CME

Understanding carpal tunnel syndrome

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ABSTRACT

Carpal tunnel syndrome (CTS) is an entrapment neuropathy affecting the median nerve. Prevalence is estimated at 4% to 5% of the population. A solid understanding of the anatomy, presentation, and diagnostics is key to efficient diagnosis and appropriate referral. Both surgical and nonsurgical interventions have led to improved clinical outcomes. Clinicians who have an in-depth knowledge of CTS symptoms and treatment options can prepare patients and streamline referrals for improved patient outcomes.

Keywords: carpal tunnel syndrome, peripheral neuropathy, median nerve, entrapment, wrist pathophysiology, carpal tunnel release surgery

Learning objectives

- Describe the anatomy and pathophysiology of CTS.
- Review risk factors, clinical features, and examination findings that increase clinical suspicion for CTS.
- Describe diagnostic imaging options for optimal workup and diagnosis.
- Describe conservative and surgical treatments.

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy, defined as nerve damage (specifically the median nerve) at narrow passage sites.[1-3] The first case reports of compression of the median nerve were published by Paget in 1854.[4] Studies by Phalen in the 1950s became the foundational principles for understanding CTS.[5] The condition tends to affect patients ages 40 to 60 years; prevalence is estimated between 4% and 5% of the population.[6] Various studies have shown that CTS is more common in women than men (2.2 to 5.4 women to 1.1 to 3 men per 1,000 people).[7-10] Short- and long-term effects of these neuropathies span various domains and have physical and economic consequences, such as absence from work, decreased neurologic function, and high healthcare costs.[3] This article describes the anatomy and pathophysiology of CTS and its treatment options so clinicians can better prepare patients and streamline referrals for improved outcomes.

ANATOMY

The carpal tunnel is a narrow space located on the palmar surface that allows the passage of various structures such as the median nerve and various flexor tendons (**Figures 1** and **2**). The borders of this tunnel include the flexor retinaculum (roof), carpal bones (base), the hook of the hamate, pyramidal bone, pisiform bone (ulnar edge), scaphoid and trapezoid bones, as well as the tendon of the flexor carpi radialis (FCR) muscle forming the radial edge.[11] The tendons passing through the carpal tunnel are the four flexor digitorum superficialis, the four flexor digitorum profundus, and the flexor pollicis longus.

The median nerve enters the hand through the carpal tunnel and divides into six branches (**Table 1**). Of these, the recurrent branch supplies the muscles of the thumb, which predominantly help with opposition, including the abductor pollicis brevis, opponens pollicis, and the superficial portion of the flexor pollicis brevis.

The proper palmar digital nerves compose the next three branches. These are cutaneous digital branches that innervate both the radial and ulnar sides of the thumb. The final branch innervates the radial side of the index finger along with motor innervation to the first lumbrical. The final two branches, the common palmar digital branches,

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Key points

- CTS is an entrapment neuropathy characterized by physiologic changes in the median nerve that result from the application of external force, compressing the nerve in the tunnel.
- The mainstay of treatment involves a combination of medications and surgical release.
- Prompt recognition of symptoms and addressing appropriate risk factors can significantly help a patient's quality of life.

supply innervation to the cleft between the index and middle finger and the cleft between the middle and ring fingers with motor innervation to the second lumbrical.

Overall, the median nerve supplies cutaneous innervation to the palmar side of the thumb, index, middle finger, and the radial side of the ring finger with motor innervation to muscles of the thenar eminence and first/second lumbricals. A number of publications have shown variations in sensory innervation with anastomoses of the ulnar nerve on the palmar and dorsal surfaces.[12] In addition, the Martin and Grüber anastomosis has been documented in the forearm, while the Riche-Cannieu anastomosis is in the hand.[13]

PATHOPHYSIOLOGY

CTS is an example of entrapment neuropathy characterized by physiologic changes in the nerve that result from the application of external force. These various forms include

- chronic low force application (such as typing on a keyboard for work or routinely playing a musical instrument)
- acute focal application of a large force, such as in Saturday night palsy, a compressive neuropathy of the radial nerve from direct prolonged pressure on the upper medial arm or axilla[14]
- repetitive application of brief larger forces (occupational such as using a chain-saw continuously as a forestry worker, or drilling as a stone quarry laborer).

