nerve and motor conduction studies of the peroneal nerve with ulnar and median nerve studies.16 Assessment for concurrent median neuropathy is commonly performed. Because ulnar lesions at the cubital tunnel frequently involve motor axonal loss, normal findings on motor conduction velocity studies performed across the elbow may indicate nerve entrapment at a site other than the cubital tunnel.37 Motor conduction velocity testing reportedly localizes a proximal ulnar nerve lesion in 67% of patients with symptoms of ulnar neuropathy, and sensory and mixed nerve conduction testing increases localization to 86%.16 Because the dorsal cutaneous branch of the ulnar nerve does not traverse the Guyon canal, abnormal findings in the affected extremity compared with those of the contralateral extremity can further aid the clinician in localizing an ulnar lesion proximal to the wrist.

In the context of the three-zone classification scheme, zone 1 lesions are characterized by diminished sensory responses and prolonged latency to the first dorsal interosseous and abductor digiti minimi muscles.14,25 Zone 2 lesions are characterized by prolonged latency of the first dorsal interosseous muscle (and possibly the hypothenar muscles) and intact ulnar palmar sensation. Zone 3 lesions are characterized by ulnar palmar sensory loss only. Increased latency across the wrist of the ulnar-innervated interosseus relative to the median-innervated second lumbrical muscle can help confirm the presence of lesions in zone 1.38 Median and ulnar nerve neuropathies at the wrist are not mutually exclusive; a recent study found that 22 of 53 hands (41.5%) with ulnar lesions also had median nerve deficits.24 Intrinsic innervation of the hypothenar muscles and the first dorsal interosseous muscle is best evaluated by electromyography needle examination.16 Action potentials associated with axonal damage manifest as positive sharp waves and fibrillations.
and reinnervation may reveal lengthened, enlarged motor units.\textsuperscript{16}

**Management**

Nonsurgical measures are indicated and effective for ulnar nerve entrapment when a distal lesion is caused by repetitive activity. Surgery is indicated for patients with symptoms that persist or worsen over 2 to 4 months.\textsuperscript{10,23} Ulnar intrinsic muscle denervation, atrophy, or weakness is an indication for surgical decompression because full recovery is less likely with prolonged muscle atrophy. Persistent ulnar sensory deficits are also an indication for surgery.

The ulnar nerve should be exposed from the distal forearm through the entire Guyon canal, regardless of the site of compression.\textsuperscript{14} To prevent contracture, an S- or Z-shaped incision should cross the volar wrist crease at 45°\textsuperscript{35} (Figure 4). After the flexor carpi ulnaris muscle is retracted ulnarily, the surgeon should identify the ulnar nerve and artery and follow their course into the Guyon canal, incising the palmar carpal ligament, palmaris brevis, and accessory hypothenar fibers\textsuperscript{14} (Figure 5). The deep branch of the ulnar nerve should be visualized distal to its branching, and the position of the ulnar artery should be confirmed. The surgeon should inspect for masses, thromboses, abberant fibrous bands, and bony protrusions that can cause compression\textsuperscript{21} and resect them as is appropriate.\textsuperscript{14}

For management of a ganglion cyst, all of its articular extensions should be resected. The surgeon should then débride the joint and leave the capsule open. Percutaneous aspiration is not recommended because of the number of sensitive anatomic structures in the region.

**Surgical Outcomes**

Aside from case reports, limited outcome data exist on surgical management of ulnar nerve entrapment at the wrist. In a retrospective review of 31 patients with ulnar tunnel syndrome treated surgically, Murata et al\textsuperscript{21} described uniform improvement of symptoms; however, 5 patients (16%) had slight persistent numbness at the ring and little fingers postoperatively. Failed resolution of symptoms may be associated with intraoperative failure to identify and address a compression site.\textsuperscript{34} In a study of 11 patients with a lesion of the deep palmar branch of the ulnar nerve caused by occupational trauma, Almeida and de Carvalho\textsuperscript{23} noted zone 3 compression. Ten patients went on to full recovery after 2 to 4 months of activity modification, and the remaining patient underwent ganglion excision. Significant relief of symptoms 3 to 5 months following ulnar decompression at the wrist has been reported.\textsuperscript{32}

**Complications**

The Guyon canal is host to a nexus of nervous and vascular tissue that varies in its anatomic arrangement. Therefore, surgeons must be aware of the arborization patterns of the ulnar nerve to be prepared when anomalous anatomic structures and varied vascular courses are encountered during dissection.\textsuperscript{35} Surgeons should carefully preserve the vascular supply to the ulnar nerve\textsuperscript{14} and avoid injury to nerve branches in the wrist.\textsuperscript{2}

**Summary**

By understanding standard ulnar branching and innervation patterns, clinicians can frequently localize distal ulnar lesions based on clinical examination and radiographic and electrodagnostic studies. Symptom persistence is an indication for surgical management. Proper identification of sites of compression and prevention of iatrogenic injury demand that surgeons understand and prepare for possible anatomic variations in the wrist.

**References**

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 16, 29, and 37 are level III studies.
References 1-3, 5-12, 14, 15, 17-28, and 30-36 are level IV studies.
References printed in bold type are those published within the past 5 years.

1. Spinner RJ, Wang H, Howe BM, Colbert MH, Amrami K: Deep ulnar intraneural ganglia in the palm. Acta Neurochir (Wien) 2012;154(10):1755-1763.

