VILNIUS UNIVERSITY

MEDICAL FACULTY

The Final thesis

Carpal Tunnel Syndrome: Ethiopathogenesis, Clinical Manifestations, Diagnostics, Options of Treatment, Results, Complications – Literature Review

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2024

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Abstract

Background: Carpal tunnel syndrome (CTS) is regarded as the most common entrapment neuropathy caused by compression of the median nerve within the carpal tunnel. This thesis aims to review carpal tunnel syndrome's pathophysiology, diagnosis, conservative treatments, and release surgery.

Methods: To evaluate the pathophysiology, diagnosis, and treatment of carpal tunnel syndrome, I conducted a comprehensive literature search using PubMed and Google Scholar. I included articles published in English within the last 15 years, focusing on the most recent insights into carpal tunnel syndrome. Due to a notable gap in recent primary research, particularly addressing the pathophysiology of carpal tunnel syndrome, I extended my search to include older studies dating back to 2002. These older foundational works have provided a substantial understanding of the nerve compression mechanisms, microcirculatory changes, and the role of inflammatory mediators in carpal tunnel syndrome, which remain relevant to current clinical practices and research. The selection of studies was guided by a combination of keywords such as "Carpal Tunnel Syndrome", "pathophysiology", "diagnosis", "treatment", and "nerve compression" among others. Each article was evaluated for its relevance to the core topics of pathophysiology, diagnosis, and treatment of carpal tunnel syndrome. Methodological rigor was assessed by examining the study design, data collection methods, and analysis techniques.

Conclusion: Carpal tunnel release surgery is the gold standard long-term treatment for carpal tunnel syndrome. While conservative treatments like glucocorticoid injections are useful initial options, especially for mild to moderate cases of carpal tunnel syndrome, their effects are mostly short-term. The pathophysiology of carpal tunnel syndrome is complex and involves multiple factors that lead to median nerve compression under the transverse carpal ligament. Diagnosis relies on clinical evaluations with additional electrodiagnostic or sonographic tests. Surgical techniques include endoscopic surgery alongside traditional open surgeries, but no single approach universally outperforms others across all patient categories. Both types maintain efficacy, yet they differ in their recovery outcomes and potential for complications.

Keywords

carpal tunnel syndrome, median nerve compression, nerve conduction studies, electromyography, corticosteroid injection for CTS, wrist splinting, ultrasound-guided injections, patient outcomes in CTS surgery, surgical vs conservative CTS management, open carpal tunnel release, endoscopic carpal tunnel release

Abbreviations

CTS – Carpal Tunnel Syndrome, CT - Carpal Tunnel, MN – Median nerve, NCS – Nerve conduction studies, EMG - Electromyography

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Pathophysiology of Carpal Tunnel Syndrome

CTS's pathophysiology is complex due to an interplay of anatomical, mechanical, and biological factors, which cause compression of the MN. Understanding those mechanisms is the key to correctly diagnosing and treating but also preventing CTS.

The entrapment of the MN, also regarded as a chronic focal compressive neuropathy resulting from compression at the CT, is responsible for causing CTS. The dysfunction results from pressure changes, intraneural microcirculation, changes in the supporting connective tissue, and damage to the myelin sheath and axon. (2)

Nerve Compression Pathophysiology

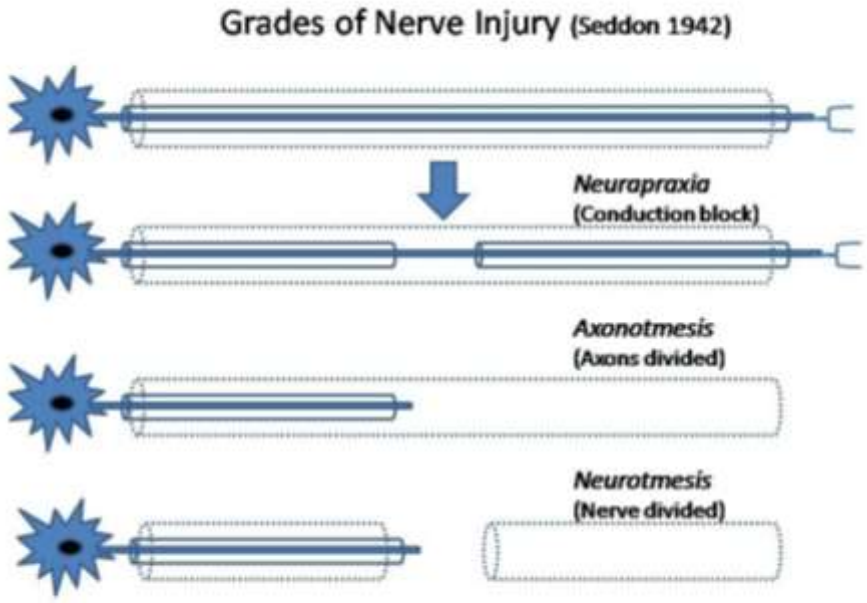

Figure 1 Grades of Nerve injury (50)

There is a total of five degrees of nerve injury, of which the first three are relevant for CTS. The I-degree injury is called neuropraxia, a regular conduction block with signs of demyelination at specific segments. In electrophysiological testing, the nerve shows an extended latency period, but full recovery can be achieved through remyelination. A II-degree injury would be called axonotmesis, which involves direct damage to the axon. Electromyographic testing would show fibrillations, while electrodiagnostic testing would present a reduced amplitude due to the loss of axons. Similar to I-degree injuries, nerve regeneration makes a full recovery possible. In III-degree injuries, however, the axonotmesis is combined with additional scar tissue formation inside the endoneurium, which prevents complete regeneration. During diagnostic testing, III-degree injuries mirror characteristics of II-degree injuries. Hence, the differentiation between

those two shows to be complicated. Most patients with CTS have I-degree injuries, while severe cases belong to either II- or III-degree injuries. Some patients show no changes in electrodiagnostic studies; their symptoms are then caused by ischemia rather than structural injury to the nerve. (7)

Increased Carpal Tunnel Pressure

The MN can be compressed at two sites due to its anatomy, first on the proximal edge of the CT, where the antebrachial fascia and the proximal part of the flexor retinaculum undergo changes in thickness and rigidity due to wrist flexion, and the second location is at the hook of the hamate. (47). The pressure of the CT in the healthy population typically ranges from 5-14 mmHg (6); however, wrist movement can affect this pressure, with wrist extension increasing it by tenfold and flexion raising it by eightfold. (5) Patients diagnosed with CTS show an increased resting pressure of 32 mm Hg, which reaches up to 94 mm Hg during wrist flexion and 110 mm Hg during wrist extension. The elevated pressure in the CT is thought to lead to ischemic compression of the MN, and some experimental studies might suggest that the level of MN dysfunction is dose-dependent on the amount and duration of CT compression. In tests of acute nerve compression, a loss of function can already be observed at 40 mmHg, while all function diminishes at 50 mmHg. (7) Pathological changes in the surrounding ligaments, including alterations in the amount and flexibility of connective tissue, can also increase pressures. If that compression becomes chronic, it might cause fibrosis of the mesoneurium, which then adheres the nerve to adjacent tissues; this prevents the nerve from gliding. To ensure physiological nervous function, nerve gliding during movements must be enabled by the flexibility of the nerves and their layers of connective tissue, especially the epineurium. The normal range of motion of the MN is 9.6 mm; however, due to rigid connective tissue, this movement can be limited, causing shearing forces to cause injury to the nerve. (2)

Median Nerve Microcirculation Injury and Inflammation

Another significant factor in MN damage is microcirculation injury. It involves ischemic vascular damage and the disruption of the blood-nerve barrier, which are crucial components in the development of CTS. Inner perineural cells and endothelial cells from endoneurial capillaries make up the blood-nerve barrier in the CT. Ischemia affects the nerve fibers, potentially altering the myelin sheath and causing axonal injury. The initial stages of ischemia and compression lead to venous outflow obstruction, resulting in nerve hyperemia and edema. Elevating the pressure in the CT can also cause the barrier to breach, which leads to the accumulation of proteins, lymphocytes, fibroblasts, and macrophages. An increase in

inflammatory markers interleukin-6, prostaglandin E-2, and vascular endothelial growth factor has also been observed in patients with CTS. This could create a locally closed compartment syndrome, which furthermore increases permeability, elevates endoneurial fluid pressure, and causes intra-fascicular edema. This can ultimately cause neuritis, resulting in axonal degeneration; however, without focal pressure, ischemia appears to injure only the axon but not the myelin. (28 p13-19)

Risk factors of Carpal Tunnel Syndrome

CTS stands out as a widely observed condition across diverse populations. It is the most common entrapment neuropathy, which results in numbness or weakness in the affected body part. The annual incidence of CTS in the UK was reported to be 276 per 100,000, with the incidence rates being 9.2% for women and 6% for men. Several risk factors are at play, leading to the complex development of CTS. (32)

Female Sex

One significant factor is gender, with women being more frequently affected than men, as suggested by epidemiological data. The precise mechanisms behind this gender disparity remain not fully understood. However, specific hypotheses indicate that women tend to engage in tasks with higher hand activity but lower force, potentially increasing their susceptibility to CTS. Additionally, women may have anatomically a relatively smaller carpal tunnel area and less free space within the carpal tunnel, predisposing them to CTS. These hand and wrist anthropometric factors have been linked to an elevated risk and severity of the condition. Furthermore, in postmenopausal women, idiopathic CTS is associated with the upregulation of estrogen receptors in tenosynovial tissue. (8, 43)