The neuropathy also may be due to a combination of stretching or shearing of the nerve, leading to physiologic change. The physiologic adaptation of the nerve to these forces results in conduction changes of the nerve, including slowing or complete blockage of conduction. In addition, the external forces may result in the production of ectopic impulses that could manifest as fasciculations of the muscle or paresthesias.[15]

In patients with CTS, median nerve compression occurs at two sites: at the most proximal portion of the carpal tunnel where flexion and thickening of the overlying fascia can impinge on the nerve, and at the area where the diameter of the tunnel becomes most narrow at the area of the hamate hook. Three theories about the pathophysiology of CTS—Lundborg, double crush, and dynamic—are discussed below.

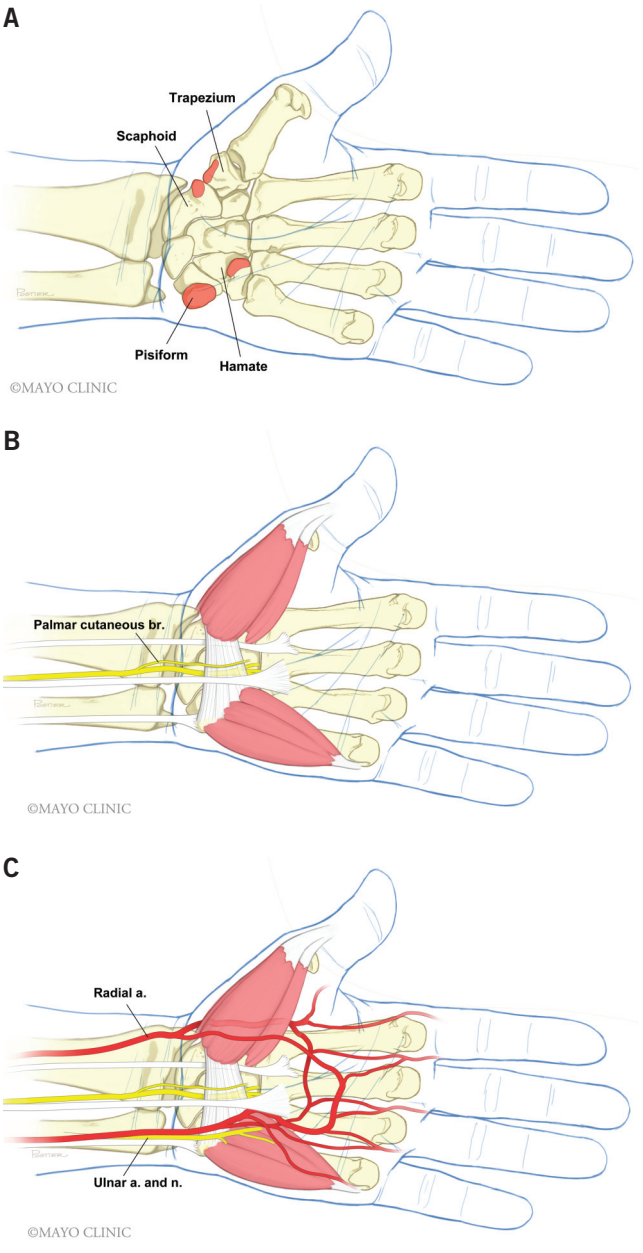


FIGURE 1. Anatomy of the wrist: Bony (A), deep (B), and arterial (C)

Lundborg theory This proposed classification is based on insults to the intraneural blood microcirculation, myelin sheath, axons, and supporting connective tissue.[16] The early stage is characterized by intermittent symptoms occurring at night caused by various factors that increase pressure in the carpal tunnel. One of these factors is the tendency to flex the wrist at night, increasing pressure on the nerve. The other causes revolve around the idea that an increase of fluid or edema in the upper limb can lead to increased intraneural and endoneural pressure that impairs the signal transduction of the nerves. These factors include a redistribution of upper limb fluid when the patient