2. Puna R, Poon P: The anatomy of the dorsal cutaneous branch of the ulnar nerve. J Hand Surg Eur Vol 2010;35(7):583-588.

3. Polatsch DB, Melone CP Jr, Beldner S, Weishaupt D: Peripheral neuropathies of the median, radial, and ulnar nerves: MR imaging features. Radiographics 2006;26(5):1267-1287.

4. Doyle JR, Botte M (eds): Anatomical Anatomy of the Hand and Upper Extremity, ed 5. Philadelphia, PA, Lippincott Williams & Wilkins, 2003.

5. Andreiech G, Crook DW, Burg D, Hawn MA: Ulnar neural entrapments at the wrist. J Hand Surg Am 2005;30(6):938-946.

6. Elhassan B, Steinmann SP: Entrapment neuropathy of the ulnar nerve. J Hand Surg Am 2003;28(4):647-651.

7. Goldfarb CA, Stern PJ Jr: Low ulnar nerve neuropathy. J Hand Surg Am 1999;24(6):1171-1184.

8. Mok D, Nikols A, Harris PG: The cutaneous innervation of the dorsal hand: Detailed anatomy with clinical implications. J Hand Surg Am 2006;31(4):565-574.

9. Gros MS, Gelberman RH: The anatomy of the distal ulnar tunnel. Clin Orthop Relat Res 1985;196:238-247.

10. Shea JD, McClain EJ: Ulnar-nerve compression syndromes at and below the wrist. J Bone Joint Surg Am 1999;81(6):1095-1103.

11. Murata K, Shih JT, Tsai TM: Causes of ulnar tunnel syndrome: A retrospective study of 31 subjects. J Hand Surg Am 2003;28(4):647-651.

12. Park JW, Kim DH: A case of acute deep palmar ulnar neuropathy due to a ganglion after weightlifting diagnosed with short segmental study and diagnostic ultrasound. Clin Neurol Neurosurg 2013;115(2):204-207.

13. Almeida V, de Carvalho M: Lesion of the deep palmar branch of the ulnar nerve: Causes and clinical outcome. Neurophysiol Clin 2010;40(3):159-164.

14. Seror P: Electrophysiological pattern of 53 cases of ulnar nerve lesion at the wrist. Neurophysiol Clin 2013;43(2):95-103.

15. Agustín PH, Bor-Seng-Shu E, Gomes-Pinto F, et al: Surgical management of Guyon’s canal syndrome, an ulnar nerve entrapment at the wrist: Report of two cases. Arg Neuropsiquiatr 2001;59(1):106-111.

16. Gunev F, Yuratun B, Karalezli N: Digital neuropathy of the median and ulnar nerves caused by Dupuytren’s contracture: Case report. Neurologist 2009;15(4):217-219.

17. Capitani D, Beer S: Handlebar palsy: A compression syndrome of the deep terminal (motor) branch of the ulnar nerve in biking. J Neurol 2002;249(10):1441-1445.

18. Claassen H, Schmitt O, Schulze M, Wree A: Variation in the hypothenar muscles and its impact on ulnar tunnel syndrome. Surg Radiol Anat 2013;35(10):893-899.

19. Gazioglu S, Boz C, Cakmak VA: Electrodiagnosis of carpal tunnel syndrome in patients with diabetic neuropathy. Clin Neurophysiol 2011;122(7):1463-1469.

20. Mondelli M, Ginzaneschi F, Rossi A: Evidence of improvement in distal conduction of ulnar nerve sensory fibers after carpal tunnel release. Neurosurgery 2009;64(5):e169-701, discussion 701.

21. Yasen S: Acute calcific tendinitis of the flexor carpi ulnaris causing acute compressive neuropathy of the ulnar nerve: A case report. J Orthop Surg (Hong Kong) 2012;20(3):414-416.

22. Pingree MJ, Bosch EP, Liu P, Smith BE: Delayed ulnar neuropathy at the wrist following open carpal tunnel release. Muscle Nerve 2003;31(3):394-397.

23. Bachoura A, Jacoby SM: Ulnar tunnel syndrome. Orthop Clin North Am 2012;43(4):467-474.

24. Silver MA, Gelberman RH, Cellman H, Rhoades CE: Carpal tunnel syndrome: Associated abnormalities in ulnar nerve function and the effect of carpal tunnel release on these abnormalities. J Hand Surg Am 1985;10(5):710-713.

25. Kokkalis ZT, Estathopoulos DG, Papanastassiou ID, Sarlikioti T, Papagelopoulos PJ: Ulnar nerve injuries in Guyon canal: A report of 32 cases. Microsurgery 2012;32(4):296-302.

26. Niiitsu M, Kuboko N, Nojima S: Variations of the ulnar nerve in Guyon’s canal: In vivo demonstration using ultrasound and 3 T MRI. Acta Orthop 2010;81(8):939-946.

27. Werner RA: Electrodiagnostic evaluation of carpal tunnel syndrome and ulnar neuropathies. PM R 2013;5(5 suppl):S14-S21.

28. Meena AK, Sriivasra Rao B, Salalja S, Mallikarjuna M, Borgohain R: Second lumbrical and interosseous latency difference in Carpal Tunnel Syndrome. Clin Neurophysiol 2008;119(12):2789-2794.