Environmental factors

The role of environmental factors in CTS is controversial. The prolonged use of computer keyboards and mice should not be considered a direct cause of CTS. Still, strong evidence links tasks involving high repetition and forceful exertion to an increased risk of developing CTS. The risk associated with vibration exposure has moderate-quality evidence and is not a strong independent predictor for CTS (9). Occupations with the highest risk of CTS include meat and fish processing, forestry work with chainsaws, and electronic assembly (1)

Hypothyroidism

Hypothyroidism is a prevalent disease in the general population, and findings show that those affected individuals show an increased lifetime risk of developing CTS. The occurrence rate of CTS is 32,5% of patients affected by hypothyroidism. Electrophysiological studies show that those patients have reduced sensory nerve conduction velocity and diminished sensory nerve action potential values. (10)

Diabetes Mellitus

Diabetes Mellitus is associated with high blood glucose levels and is also closely associated with CTS. The prevalence rate can be as high as 71,2%. This increased risk could be attributed to increased intracellular sorbitol accumulation, which increases osmotic pressure and, in return, causes edema and hydropic degeneration. (10) Another possible mechanism is the increased glycosylation of collagen fibers, which decreases the compliance of the collagen fibers. These fibers accumulate in the now-thickened flexor synovium, ultimately leading to carpal tunnel syndrome. (28 p.23-24)

Pregnancy

The prevalence of CTS in pregnant women is nine times more common than in the general population, yet the symptoms are milder, contributing to underdiagnosis. Common symptoms include nighttime tingling and pain, affecting sleep quality and potentially impacting mental health. During pregnancy, fluid retention increases, particularly after the 30th week, leading to a higher prevalence of CTS symptoms. Around 40% of women experienced CTS symptoms after 30 weeks of gestation, regardless of whether they had CTS in previous pregnancies. (31.)

Clinical Manifestation

Pain and Paresthesia are the two key symptoms of CTS, which, generally speaking, is often a clinical diagnosis. They usually manifest in the innervation area supplied by the sensory branches of the MN, as illustrated in Figure 2. While the most prevalent location for these symptoms lies in the wrist or hand, they can extend further, occasionally reaching the forearm or the shoulder. Nocturnal pain is quite common in individuals with CTS, which can disrupt their sleep by waking. Patients try to alleviate their pain by shaking their hand, which is called the “flick sign”, it has a very high sensitivity and specificity for CTS. Furthermore, in addition to the primary symptoms, some patients have reported a range of secondary manifestations. These may include sensations like tremors or a persistent ringing sensation in the affected hand. Numbness in specific fingers, neck pain, and decreased hand dexterity have also been

documented. (12) The sequence of symptom development in CTS is influenced by the vulnerability of sensory fibers to compression. That is why the early stages of CTS are usually characterized by paresthesia and pain. Motor involvement tends to show later in the disease progression, especially as CTS advances and becomes more severe.

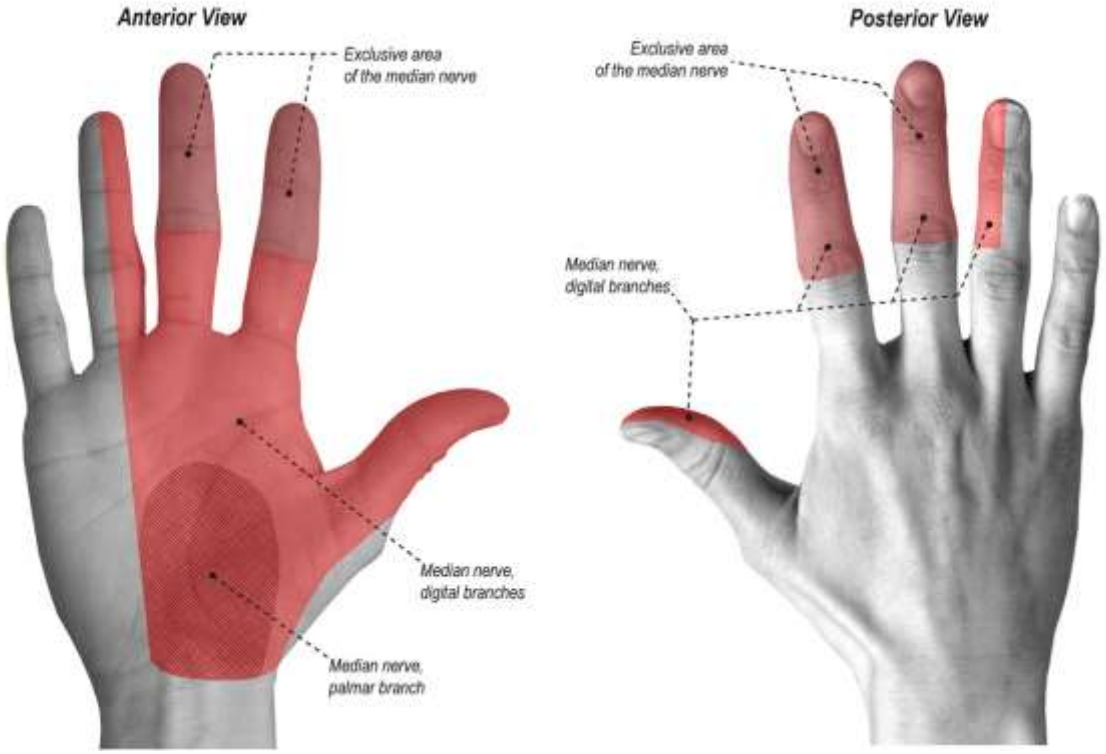

Figure 2 MN distribution (51)

This heightened level of motor involvement can manifest as a noticeable reduction in grip strength, particularly in everyday tasks such as opening containers or fastening buttons. In the later stages of CTS, it is not uncommon for pain to gradually diminish, although this often signals a permanent loss of sensory function. Understanding these evolving symptoms and their timing can be crucial in correctly diagnosing and managing CTS effectively. (11)

Physical Examination

The first step in the physical examination is careful inspection. A comprehensive assessment of the entire arm is conducted to identify any indications of atrophy, color changes, and skin turgor; special attention should be paid to thenar atrophy. The cervical spine should also be tested for range of motion and tenderness for differentials. (27 p27-28, 11)

In cases of CTS, the sensory examination can often appear normal, even when the patient has already developed symptoms. Anatomical variations can lead to deviations from the traditional

MN distribution pattern for sensory loss in the hand. The patient's sensation should be tested in all regions of both hands and arms. Despite its subjective nature, pin sensation examination gains objectivity by using monofilament testing, effectively mapping sensory loss within the MN distribution. (29) Sensation in the thenar eminence is typically unaffected in patients with CTS as it is innervated by the palmar cutaneous branch of the MN, which originates proximal to the CT. Provocative tests can be used to diagnose CTS since they are straightforward to conduct clinically. Commonly used tests are the Phalen maneuver and Tinel sign. In the Phalen test, the patient's wrist is held in full flexion for one minute; if paresthesia is present in the fingers supplied by the median nerve within a minute, it is specific to CTS. The Tinel sign is a tingling sensation when a damaged or irritated nerve is tapped or percussed. (11)

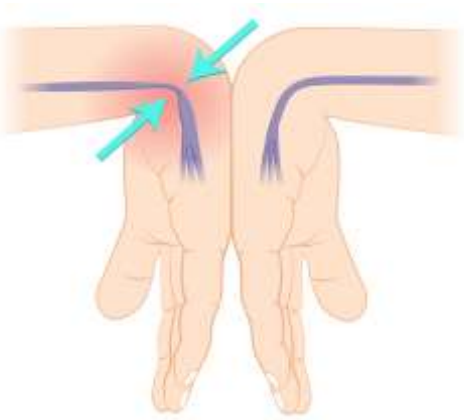

Figure 3 Phalen test (left) (52) *Figure 4 Tinel test (right) (53)*

An increasing amount of evidence indicates that physicians should avoid depending on the outcomes of a single sensory or motor test to diagnose CTS. Instead, they are encouraged to use a combination of sensory and motor tests to confirm or exclude CTS effectively. Many studies are inconclusive on which single test had the highest diagnostic accuracy (30).

