

Carpal Tunnel Syndrome: Current Concepts.

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Abstract: Carpal tunnel syndrome is the most common condition surgically treated by hand surgeons. The entity represents compression neuropathy of median nerve at wrist producing classical nocturnal pain, paresthesias, weakness in hand and digits and in advanced cases, thenar muscle atrophy. Idiopathic form is most commonly encountered, however anatomic, systemic and occupational factors are not uncommon and significantly influence the treatment. The diagnosis is based on patient history and physical examination that can be confirmed by electrodiagnostic studies. Treatment is directed to relieve symptoms and prevent further damage to the nerve. Observation and nocturnal splinting to surgical treatment methods have all been used depending primarily on the severity of involvement. The preference of open, mini-open or endoscopic carpal tunnel release and superiority of one over other has yet to be established.

INTRODUCTION

The source of term "carpal tunnel syndrome" in print can be attributed to an article by Kremer et al in 1953¹. The first description of condition is not well established, however classical work of Brain in 1947 and George Phalen in 1950 and 1951 have been ascribed to popularization of carpal tunnel syndrome (CTS)²⁻³. Historically the evolution of CTS description and knowledge have various lineages that can be partially explained to varied etiology of the condition. In historical literature there were three major threads of acroparesthesia, thenar neuritis, and median neuropathy after wrist fracture; which needed to unite in order to establish our current understandings of CTS. Although Herbert Galloway in 1924 did the first carpal tunnel release⁴ the use of steroids was popularized by Phalen in 1957⁵. The review of historical literature suggests that our understanding continues to evolve and there is a considerable debate especially over the effectiveness of endoscopic carpal tunnel release, utility of diuretics and vitamins in therapy and the diagnostic criteria for CTS etc.

The exact epidemiology in Indian population is unknown, however, data from west suggest 1-3.5 cases per 100000 person years incidence in region specific distribution⁶. Clinical and economic burden could still be larger as there seems to be an occult reservoir for the condition.

ANATOMY AND PATHOLOGY

The carpal tunnel is bordered dorsally by the concave arch of the carpus and volar aspect by the transverse carpal ligament (TCL), with a variable depth of 10 to 13mm⁷. Ten structures from the volar forearm pass through the carpal tunnel—eight flexor tendons to the fingers, flexor pollicis longus and the median nerve. The median nerve lies most superficial within the canal, entering the space in the midline or just radial to it. The median nerve divides into terminal branches at the distal end of the TCL however known variations have been described by Lanz⁸ into four groups. Most important of these (group I) is with respect to the course of thenar motor branch. With regard to the relation between the thenar branch and the flexor retinaculum, Poisel⁹ described three subtypes: 46% of thenar branches were extraligamentous, 31% were subligamentous, and 23% were transligamentous [figure 1]. The other variations that influence the treatment and should be looked for include duplication of the thenar branch, high division of the median nerve into forearm which is accompanied by accessory lumbrical muscle and median artery¹⁰. The unyielding nature of fibroosseous tunnel makes median nerve susceptible to compression. Aberrant muscles like palmaris profundus,

lumbricalis, and/or muscles bellies can further narrow the tunnel volume [figure 2]. Normal pressure within the carpal tunnel measures 2.5mmHg¹¹. Rydevik¹² demonstrated that external compression of 20-30mmHg induces a slower epineurium venule flow which progresses to complete intraneural flow stasis if the pressure increases to 80mmHg (ischemia). It should be noted that the critical pressure level for microvessels that causes their obliteration and consequent ischemia with total nerve conduction block is around 40-50mmHg¹³.

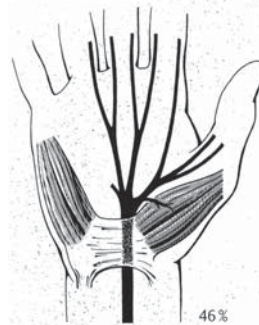
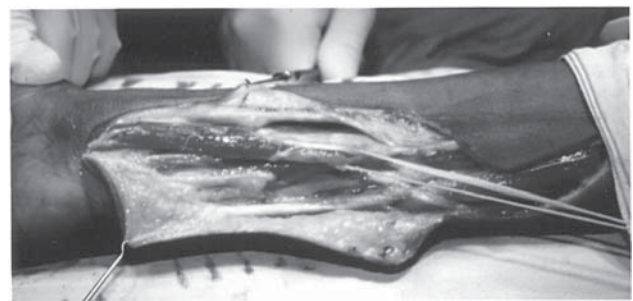


Figure 1: Line diagram illustrating division of median nerve in palm and the most common 'extraligamentous' presentation



Reverse Palmaris longus

Figure 2: Aberrant Palmaris longus muscle – note the reversed orientation of the muscle where the tendon is in the forearm and the muscle belly is encroaching into the carpal tunnel.