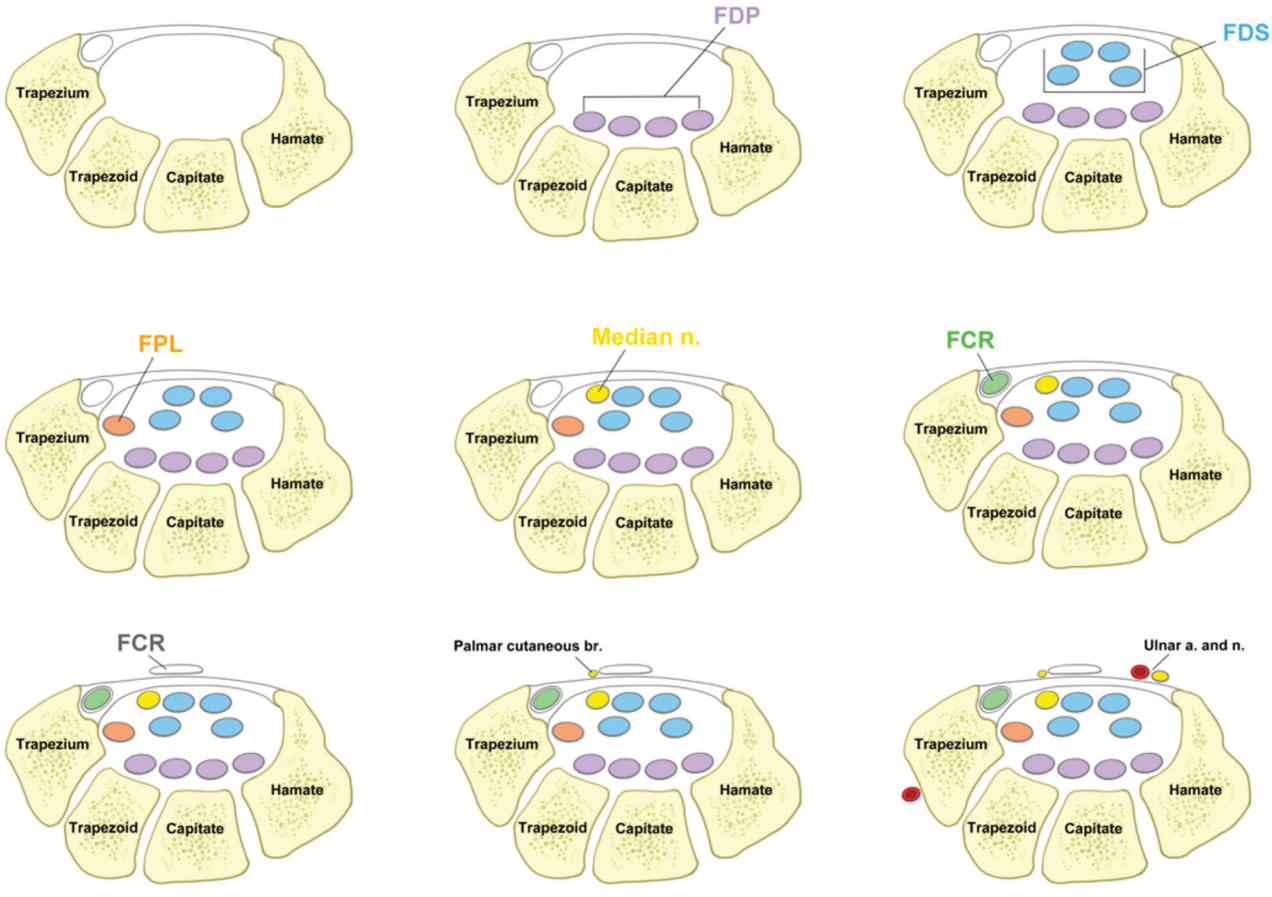


FIGURE 2. Transverse cut revealing anatomy of the wrist

is supine at night, mechanical deficiencies of muscle pumps, and an increase in arterial pressure that interferes with the venous return of the intraneural microcirculation, leading to metabolic effects that upset the homeostatic balance of the nerve and its conductive capabilities. This stage is associated with intermittent symptoms due to the reversibility of the improper drainage by repositioning of the wrist and fingers.

The intermediate stage is defined by symptoms occurring both nocturnally and diurnally. The underlying mechanism causing these symptoms to persist is epineural and intrafascicular interstitial edema, which generates a thickening of the epineurium's connective envelope. In addition, the myelin sheath and nodes of Ranvier are damaged, causing problems with saltatory conduction of the nerve. Relief of compression leads to rapid amelioration of symptoms due to reinstitution of the microcirculation. Intermittent symptoms and electrophysiologic abnormalities may linger from weeks to months after the resolution of the compression because of the active repair of the myelin sheath.