Diagnostic Studies

While diagnosing patients with characteristic symptoms and signs could be done clinically, electrodiagnostic testing and neuromuscular ultrasound are the only tools that provide objective findings to help confirm or exclude CTS. The goal is to find significant and pathological changes in nerve conduction or structure, which can be achieved by looking for axon and myelin damage. It is also crucial to confirm CTS and exclude any other causes before planning surgical management of CTS. (29)

Electromyography and nerve conduction studies

Electrodiagnostic medicine uses electromyography (EMG) and nerve conduction studies (NCS) to diagnose CTS. These studies are particularly valuable as they extend beyond the static images of radiologic imaging, offering insights into the functional aspects of the nervous and muscular systems. They are also used to assess the severity and prognosis of MN injuries. The basis for electrodiagnostic testing lies in the properties of neurons and muscle cells. Axons maintain a resting membrane potential that generates an action potential when changed by a stimulus. This "all-or-none" response is essential in EMG/NCS, allowing us to find abnormalities along a nerve distribution. Usually, NCS are routinely done as the primary tool for CTS diagnosis before EMG due to the latter's significant discomfort. NCS evaluate motor and sensory nerves by stimulating them to produce an action potential detected by electrodes and represented as waveforms—these waveforms' velocity and morphology help in correlating findings with potential disease processes. Conversely, EMG assesses the entire motor unit, including the nerve's cell body, axon, and innervated muscle fibers. (28 p. 59-68)

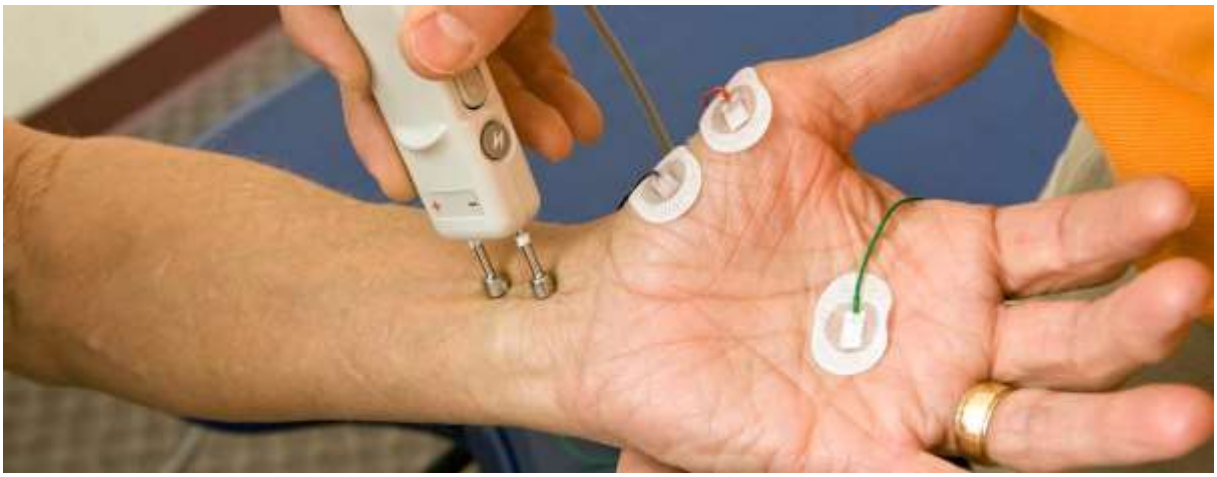

Figure 6 NCS (54)

NCS evaluate the onset latency for motor nerves and either the onset or peak latency for sensory nerves. While sensory nerves are measured in amplitude, motor nerves are measured in mV. Onset latency is the time from stimulation to the waveform's beginning, and peak latency measures the time until the waveform's peak. Accurate motor nerve conduction velocity assessment involves accounting for latency at the neuromuscular junction and muscle fibers, using two stimulation sites, and calculating the change in latency over distance. For CTS, a distal sensory latency of greater than 3.2 ms or motor latency of greater than 4.3 ms indicates pathological changes and waveform amplitude evaluation estimates the number of functional motor units showing axon loss or conduction blocks. Axon loss or a conduction block could

appear as a low-amplitude wave in motor NCS. Usually, NCS is the only primary tool needed to diagnose CTS. EMG gives valuable information about the lesion's location, estimating the lesion's duration, and assessing nerve regeneration. (28 p. 59-68) EMG is mainly used for differential diagnosis or when NCS are inconclusive, but up to 19% of patients with CTS also have an associated cervical radiculopathy, which can be missed without the use of EMGs (48,49)

Figure 5 EMG (55)

Overall, Electrodiagnostic testing is effective in ruling out other conditions like polyneuropathy and radiculopathy due to its high specificity of 94% to 99%. Still, the outcome can be normal in around one-third of patients with mild CTS symptoms. Also, before invasive treatment is performed, NCS should be obtained to confirm the diagnosis and predict the chances of recovery. (11)

Sonography

Ultrasound could be an alternative to NCS for diagnosing CTS. In CTS Ultrasound, the cross-sectional area of the MN is used as the diagnostic parameter, which, if its size is more than 5-10mm² at the pisiform bone or tunnel inlet, can be regarded as an indicator for CTS. In Picture A of Figure 7, the ultrasound probe is placed on the anterior wrist to evaluate the MN. Picture B depicts the carpal tunnel and adjacent structures. Picture C shows the application of a tracing technique for calculating the cross-sectional area of the enlarged MN, which measures 18 mm². Picture D is a longitudinal image of the median nerve displaying its increased size as it enters the carpal tunnel. Ultrasound can also be used in therapeutic interventions, such as corticosteroid injections, thus decreasing the risk of injuring the MN. In some reports, a few patients with clinically diagnosed CTS appear to have a normal cross-sectional area on Ultrasound while getting positive results in NCS (3)

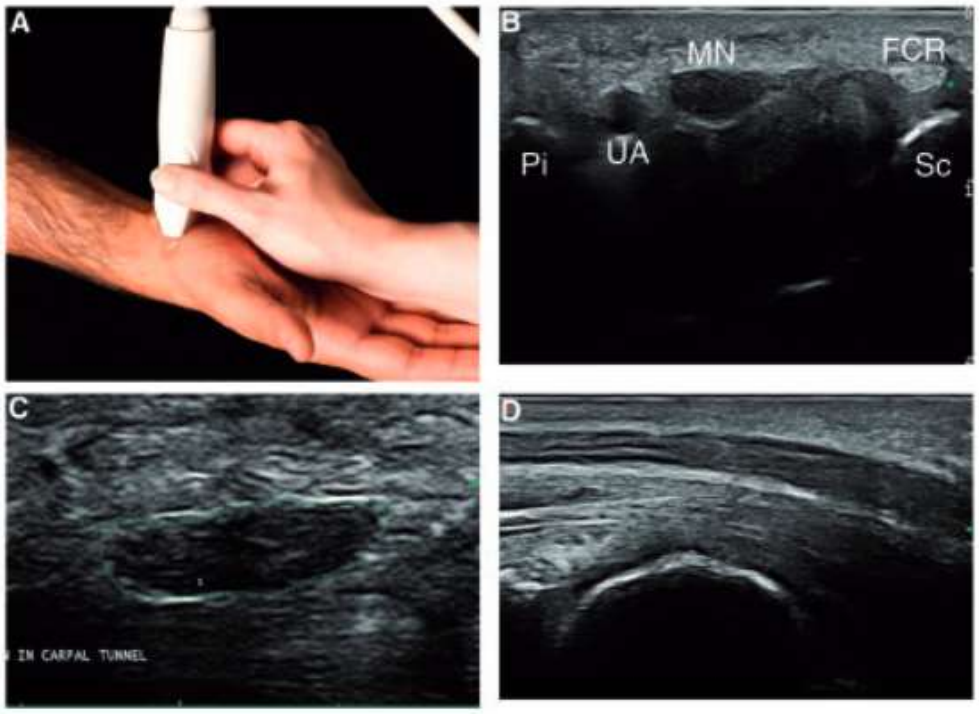

Figure 7 US IN CTS (3)

Unfortunately, sonography always relies on the physician's expertise in performing the examination and cannot always be regarded as a foolproof method. Its advantages, however, are low costs, decreased patient discomfort, and noninvasiveness when carried out correctly. (11) Currently, there is no clear consensus on whether ultrasound testing can be carried out instead of electrodiagnostic studies for the confirmation of CTS and, subsequently, planning of surgical treatment. (44, 45)

Conservative Therapy of Carpal Tunnel Syndrome

Initially, conservative treatment of CTS is essential due to its quick short-term relief. Since it is a prevalent disease affecting a significant part of the population, the ability to manage CTS symptoms effectively without resorting to surgery can significantly improve patient's quality of life. Conservative therapies have the potential to be more cost-effective, have fewer risks and side effects, and are potentially more accessible to a broader range of patients. (11)

Through electrodiagnostic evaluation, CTS patients can be divided into three subgroups according to sensory and motor changes in the median nerve, which can subsequently be used to help determine treatment planning. (20)

Table 1 Classification of CTS by severity (20):

Mild CTS	Prolonged sensory latencies with normal motor studies. There is no evidence for axon loss.
Moderate CTS	Abnormal MN sensory latencies like mild CTS and MN motor distal latency prolongation. No evidence of axon loss.
Severe CTS	Any of the already mentioned abnormalities with evidence of axon loss.