ETIOPATHOGENESIS

Presentation can be acute or insidious, former being characterized by rapid and sustained increase in pressure within carpal tunnel

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requiring urgent decompression. The factors are few but not uncommon and include, wrist trauma, infection, hematoma and high pressure injections. Majority of the cases present with chronic symptoms having varied pathology (table 1), however idiopathic one is the commonest. In idiopathic variety the exact cause is not identifiable however there is notable fibrous hypertrophy consequent upon chronic edema with minimal inflammation. Women are more commonly affected. The compression has been localized to the thickest part of TCL which is somewhere 1 cm distal to the proximal border of ligament. Anatomic factors operate locally and have in common the characteristic of behaving as space occupying lesions. Systemic factors either raise the interstitial tissue pressure or lead to deposition of pathological material that constricts the already tenuous space in carpal tunnel. Pregnancy deserves special mention as the reported incidence is up to 45% developing in third trimester that often abates post-partum with conservative treatment¹⁴. Repetitive movements of wrist and finger flexion have been associated with the development of exertional CTS although objective evidence is lacking. Keyboarding and occupational vibratory exposure have been symptomatically associated to CTS in retrospect however¹⁵.

Table 1: Causes of carpal tunnel syndrome

Idiopathic	Occupational
Local anatomic <i>Acute form</i> (fracture, crushing hand injury, hemorrhage, burn, median artery thrombosis, infection, pregnancy) <i>Distal radius malunion</i> <i>Carpal canal stenosis</i> (deformity congenital or acquired) <i>Anomalous structures</i> (palmaris profundus, proximal origin of a Lumbrical, reversed palmaris longus, anomalous branch of radial artery) <i>Space occupying lesions</i> (ganglion, lipoma, fibroma, synovial sarcoma, neuroma, neurofibroma, hemangioma)	Systemic <i>Pregnancy</i> <i>Endocrinopathy</i> (diabetes mellitus, thyroid disease, growth hormone, estrogen, progesterone) <i>Congestive heart failure</i> <i>Collagen and autoimmune diseases</i> (tenosynovitis, rheumatoid arthritis, scleroderma, gout, chondrocalcinosis etc) <i>Amyloidosis</i> <i>Polyneuropathy</i> <i>Alcoholism</i> <i>Myeloma</i> <i>Obesity</i> <i>Consequential forms</i> (oral contraceptives, anticoagulants, lack of vitamin B6) <i>Children's forms</i> <i>Congenital diseases</i> (mucopolysaccharidosis, mucopolipidosis)

DIAGNOSIS

Diagnosis of carpal tunnel syndrome is substantially clinical. The most common subjective symptom is "nocturnal acroparesthesia," consisting of a painful tingling sensation which may even disturb sleep however daytime paresthesias may also occur. Certain positions or activities such as the act of sewing, pray position, holding the phone or a book while reading may trigger paresthesias in daytime. Initially a high percentage of patients are not able to describe on which fingers paresthesia occurs; they thus relate it to the whole hand and often, to the back of the hand as well as to the palmar surface. Performing some maneuvers to reproduce symptomatology, often aptly localises paresthesia over the radial three fingers and to the radial side of the fourth finger. With chronic delayed presentations the symptoms may progress to gritty or numb feeling in fingers, weakness of grip or pinch and diminished finger dexterity. Bilateral CTS is common; however the symptoms may be more marked in one hand. A thorough physical examination including cervical spine and neurological upper limb examination should be done to exclude double crush syndrome and CTS mimics (Table 2). Spurling's maneuver is helpful in diagnosing cervical spine pathology along with other routine examination of cervical movements. Adson's test, Wright's hyperabduction maneuver, costoclavicular test and assessment of blood flow help in excluding thoracic outlet syndrome and raynaud's disease. Various provocative tests for CTS¹⁶ have been described (Table 3). Tinel's sign is elicited by gentle but firm tapping over the nerve at TCL region. An electric shock or tingling sensation in median nerve distribution describes a positive test. Phalen's test is

performed by making the patient flex his wrists for 60 seconds [figure 3]. Reporting of paresthesias in median nerve distribution by patient describes a positive test. Durkan's direct median nerve compression at TCL for 30 seconds also elicits similar response in a patient with CTS¹⁶.

Table 2: CTS mimics

- Median nerve contusion
- Cervical radiculopathy (double-crush syndrome)
- Thoracic outlet syndrome
- Pronator syndrome
- Idiopathic brachioplexitis (Parsonage-Turner syndrome/neuralgic amyotrophy)
- Intracranial neoplasm
- Multiple sclerosis
- Cervical syringomyelia
- Pancoast tumor
- Peripheral nerve tumor (schwannoma, hamartoma, etc.)
- Lower trunk brachial plexopathy
- Ulnar neuropathy
- Radial neuropathy
- Generalized neuropathy (diabetes/mononeuritis multiplex)
- Churg-Strauss syndrome



Figure 3: Phalen's test.