The final or advanced stage is characterized by a persistence of sensory and motor deficits. The underlying mechanism of this stage is axonotmesis (a complete interruption of axons resulting in loss of conduction in the nerve fiber beyond the injury). Release of the nerve leads to variable rates of recovery that depend on proper nerve regeneration. Various factors influence successful rates of regeneration and include age, history of polyneuropathy, and compression severity.[11]

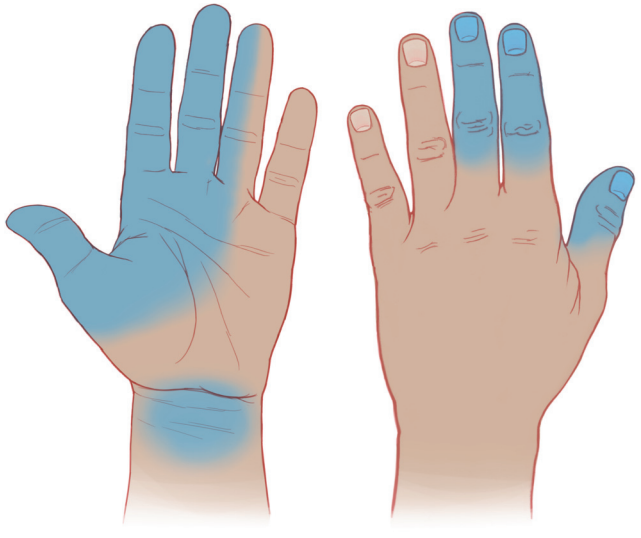
Double crush theory Upton and McComas postulated that proximal compression of a nerve interrupts the axoplasmic transportation in anterograde and retrograde fashions.[17] This increases the susceptibility of symptomatic neuropathy distally in the nerve due to disruption of this transport system. Various researchers later supported this theory by reporting patients who had an association of CTS with various proximal compression syndromes such as cervical radiculopathy and brachial plexus compression. Understanding this mechanism can help clinicians identify the main compression site and tailor treatment to the cause of the injury. When evaluating a patient's symptoms, consider a differential diagnosis that involves alternative cervical spine or brachial plexus compression sites that could lead to CTS symptoms.

TABLE 1. Median nerve and what it innervates[11-13]

Branch of the median nerve	Muscle	Function
Forearm		
Muscular branch	Pronator teres, palmaris longus, flexor digitorum superficialis, flexor carpi radialis	Pronation of the forearm, flexion of the wrist and small joints of the hand, flexion of the medial four digits at the proximal interphalangeal joints, some abduction of the hand and wrist
Anterior interosseous nerve	Flexor pollicus longus, radial portion of flexor digitorum profundus, pronator quadratus	Flexion of distal phalanx of thumb at interphalangeal joint, flexion of MCP and DIP of medial four digits, pronation of radioulnar joint
Hand		
Palmar cutaneous nerve		Cutaneous sensation to the palm, outside of the carpal tunnel
Palmar digital nerves	Radial two lumbricals	MCP joint flexion and extension of the interphalangeal joints (PIP and DIP), cutaneous sensation
Recurrent branch	Muscles of the thenar eminence–flexor pollicis brevis, abductor pollicis brevis, opponens pollicis	Flexion, abduction, and opposition of the thumb

Dynamic A variant of CTS known as dynamic CTS occurs in patients who have no symptoms or physical examination findings during rest, but symptoms are exacerbated by increased workload of the hands. Increased pressure inside the carpal tunnel has been associated with repetitive motions such as wrist extension, flexion, supination of the forearm, and flexion of the fingers.[18] In particular, occupations such as rock drilling, forestry work, repetitive assembly work, manufacturing, and food packing lead to increased pressure inside the tunnel. These motions increase pressure and lead to a possible incursion of muscle bodies of both superficial and deep flexors.[19] The combination of these factors leads to a transient CTS that occurs in the presence of an increased workload.