The likelihood of undergoing CT release surgery increased with greater severity, while there was no significant trend for the use of conservative treatments across different severity groups. This suggests that conservative treatments are frequently used even in severe cases. (46)

Glucocorticoid Injections

One of the most common treatments for mild to moderate CTS is corticoid injections. The exact mechanism of action is still debated. The current assumed hypothesis is that the anti-inflammatory effect of the steroid medication and its ability to reduce edema within the CT are the main factors that alleviate pressure and the symptoms experienced by CTS. (7) There are two modes of injections, the first being ultrasound-guided injections and the other landmark-based injections. Comparing those two, ultrasound-guided injection resulted in better outcomes for symptom severity and functional status. Therefore, it is recommended to use ultrasound-guided corticosteroid injection as a treatment for patients with CTS if available for those patients. (33) The three types of corticosteroids are used for the injections: methylprednisolone, triamcinolone, or hydrocortisone. There has been some debate about the different doses used, but the clinical effect on long-term treatment does not significantly improve with higher doses. (34) Glucocorticoid injections were shown to be a relatively safe method of treatment; the most frequently observed side effect was temporary localized pain, affecting 13% of the treated limbs, with all instances resolving within three weeks. While most adverse reactions were brief and resolved over time, very few cases displayed persistent skin depigmentation or subcutaneous atrophy. (15)

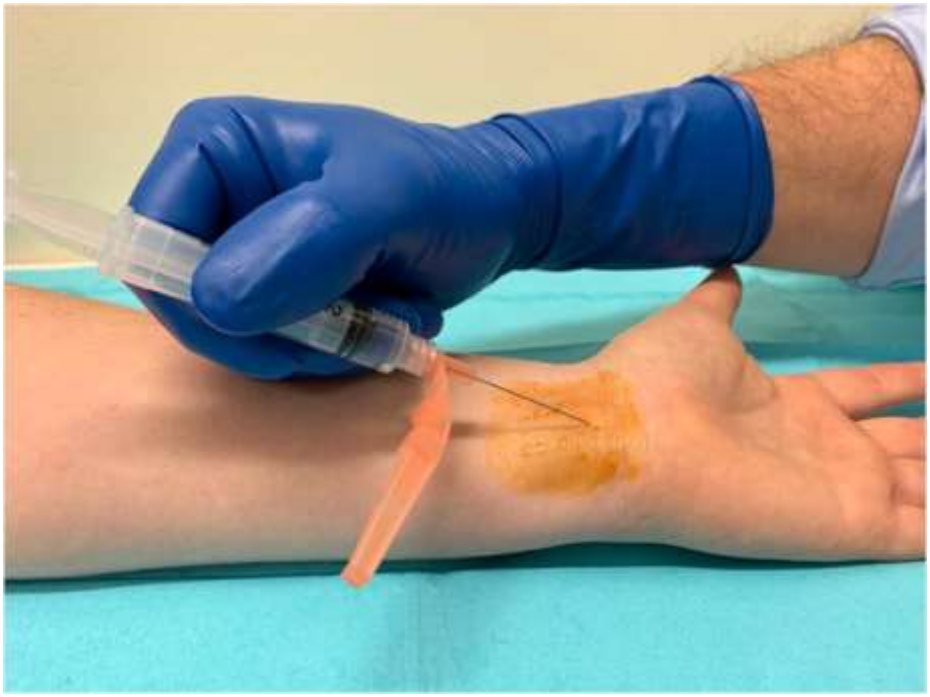

Figure 8 Corticosteroid injection (14)

Various corticosteroid types and dosages have been explored in CTS treatment with corticosteroid injections. For instance, some studies have compared the efficacy and safety of different corticosteroids at varying dosages. It was found that administering 25 mg of hydrocortisone was as effective as 100 mg of hydrocortisone or 20 mg of triamcinolone. Comparing 40 mg and 80 mg, triamcinolone showed minor differences in outcomes. Another investigation involved the local injection of 20 mg, 40 mg, and 60 mg hydrocortisone, with no significant differences observed among these dosages. These findings suggest considerable potential for using lower corticosteroid dosages; however, particularly in triamcinolone, better outcomes in functional status were associated with higher doses. (16) The recommended injection technique for landmark-based injections describes the seated patient with the forearm supinated with the wrist extended; the usual injection site should be medially to the tendon palmaris longus (Figure 9 A) or alternatively midway between the palmaris longus and the flexor carpi ulnaris tendons (Figure 9 B). The area should be cleansed with chlorhexidine or povidone-iodine solution. Then, a 25-gauge needle should be used with the chosen corticosteroid (e.g., triamcinolone acetonide) and lidocaine 1%. The needle should be injected at a 45-degree angle distally until the tip of the needle reaches under the midpoint of the flexor

retinaculum. The injection should be slow and should be stopped immediately if the patient feels shock-like pain or paresthesia. (11)

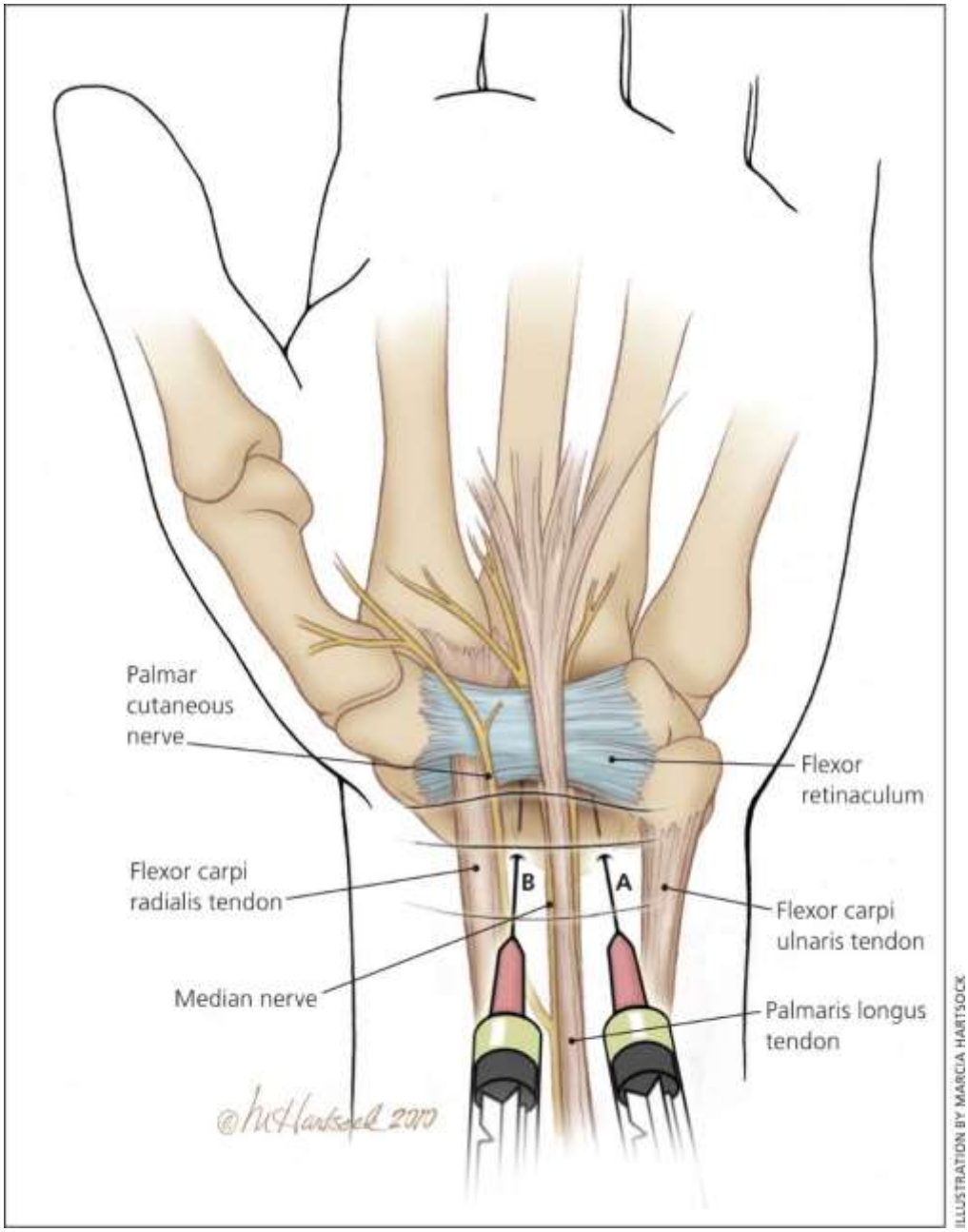

Figure 9 Sites of injection (11)

Wrist Splinting

Splinting remains a very popular primary treatment choice, especially in primary care. The most common mode is nighttime splinting. Splints keep the wrist in a neutral position and prevent prolonged extreme flexion and extension of the wrist joint. Some splints extend beyond the distal palmar crease, keeping the metacarpophalangeal joints extended. These mechanisms overall reduce the pressure within the carpal tunnel. Its advantage is that it is a non-invasive intervention with minimal need for follow-up visits, keeping costs low. (13)

Figure 10 Wrist splint (56)

Combination Therapy

A small study evaluated a possible treatment with corticosteroid injections combined with splinting instead of injections alone. They used ultrasound-guided injections with 1mL of 10mg triamcinolone acetonide and 1mL of 2% lidocaine for both patient groups, but one group got additional splints during night and daytime. Patient outcomes were measured after six weeks and 12 weeks. This study's key results show that using steroid injections together with wrist splinting worked better to reduce symptoms and hand functionality and enhance nerve function after 12 weeks. More long-term studies with larger sample sizes are needed to confirm this result, but this trial shows a possible treatment method that reduces the need for multiple corticosteroid injections. (18)

Ultrasound therapy

Ultrasound, commonly used for diagnostic methods or for guiding injections, could possibly be used for non-severe cases of CTS. Ultrasound emits high-frequency waves with thermal and non-thermal effects, hypothetically reducing inflammation and promoting nerve regeneration through improved blood flow and membrane permeability. (14) The current trials show no high-quality evidence that therapeutic ultrasound, even as part of a multi-component intervention, is more effective than other conservative treatments for CTS. No studies have

reported adverse effects of therapeutic ultrasound, but more data is needed to determine its safety and efficacy. (19)

Surgical treatment of Carpal Tunnel Syndrome

Successful surgical treatment of CTS has been performed for around 100 years. Today, it has become one of the most common and safest hand surgeries. (21) In Canada, CT release surgery is performed at an annual rate of 100 patients per 100,000 population. Female and older patients tend to have surgery more often than the average. (23) Another study shows that in the UK, 27,41% of individuals diagnosed with CTS had decompression surgery in the year 2013. (22)

There are two established techniques for CT release surgery. The first one is the open CT release, which can be performed through either a standard or a limited incision. The second technique is endoscopic CT release, which can be performed using a single or a double portal. There is also a lesser-known method: ultrasound-guided minimally invasive CT release; it can be performed through a minimal skin incision or entirely percutaneously. Each of these procedures has its risks and benefits, and there is some controversy among leading hand surgeons about the best technique to use. (24)

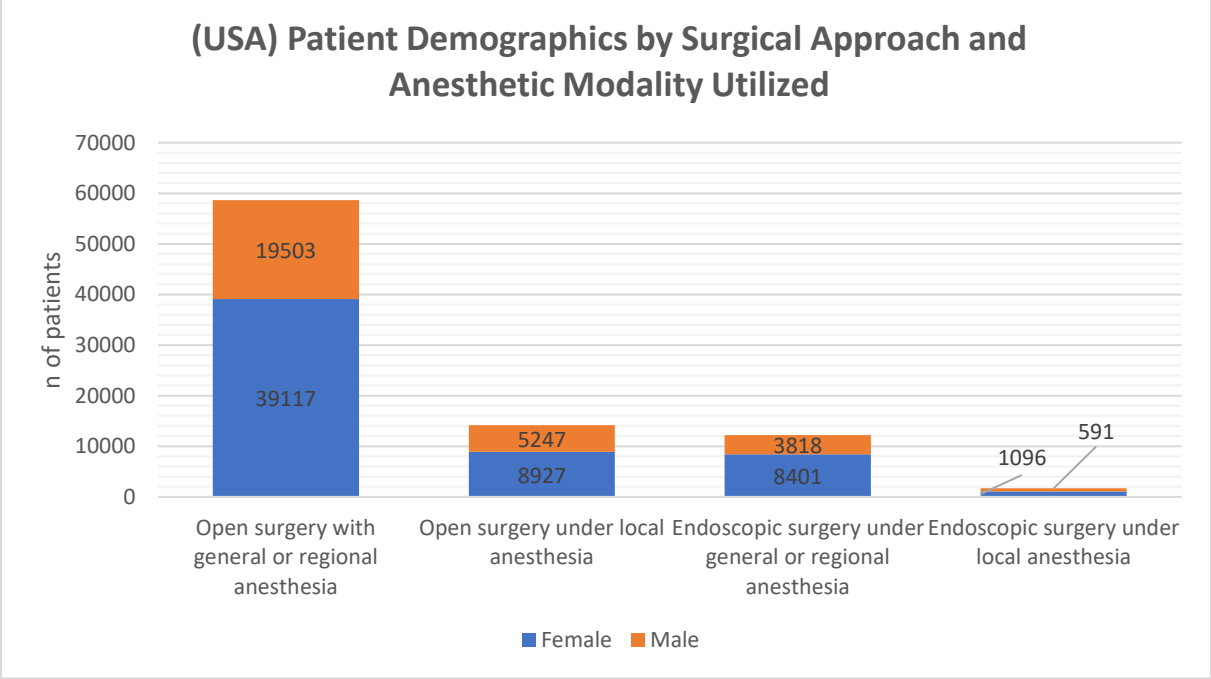

Table 2, taken from Foster et al. (24)

A 2017 study from the US with 86 687 patients showed that open CT release performed under general or regional anesthesia accounted for 67.6% of procedures in the years 2007-2011. In contrast, endoscopic surgery using local anesthesia was the least used, with 1.9% of all CT release procedures. So, only 16% of surgeries were endoscopic. Of those patients, 66,4% were

female, while 33,6% were male. (24.) In Japan, the trends in carpal tunnel release surgeries were slightly different. While most surgeries still utilized the open technique, approximately one-third of the cases already used endoscopic CT release surgery between 2014 and 2019. The ratio of inpatient to outpatient surgeries was about 1:2 in Japan. Endoscopic surgery was more likely to be performed on an outpatient basis than open surgery, likely because it is less invasive. Recently, ambulant surgery has become more common in Japan. (25) By 2006, more than 99% of all CT release surgeries were performed in an ambulatory setting in the US. (26)

Open Carpal Tunnel release surgery

Open carpal tunnel release can be performed using a traditional incision or a mini-incision. The traditional incision begins distal at the Kaplan cardinal line and extends proximal to the distal wrist crease. The axis is identified by the radial plane of the ring finger. The incision should be around 3-4 cm long and cross the distal crease to prevent hypertrophic scarring. Nowadays, the smaller mini-open technique is the preferred modality for most patients. The mini-incision minimizes pain and scarring compared to the open incision while maintaining enough visualization of the CT. It begins distal at Kaplans line, similar to the traditional incision, but only extends 2cm. (28 p.125-138)

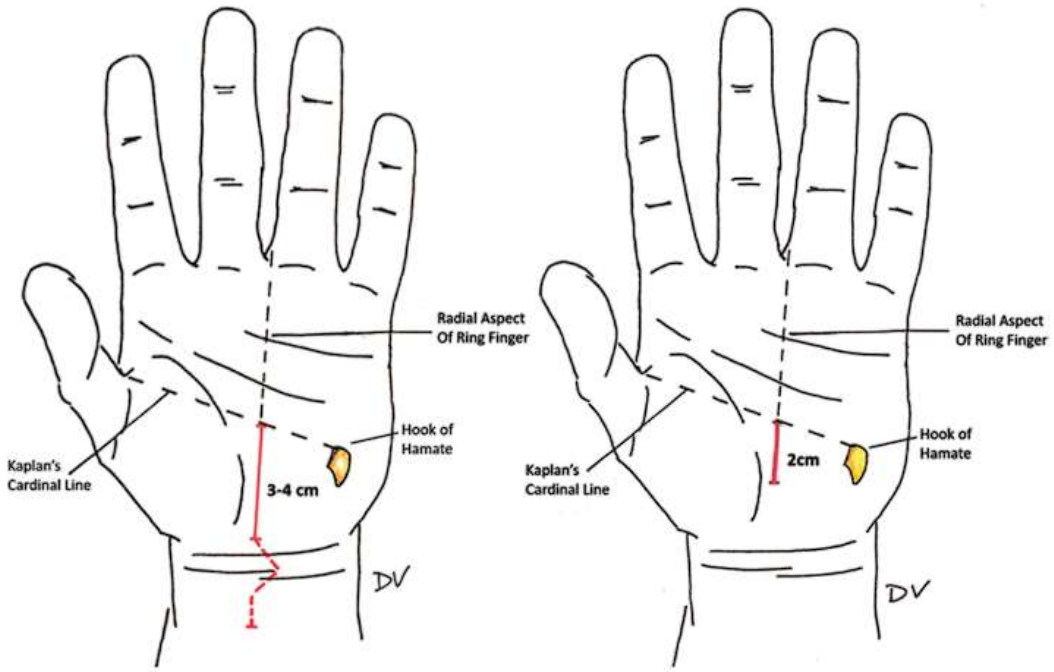

Fig. 12.5 (**a**) Standard open incision with optional extension proximal to wrist crease (*dotted line*) (*left*) and (**b**) mini-open incision (*right*)

Figure 11 Incision (28)

After the first incision in the skin, the subcutaneous fat should be exposed and carefully dissected. The palmar cutaneous branch of the MN is in this layer and should be avoided. Self-retaining retractors can be carefully placed to optimize visualization. After the palmar fascia is revealed, an incision parallel to its fibers in the entire length of the skin incision is made, the retractors can be repositioned underneath this layer. The transverse carpal ligament should be exposed, which then should be cut and divided longitudinally towards the ring finger to avoid the MN. The incision should reach the volar fat pad distally and then be proximally extended until the whole ligament is transected. To prevent a relapse of CTS, the antebrachial fascia could also be released, especially in cases where it is thickened. (28 p.125-138)