FIGURE 3. Typical symptom mapping for carpal tunnel syndrome



RISK FACTORS

Environmental or workplace risk factors include sustained wrist or palm pressure, repetitive hand and wrist use, prolonged wrist extension and flexion, and working with tools that vibrate. Repetitive use thickens the overlying fascia and causes tendon and muscle hypertrophy that leads to median nerve compression.[20-22]

Another category of risk factors for CTS is coexisting conditions such as obesity, pregnancy, renal failure, hypothyroidism, oral contraceptive use, menopause, and heart failure that potentially alter the body's fluid balance, leading to the increasing pressure on the nerve.[23] In addition, tumors or tumorlike lesions can compress the median nerve as can fractures of the bones near the median nerve.

A subset of factors such as diabetes, alcohol use, vitamin excess and/or deficiencies, and exposure to toxins can have neuropathic effects on the median nerve, predisposing patients suffering from these conditions to potential CTS symptoms in the future.[23] For example, patients with diabetes have a higher propensity to suffer from CTS symptoms because of the nerve damage associated with diabetes. Some studies also have mentioned the presence of carpal tunnel symptoms to be initial presentations of inflammatory connective tissue disorders, most commonly rheumatoid arthritis.[24]

CLINICAL FEATURES

The predominant clinical feature of CTS is pain and paresthesias in distributions of the median nerve (**Figure 3**). These paresthesias can occur at any time but worsen at night. As the severity of CTS increases, the paresthesias and pain occur more frequently and last longer.[25] In patients

TABLE 2. Provocative tests for CTS[65-67]

Test	Technique and results	Sensitivity	Specificity
Tinel sign	Percuss above the region of the carpal tunnel on the palmar surface of the wrist. The test is positive if percussion of this region results in paresthesia.	26% to 79%	40% to 100%
Phalen sign	Have the patient maximally flex the palms at the wrist with the elbow extended. The test is positive if it elicits paresthesias in the region of the median nerve.	67% to 83%	47% to 100%
Paley/McMurphy test	Apply manual pressure close to the median nerve about 1 to 2 cm proximal to the wrist flexion crease. The test is positive if pressure causes pain or paresthesia.	89%	45%

with severe CTS, the thenar muscles and other muscles innervated by the motor branch of the median nerve are weakened, causing difficulties with daily activities such as opening a door and holding objects. This typically presents as thenar atrophy, which can readily be visually noted on clinical examination. Sensory symptoms of CTS usually are limited to the median nerve distribution in the hand (the first three digits and the radial half of the fourth digit). At times, the sensory deficit may be variable and include the wrist, forearm, upper arm, and shoulder. Evidence has shown that the localization of symptoms to the first three digits may be associated with more severe involvement of the median nerve; thoroughly consider symptom distribution when evaluating treatment modalities and prognosis.[26] Provocative tests for CTS are described in **Table 2**.

DIAGNOSTIC TESTS AND IMAGING

In addition to provocative tests, diagnosis of CTS also relies on electromyography/nerve conduction studies (EMG/NCS). NCS aims to confirm damage to the median nerve, quantify the severity of injury by measuring conduction velocity across the nerve, and define the underlying pathophysiology (conduction block versus demyelination versus axonal degeneration). This is done by comparing latencies and conduction velocities of the median nerve across the carpal tunnel segment with other nerve segments, such as the radial or ulnar nerve. A decrease in sensory conduction velocity suggests possible nerve pathology caused by focal demyelination. A transtunnel velocity of less than 45 m/s suggests a pathologic state (a normal value is greater than 50 m/s).[27] EMG is not necessary for the diagnosis of CTS in patients who have classic symptoms and a confirmatory NCS. However, EMG is useful to assess severity in patients who may undergo surgical decompression as an option. The electrophysiologic classification of CTS in agreement with American Association of Electrodiagnostic Medicine (AAEM) guidelines range from a negative CTS class (normal finding on all tests) to an extreme CTS class, which indicates an absence of thenar motor response.[28]

Following the use of NCS, ultrasound and MRI are the best imaging studies to visualize the median nerve and any evidence of pathology as it passes through the carpal tunnel.