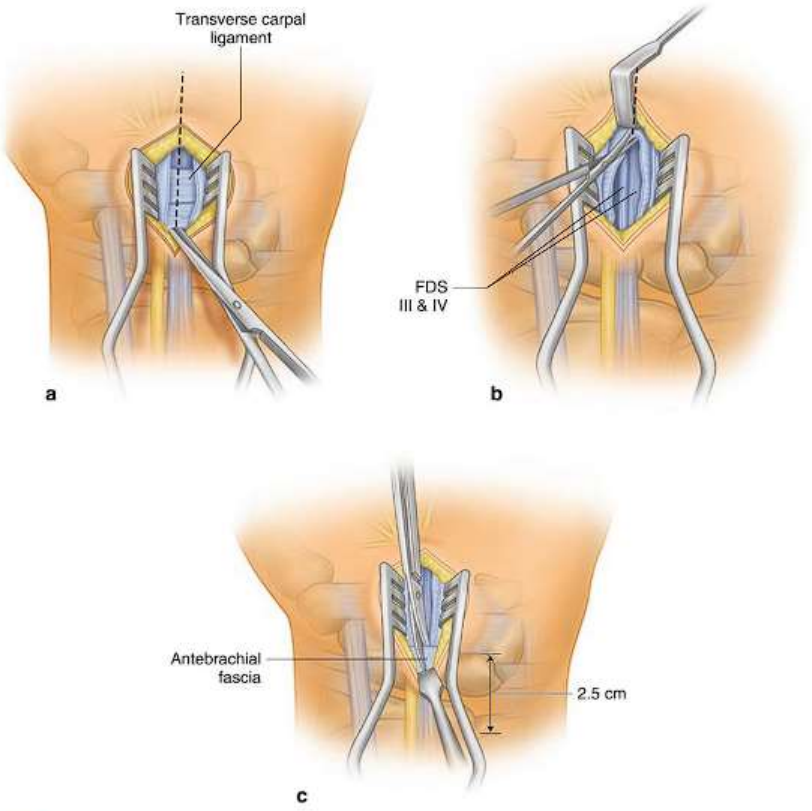

Fig. 12.7 (a) Exposure of transverse carpal ligament—modify image to show vertical incision and blade instead of scissors making cut. (b) Release of TCL. (c) Release of antebrachial fascia

Figure 12 Transverse carpal ligament (28)

When the ligament has been cut, the MN should be freely exposed, and the surgeon should check for any irregularities. After everything has been inspected, closure can be initiated. In postoperative care, the patient's hand should be dressed softly and can be safely discharged; the sutures should be removed after two weeks. (28 p.125-138)

Endoscopic Carpal Tunnel release surgery

Although open CT release surgery is still regarded as the gold standard for surgical treatment, endoscopic surgeries have steadily increased over the years. It has been developed to reduce morbidity and to shorten recovery from surgery. In theory, it offers the advantages of reduced postoperative pain, faster recovery of grip strength, faster return to work, and fewer wound-related complications. Endoscopic CT release is generally indicated for cases similar to open CT release. However, it is contraindicated when additional procedures, such as exploration or dissection of the MN and its contents, are necessary. Severe MN neuropathy requiring extensive neurolysis is a relative contraindication. Also, if scarring of the MN is observed, a revision open CT release is recommended. Anatomically, the CT has three dorsal walls formed by the volar arch of the carpal bones, with the transverse carpal ligament as the roof. A key consideration in endoscopic surgery is carefully inserting the endoscope along the ring finger axis. This strategic placement aims to increase the interval between the endoscope and the MN, minimizing the risk of iatrogenic nerve injury. The patient's positioning is critical for the procedure's success, with the individual placed in a supine position, the shoulder in 70–80° of abduction, and the hand resting on a broad operating arm table. The procedure typically uses a patented device known as the MicroAire Smart Release, which includes a 2.7 mm/30° angle arthroscope, a camera, a fiber optic light source, and a pistol-like handpiece with an attached disposable blade cartridge for the endoscope's insertion. (27 p.53-60)

Figure 13 MicroAire SmartRelease (57)

The surgeon and patient may choose general, regional, or local anesthesia. However, the preference for local anesthesia in endoscopic carpal tunnel release is emphasized in some practices. The surgeon infiltrates the distal wrist crease and proximal forearm fascia with a solution containing 1% lidocaine with 1:100,000 epinephrine and 0.5% bupivacaine. The surgical procedure begins with marking key anatomical landmarks before the incision, such as the flexor carpi ulnaris tendons and flexor carpi radialis, pisiform bone, and hook of the hamate. A 2 cm transverse incision is made between the tendons of the flexor carpi radialis and the flexor carpi ulnaris at the level of the proximal wrist flexion crease. The surgeon performs a longitudinal dissection in the subcutaneous layer, creating a rectangular flap distally based on the transverse carpal ligament. This allows for exposure and visualization of the antebrachial fascia. (27 p.53-60)

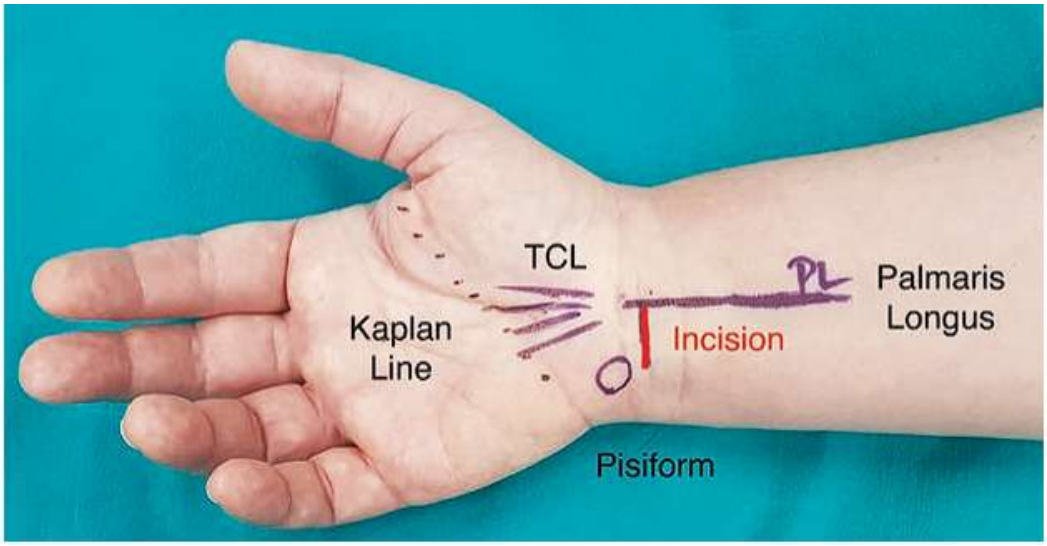

Figure 14: Landmarks for surgery (27)

The surgeon elevates the forearm fascia flap from the underlying synovium, creating a plane between the synovium and the deep side of the transverse carpal ligament. Subsequently, a synovium elevator is positioned in line with the base of the ring finger and radial to the hook of the hamate. The surgeon then proceeds to create a path for the blade assembly using a hamate finder. (27 p.53-60)

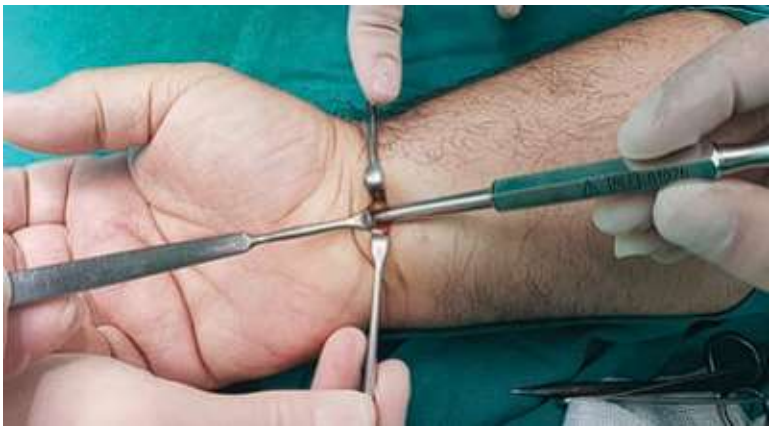

Figure 15 Preparing a path for the Smart Release device surgery (27)

The “MicroAire Smart Release” blade assembly is inserted into the carpal tunnel aimed at the axis of the ring finger; the goal is to get a clear camera view of the distal edge of the transverse carpal ligament. The cutting blade is then deployed, and the device is withdrawn proximally, ensuring incision of the distal half of the transverse carpal ligament. This step-by-step process involves inspection of the ligament and additional passes and incisions of the ligament with the endoscope if needed. After the division of the distal part of the transverse carpal ligament, the endoscope is placed distal to the most proximal portion of the cut ligament. The cutting blade is triggered, and the endoscope is pulled to the proximal edge of the transverse carpal ligament. Subsequently, the entire cut ligament is examined with the blade in a retracted position, and any unsevered fibers are divided during this inspection. (27 p.53-60)

Figure 16 Inserted Smart Blade Assembly (27)

Following the release, a small right-angled blunt retractor may be employed to inspect the proximal part of the carpal tunnel under direct vision, confirming the adequate separation of the cut edges of the transverse carpal ligament. The wound is then irrigated and closed with a subcuticular running absorbable monofilament 4.0 suture and sterile strips. Patients are advised to engage in active range-of-motion exercises immediately after discharge. Within 3-5 days, full hand motion typically returns, allowing for gradual resumption of light activities based on the patient's comfort. Generally, more strenuous tasks can be resumed around 4-6 weeks post-surgery. The cosmetic results of endoscopic release are rather impressive at 3 months post-surgery. (27 p.53-60)