Visualization of the median nerve on ultrasound is best done from the site of the proximal carpal tunnel or at the level of the distal radius or pisiform, where maximum edema of the nerve is known to occur. The area of the median nerve in the proximal carpal tunnel, if an elliptical shape is captured, should be at most 10 mm.[29]

T2-weighted MRI will show edema of the median nerve with increased signal intensity resulting from edema, myelin sheath degeneration, or accumulation of axonal transportation that are key indicators to watch for in the diagnosis of CTS.[30-32] Sagittal MRI also allows accurate determination of the severity of median nerve compression at a sensitivity of 96%; unfortunately, specificity is 33% to 38%.[29] In addition, the median-ulnar sensory latency difference and abnormal nerve signal found on the T2-weighted images are useful predictors of a positive surgical outcome.[33]

The results and perceived severity based on the MRI scans do not correlate with the patients' perceived severity of CTS symptoms.[33] Although the MRI shows detailed anatomy, it does not provide information on impairment in the function of the median nerve.

NONSURGICAL TREATMENTS

All first-line treatment options should include direct patient education on the underlying pathophysiology of CTS.[34] Teach patients about activity modification such as wrist bracing and reduced heavy lifting, and the use of specifically designed tools. Although these may reduce stress on the median nerve, evidence that this approach resolves CTS is limited.[34] Pharmacotherapy including diuretics, nonsteroidal anti-inflammatory drugs (NSAIDs), pyridoxine (vitamin B6), and orally administered corticosteroids with varying dosages per preference of the clinical provider have been used.

Another nonsurgical option, low-power laser therapy, exposes the transverse carpal ligament to low levels of red near-infrared light.[35] In the short term, laser therapy can improve function, symptoms, and conduction measures.[36] Laser treatment was shown in a randomized controlled trial to be more effective than placebo, with the greatest evidence in patients with mild to moderate CTS.[36] Another study compared high-intensity laser therapy with transcutaneous electrical nerve stimulation (TENS).[37] In this study,

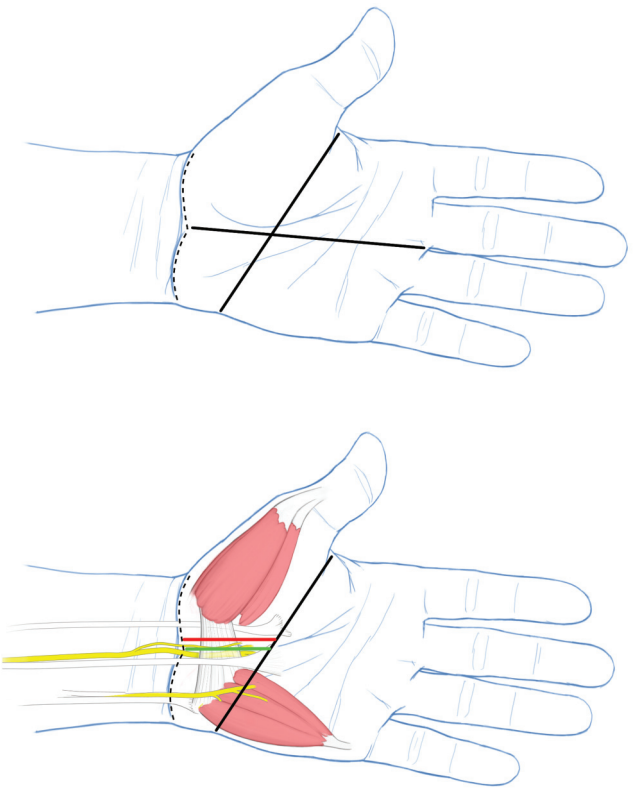


FIGURE 4. Landmarks for surgical approach: superficial (A) and deep anatomy (B). Dotted line demarcates the border of the hand.

laser therapy, rather than TENS, showed greater improvement in the areas of pain, paresthesia, median nerve conduction velocity, and distal motor latency.[37]

Local injections of corticosteroids are commonly used to reduce edema in the carpal tunnel. In a randomized trial, 111 patients received an 80- or 40-mg methylprednisolone injection into the carpal tunnel, which proved more effective than placebo in reducing symptom severity and rate of subsequent surgery at the 1-year mark.[38] Although the study showed effectiveness in mitigating CTS symptom progression, 75% of the patients enrolled in the study had surgery within 1 year.[38]