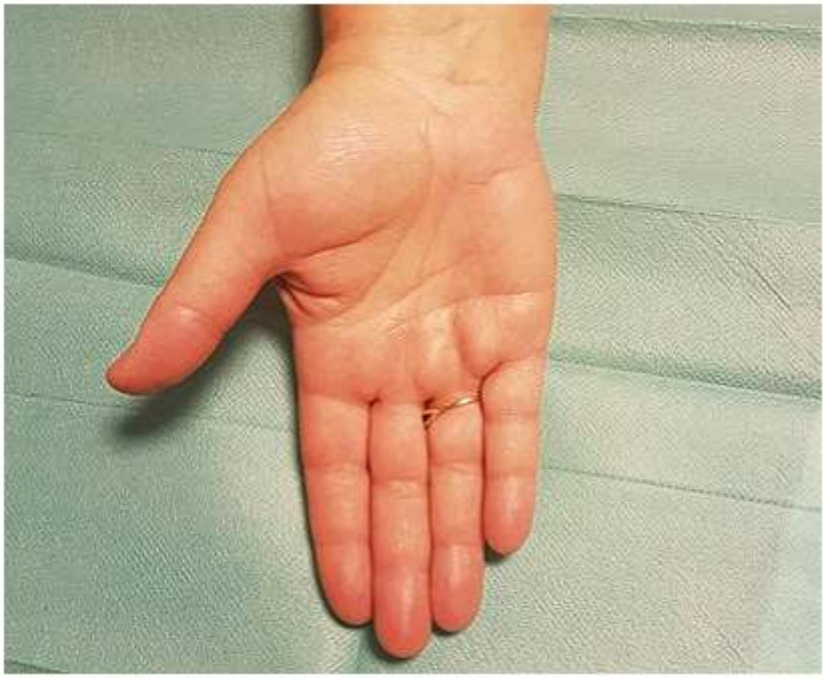

Figure 17 3 months post-op scar (27)

Results

1. The short-term efficacy of corticosteroid injections was proven in randomized controlled trials, showing that these injections improve symptoms. However, this initial improvement diminishes after six months, showing that injections are not a long-term cure. Furthermore, three out of four patients eventually undergo surgical release within one year. (34) Repeated conservative treatments have proven more effective than a

single treatment in managing CTS, improving hand function, and resolving subjective symptoms. (37)

2. The short-term effectiveness of splinting is relatively low compared to corticosteroid injections or surgical options, but it can be tried as a first-line treatment when invasive interventions are rejected. (13)
3. Due to their minimal risks and benefits, conservative treatments remain a valid first-line option compared to surgical interventions. (38)
4. Surgical interventions have demonstrated superiority over conservative methods in improving symptoms and functional status at six months, although with a higher complication rate. (36)
5. Even in severe cases of bilateral CTS, CT release surgery showed favorable long-term outcomes, with 93.8% of patients experiencing complete numbness resolution and significant reductions in symptom severity and functional impairment. (35)
6. Endoscopic release surgery reduces postoperative hand pain but poses a higher risk of iatrogenic nerve injury than open surgery. No significant differences were found between endoscopic and open surgical techniques regarding other complications, patient satisfaction, or recovery time for returning to work. (39)

Complications

Although rare, complications following CT Release surgery can significantly impact patient outcomes and satisfaction. These complications can be categorized into intraoperative technical errors, postoperative infection, pain, and persistent or recurrent symptoms. During the operation, there is a risk of damaging the MN or nearby vascular structures. Postoperative complications include surgical site infections or scar tenderness. Persistent symptoms can arise from incomplete release of the transverse carpal ligament, scar formation causing recurrent compression, or misdiagnosis of another condition. Treatment for those complications can vary from non-operative management to revision surgery. (40) In a cohort analysis encompassing all CT release surgeries in England's NHS from April 1, 1998, to March 31, 2017, involving 855,832 surgeries, the incidence of reoperation was 3.42%, with a serious complication rate within 30 days of surgery at 0.070% and within 90 days at 0.082%. Factors associated with an increased risk of complications included male gender and younger age. In contrast, risk factors for reoperation included male sex, older age, higher levels of comorbidity, and socioeconomic deprivation. The complications mentioned following CT release surgery include wound complications and neurovascular or tendon injury, which required hospital admission or further surgery within 30- and 90 days post-operation. This shows the relative safety of CT release

surgery measured in the UK, with a low incidence of serious postoperative complications. (41) In recent years, the association between CT release surgery and the subsequent development of the trigger finger has been established, revealing a significant incidence of post-CT release trigger finger at 7.7% among 9207 surgeries. A trigger finger is a condition where a bent finger gets stuck and then snaps straight, resembling a trigger being pulled and released due to inflammation and narrowing around the tendon sheath. Interestingly, the trigger finger predominantly manifested within the first-year post-surgery, with an average onset of 5.5 months. The increased susceptibility of women to post-surgery trigger finger is potentially linked to low estrogen levels, particularly in postmenopausal women, which may induce synovial membrane swelling. These are quite recent findings and need further research to be appropriately considered during the treatment planning. (42)

References

1. van Rijn RM, Huisstede BM, Koes BW, Burdorf A. Associations between work-related factors and the carpal tunnel syndrome—a systematic review. Scandinavian Journal of Work, Environment & Health. 2009;35(1):19–36.

2. Aboonq MS. Pathophysiology of carpal tunnel syndrome. Neurosciences (Riyadh). 2015 Jan;20(1):4–9.

3. McDonagh C, Alexander M, Kane D. The role of ultrasound in the diagnosis and management of carpal tunnel syndrome: a new paradigm. Rheumatology. 2015 Jan 1;54(1):9–19.

4. Werthel JDR, Zhao C, An KN, Amadio PC. Carpal Tunnel Syndrome Pathophysiology: Role of Subsynovial Connective Tissue. J Wrist Surg. 2014 Nov;03(04):220–6.

5. Werner RA, Andary M. Carpal tunnel syndrome: pathophysiology and clinical neurophysiology. Clin Neurophysiol. 2002 Sep;113(9):1373–81.

6. Ahn SY, Hong YH, Koh YH, Chung YS, Lee SH, Yang HJ. Pressure Measurement in Carpal Tunnel Syndrome : Correlation with Electrodiagnostic and Ultrasonographic Findings. J Korean Neurosurg Soc. 2009 Sep;46(3):199–204.

7. Mackinnon SE. Pathophysiology of nerve compression. Hand Clinics. 2002 May;18(2):231–41.

8. Farioli A, Curti S, Bonfiglioli R, Baldasseroni A, Spatari G, Mattioli S, et al. Observed Differences between Males and Females in Surgically Treated Carpal Tunnel Syndrome Among Non-manual Workers: A Sensitivity Analysis of Findings from a Large Population Study. Annals of Work Exposures and Health. 2018 Apr 18;62(4):505–15.

9. Kozak A, Schedlbauer G, Wirth T, Euler U, Westermann C, Nienhaus A. Association between work-related biomechanical risk factors and the occurrence of carpal tunnel syndrome: an overview of systematic reviews and a meta-analysis of current research. BMC Musculoskelet Disord. 2015 Sep 1;16:231.

10. Oktayoglu P. Assessment of the Presence of Carpal Tunnel Syndrome in Patients with Diabetes Mellitus, Hypothyroidism and Acromegaly. JCDR [Internet]. 2015 [cited 2023 Sep 2

11. Wipperman J, Goerl K. Carpal Tunnel Syndrome: Diagnosis and Management. afp. 2016 Dec 15;94(12):993–9.

12. Eslami S, Fadaei B, Baniasadi M, Yavari P. Clinical presentation of carpal tunnel syndrome with different severity: a cross-sectional study. Am J Clin Exp Immunol. 2019 Aug 15;8(4):32–6.

13. Karjalanen T, Raatikainen S, Jaatinen K, Lusa V. Update on Efficacy of Conservative Treatments for Carpal Tunnel Syndrome. Journal of Clinical Medicine. 2022 Jan;11(4):950.

14. Ostergaard PJ, Meyer MA, Earp BE. Non-operative Treatment of Carpal Tunnel Syndrome. Curr Rev Musculoskelet Med. 2020 Mar 2;13(2):141–7.

15. Kaile E, Bland JDP. Safety of corticosteroid injection for carpal tunnel syndrome. J Hand Surg Eur Vol. 2018 Mar 1;43(3):296–302.

16. Karimzadeh A, Bagheri S, Raeissadat SA, Bagheri S, Rayegani SM, Rahimi-Dehgolan S, et al. The comparison of the effectiveness between different doses of local methylprednisolone injection versus triamcinolone in Carpal Tunnel Syndrome: a double-blind clinical trial. Journal of Pain Research. 2019 Feb 5;12:579–84.

17. Chesterton LS, Blagojevic-Bucknall M, Burton C, Dziedzic KS, Davenport G, Jowett SM, et al. The clinical and cost-effectiveness of corticosteroid injection versus night splints for carpal tunnel syndrome (INSTINCTS trial): an open-label, parallel group, randomised controlled trial. The Lancet. 2018 Oct 20;392(10156):1423–33.

18. Wang JC, Liao KK, Lin KP, Chou CL, Yang TF, Huang YF, et al. Efficacy of Combined Ultrasound-Guided Steroid Injection and Splinting in Patients With Carpal Tunnel Syndrome: A Randomized Controlled Trial. Archives of Physical Medicine and Rehabilitation. 2017 May 1;98(5):947–56.

19. Page MJ, O'Connor D, Pitt V, Massy-Westropp N. Therapeutic ultrasound for carpal tunnel syndrome. Cochrane Database of Systematic Reviews [Internet]. 2013 [cited 2023 Oct 6];(3). Available from: https://www.readcube.com/articles/10.1002%2F14651858.cd009601.pub2

20. Werner RA, Andary M. Electrodiagnostic evaluation of carpal tunnel syndrome. Muscle Nerve. 2011 Oct;44(4):597–607.

21. Tulipan JE, Ilyas AM. Carpal Tunnel Syndrome Surgery: What You Should Know. Plast Reconstr Surg Glob Open. 2020 Mar 20;8(3):e2692.

22. Burton CL, Chen Y, Chesterton LS, Van Der Windt DA. Trends in the prevalence, incidence and surgical management of carpal tunnel syndrome between 1993 and 2013: an observational analysis of UK primary care records. BMJ Open. 2018 Jun;8(6):e020166.

23. Fnais N, Gomes T, Mahoney J, Alissa S, Mamdani M. Temporal Trend of Carpal Tunnel Release Surgery: A Population-Based Time Series Analysis. PLoS One. 2014 May 14;9(5):e97499.

24. Foster BD, Sivasundaram L, Heckmann N, Cohen JR, Pannell WC, Wang JC, et al. Surgical Approach and Anesthetic Modality for Carpal Tunnel Release. Hand (N Y). 2017 Mar;12(2):162–7.

25. Yamamoto M, Curley J, Hirata H. Trends in Open vs. Endoscopic Carpal Tunnel Release: A Comprehensive Survey in Japan. Journal of Clinical Medicine. 2022 Jan;11(17):4966.

26. Fajardo M, Kim SH, Szabo RM. Incidence of carpal tunnel release: trends and implications within the United States ambulatory care setting. J Hand Surg Am. 2012 Aug;37(8):1599–605.

27. Sotereanos DG, Papatheodorou LK. Compressive Neuropathies of the Upper Extremity: A Comprehensive Guide to Treatment. Springer Nature; 2020. 288 p.

28. Duncan SFM, Kakinoki R. Carpal Tunnel Syndrome and Related Median Neuropathies: Challenges and Complications. Springer; 2017. 309 p.

29. Sucher BM, Schreiber AL. Carpal Tunnel Syndrome Diagnosis. Physical Medicine and Rehabilitation Clinics of North America. 2014 May;25(2):229–47.

30. Dabbagh A, MacDermid JC, Yong J, Packham TL, Macedo LG, Ghodrati M. Diagnostic accuracy of sensory and motor tests for the diagnosis of carpal tunnel syndrome: a systematic review. BMC Musculoskelet Disord. 2021 Apr 7;22(1):337.

31. Meems M, Truijens S, Spek V, Visser L, Pop V. Prevalence, course and determinants of carpal tunnel syndrome symptoms during pregnancy: a prospective study. BJOG: An International Journal of Obstetrics & Gynaecology. 2015;122(8):1112–8.

32. Genova A, Dix O, Saefan A, Thakur M, Hassan A. Carpal Tunnel Syndrome: A Review of Literature. Cureus [Internet]. 2020 Mar 19 [cited 2024 Feb 14]; Available from: https://www.cureus.com/articles/29112-carpal-tunnel-syndrome-a-review-of-literature

33. Yang FA, Shih YC, Hong JP, Wu CW, Liao CD, Chen HC. Ultrasound-guided corticosteroid injection for patients with carpal tunnel syndrome: a systematic review and meta-analysis of randomized controlled trials. Sci Rep. 2021 May 17;11:10417.

34. Atroshi I, Flondell M, Hofer M, Ranstam J. Methylprednisolone Injections for the Carpal Tunnel Syndrome.

35. Tang CQY, Lai SWH, Tay SC. Long-term outcome of carpal tunnel release surgery in patients with severe carpal tunnel syndrome. The Bone & Joint Journal. 2017 Oct 1;99-B(10):1348–53.

36. Klokkari D, Mamais I. Effectiveness of surgical versus conservative treatment for carpal tunnel syndrome: A systematic review, meta-analysis and qualitative analysis. Hong Kong Physiother J. 2018 Dec;38(02):91–114.

37. Zwolińska J, Kwolek A. Factors determining the effectiveness of conservative treatment in patients with carpal tunnel syndrome. International Journal of Occupational Medicine and Environmental Health. 2019;32(2):197–215.

38. Shi Q, Bobos P, Lalone EA, Warren L, MacDermid JC. Comparison of the Short-Term and Long-Term Effects of Surgery and Nonsurgical Intervention in Treating Carpal Tunnel Syndrome: A Systematic Review and Meta-Analysis. Hand (New York, N,Y). 2020 Jan 1;15(1):13–22.

39. Zuo D, Zhou Z, Wang H, Liao Y, Zheng L, Hua Y, et al. Endoscopic versus open carpal tunnel release for idiopathic carpal tunnel syndrome: a meta-analysis of randomized controlled trials. Journal of Orthopaedic Surgery and Research. 2015 Jan 28;10(1):12.

40. Karl JW, Gancarczyk SM, Strauch RJ. Complications of Carpal Tunnel Release. Orthopedic Clinics. 2016 Apr 1;47(2):425–33.

41. Lane JCE, Craig RS, Rees JL, Gardiner MD, Green J, Prieto-Alhambra D, et al. Serious postoperative complications and reoperation after carpal tunnel decompression surgery in England: a nationwide cohort analysis. The Lancet Rheumatology. 2021 Jan 1;3(1):e49–57.

42. Lo YC, Lin CH, Huang SW, Chen YP, Kuo YJ. High incidence of trigger finger after carpal tunnel release: a systematic review and meta-analysis. International Journal of Surgery. 2023 Aug;109(8):2427.

43. Mitake T, Iwatsuki K, Hirata H. Differences in characteristics of carpal tunnel syndrome between male and female patients. Journal of Orthopaedic Science. 2020 Sep 1;25(5):843–6.

44. Claes F, Kasius KM, Meulstee J, Verhagen WIM. Comparing a new ultrasound approach with electrodiagnostic studies to confirm clinically defined carpal tunnel syndrome: a prospective, blinded study. Am J Phys Med Rehabil. 2013 Nov;92(11):1005–11.

45. Fowler JR, Munsch M, Tosti R, Hagberg WC, Imbriglia JE. Comparison of ultrasound and electrodiagnostic testing for diagnosis of carpal tunnel syndrome: study using a validated clinical tool as the reference standard. J Bone Joint Surg Am. 2014 Sep 3;96(17):e148.

46. Lu YT, Deol AK, Sears ED. The Association Between Electrodiagnostic Severity and Treatment Recommendations for Carpal Tunnel Syndrome. J Hand Surg Am. 2021 Feb;46(2):92–8.

47. Chammas M, Boretto J, Burmann LM, Ramos RM, dos Santos Neto FC, Silva JB. Carpal tunnel syndrome – Part I (anatomy, physiology, etiology, and diagnosis). Rev Bras Ortop. 2014 Aug 20;49(5):429–36.

48. Sonoo M, Menkes DL, Bland JDP, Burke D. Nerve conduction studies and EMG in carpal tunnel syndrome: Do they add value? Clinical Neurophysiology Practice. 2018 Jan 1;3:78–88.

49. Zuniga LA, Ross M. T34. Diagnosing patients with carpal tunnel syndrome: Do you need needle EMG? Clinical Neurophysiology. 2018 May 1;129:e14.

50. Hems T. https://books.publisso.de/en/publisso_gold/publishing/books/overview/49/43. German Medical Science GMS Publishing House;Berlin; 2016 [cited 2024 Apr 30]. Nerve injury: Classification, clinical assessment, investigation, and management. Available from: https://books.publisso.de/en/publisso_gold/publishing/books/overview/49/43

51. NeurologyNeeds.com [Internet]. [cited 2024 Apr 30]. Median nerve. Available from: https://www.neurologyneeds.com/neuroanatomy/peripheral-nerves/median-nerve/

52. Gundelfingen MGK. Phalen-Test [Internet]. [cited 2024 Apr 30]. Available from: https://gelenk-klinik.de/orthopaedie-glossar/phalen-test.html

53. Tinel Test at the Wrist (Carpal Tunnel) – Student OMT [Internet]. [cited 2024 Apr 30]. Available from: https://studentomt.org/knowledge-base/tinel-test-at-the-wrist/

54. Nerve Conduction Studies [Internet]. 2021 [cited 2024 Apr 30]. Available from: https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/nerve-conduction-studies

55. Electromyography (EMG) [Internet]. 2023 [cited 2024 Apr 30]. Available from: https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/electromyography-emg

56. OTCBrace [Internet]. [cited 2024 Apr 30]. 2083 / 8. Available from: https://otcbrace.com/products/otc-8-wrist-splint

57. Microaire Smartrelease - Upper Extremity - Carpal Tunnel - Upper Extremity Endoscopic Soft Tissue Release System By Microaire Surgical Instruments, LLC. [Internet]. [cited 2024 Apr 30]. Available from: https://www.medical-xprt.com/products/microaire-smartrelease-upper-extremity-endoscopic-soft-tissue-release-system-760470