Another study showed that compared with the distal (palmar) approach, proximal (wrist) needle insertion for corticosteroid injection produced more pain based on the measurements from patients on a visual analog scale.[39] No difference was found between the two approaches, however, on objective measures such as NCS.[39] Using ultrasound-guided corticosteroid injections provides improved accuracy compared with blind administration and also can reduce the time necessary for complete symptom resolution.[40,41]

Studies have investigated the potential of using NSAIDs to treat CTS.[34,42] A study of 240 patients found that NSAIDs were prescribed to 38.8% of patients and alleviated symptoms in 74%.[42] Another randomized controlled trial assessing the effectiveness of gabapentin compared with placebo did not show any significant improvement in reducing paresthesias, weakness, clumsiness, pain, or nocturnal awakenings.[43]

Researchers also have investigated the use of ultrasound to mitigate the advancement of CTS and reduce inflammation. Various studies have found no conclusive evidence that ultrasound waves directed to the area of entrapment are more effective than placebo or other nonsurgical treatments for CTS.[44-46]

SURGICAL TREATMENT

Surgical treatment for CTS involves the release of the contents of the carpal tunnel by transecting the transverse carpal ligament (**Figure 4**). This is considered the most effective treatment. Decompression surgery can be performed by endoscopic techniques, minimally invasive short wrist incision, or by a traditional open technique (longitudinal wrist incision with direct visualization of the transverse carpal ligament). Studies have not demonstrated a significant difference when examining long-term *functional* outcomes between these techniques.[47-52] However, even as both return function to a similar extent, studies have shown that a minimally invasive approach results in better outcomes, including fewer complications, symptom improvement, patient satisfaction, and improvement in various other assessment modality results.[53,54] The endoscopic technique shows reduced scar tenderness, shorter postoperative recovery period, and earlier return to work compared with the standard open approach.[51] Although endoscopic release does show some advantages in the length of recovery, its drawbacks include cost and increased rates of temporary nerve damage.[48]

Between 1% and 25% of patients have postoperative complications.[55] Of patients with complications, about 0.5%, primarily those undergoing open-approach surgery, have damage to important structures such as nerves, arteries, and tendons.[56] Postoperative complications include incision site tenderness, tenderness near the site of ligament release, transient loss of motor or sensory function, and need for a repeat operation. One study that looked at endoscopic carpal tunnel release in 34 hands and open technique in 21 hands found that 32 patients required reexploration and were found to have incomplete release, and five patients required a third operation.[57] Complex regional pain syndrome (CRPS) is a potentially severe complication that results in extreme pain, swelling, and autonomic dysfunction consisting of sweating and flushing in the affected limb, although the incidence after CTS surgery (2.1% to 5%) is lower than other hand surgeries. Nevertheless, this is associated with detrimental effects on the patient's quality of life, so clinicians must recognize this complication early.[58,59]

Although postoperative rehabilitation interventions, such as wrist orthoses, dressings, exercise, and ice therapy, have anecdotally helped patients, one study showed that these

interventions have limited and low-quality evidence for their benefit; more high-quality trials have recommended that the decision to pursue such interventions be based on the clinician's expertise and patient preferences. Minimal evidence shows that postoperative rehabilitation interventions are beneficial for patients in the postsurgical phase of treatment.[60] In patients who fail to improve and who require repeat surgery, the use of a vascularized flap for decompression has been associated with a higher success rate.[61] One meta-analysis on a small sample of patients showed that the recurrence of symptoms began typically between 3 months and 4 years after surgery, with the mean time before revision surgery being 31 months.[55]

SURGICAL VS. NONSURGICAL TREATMENT

Several studies have shown that a combination of nonsurgical and surgical treatments provides clinical benefits for patients with CTS.[62-64] A randomized trial demonstrated that local corticosteroid injections were associated with improved symptoms at a follow-up of 3 months; more invasive interventions such as surgery led to improved symptoms at a longer follow-up of 2 years.[63]

CONCLUSION

CTS results from compression of the median nerve as it traverses the carpal tunnel at the wrist, and is diagnosed in patients with a recognizable pattern of symptoms. Clinicians who understand the anatomy, pathophysiology, symptoms, diagnostics, and treatment of CTS can better prepare patients and streamline referrals to achieve better outcomes. **JAAPA**

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