Table 3: Tests and signs for CTS

Test/ sign	Method	Significance	Sensitivity	Specificity
Tinel's sign	Percussion at wrist over carpal tunnel	Acceptable (+ Phalen's)	0.41	0.90
Phalen's test	Wrist hyperflexed at for 60 secs	Acceptable (Tinel's)	0.59	0.93
Durkan's direct median nerve compression test	Manual pressure over carpal tunnel for 30 seconds	Acceptable (Tinel's)	0.42	0.99
Wrist extension (reverse Phalen's test; Pray position)	Active extension of wrist for 2 minutes	Acceptable (Tinel's)	0.55	0.96
Tourniquet test (Gilliat and Wilson)	Arm tourniquet inflated above systolic pressure for 60 secs	Not significant	-	-
Closed fist sign	Making tight fist for 60 seconds	Significant only if at least one more sign positive	-	-
Hand elevation test	Hand elevated above head for 60 seconds	Not significant	-	-
Ames test	Make fist and ask to press the fists together	Identifies malingering if positive	-	-

DIAGNOSTIC STUDIES

Electrodiagnostic testing

The goals of an electrodiagnostic examination are basically to localize the lesion; to show the involvement of motor, sensory fibers, or both; to define the physiologic basis (axon loss, demyelination) and the severity of the lesion (degree of axonal loss, the continuity of axons), as well as the time course of the lesion (evidence of reinnervation or of ongoing axonal loss). Diagnosis of CTS is based on specific criteria evident for sensory and motor nerve fiber compression (table 4). The main objective of the neurophysiological assessment of a patient with supposed CTS is to confirm the clinical suspicion of median nerve compression at wrist suggested by history and clinical examination. Sensory and motor nerve conduction velocity of the median nerve and other nerve segments with the needle electromyographic examination of one or several muscles allows the diagnosis of other diseases often associated with CTS such as radiculopathies, plexopathies, and others not evidenced by clinical examination alone. In the preoperative work-up of a CTS patient the neurophysiological examination allows quantification of the severity and the type of nerve lesion; moreover, it can be of some value in litigation should the intervention be less than satisfactory for the patient¹⁷. The neurophysiological examination for CTS is seemingly more sensitive than routine clinical testing and may come positive even in 'clinically silent' patients. In patients with initial CTS (irritative stage), the phenomenon of increased excitability and ectopic impulse discharge cannot be demonstrated and the test will be normal⁸.

Table 4: Diagnostic criteria for CTS on electrodiagnostic study

Evidence of sensory nerve fiber compression

- Absent or delayed motor nerve SAP (>3.4 ms)
- Increased median-to-ulnar latency difference of the fourth finger SAP (& 0.5 ms)

Evidence of motor nerve fiber compression

- Increased distal motor latency (>4.2 ms)
- Denervation signs in the abductor pollicis brevis muscle

Imaging

Routine radiographs are normal in great majority of cases barring those with post traumatic or arthritic cause for CTS¹⁹. MRI and ultrasonography^{20,21} have been variably shown to be of use in measuring differing canal size and defining pathology in uncommon cases. There is usually flattening of nerve at the level of hook of hamate. Cross-sectional diameter ratio of median nerve at the level of pisiform to distal radius should be 1; an increase is seen in CTS. Fatty infiltration of median nerve, bursitis and inflammation of other structures, demonstration of neuroma or other space occupying lesions can be detailed in MRI. Their routine use preoperatively is however limited as the diagnosis is primarily clinical and only rare pathologies require advanced imaging. An important indication for the use of these imaging modalities is recurrent CTS after surgical release to look for real canal widening, inflammation, incomplete resection of ligament, scarring or algodystrophy.

DIFFERENTIAL DIAGNOSIS

Even though the classical symptoms and findings are described by many, sometimes the patients describe vague symptoms not fitting typical CTS. Quite often it is due to unclear description and poor

communication due to various reasons, but sometimes due to really different pathology that should be aptly differentiated from CTS (table 5). X-rays of the cervical spine may show evidence of cervical spondylosis. Laboratory studies may show evidence of abnormalities of blood sugar, inflammatory markers such as rheumatoid factor, or endocrine markers such as thyroid hormone levels, which may explain the symptoms. In rare cases, a magnetic resonance imaging (MRI) may be useful to diagnose nerve tumors in the region of the brachial plexus.

TREATMENT

Management options for CTS range from non-surgical measures to steroid injections to various described surgical carpal tunnel release including endoscopic methods. The decision for specific modality relies on the clinical and electrophysiological severity of involvement, chronicity of symptoms and individual patient choices. Splinting may be appropriate in initial disease or mild chronic symptoms. Surgical release is typically prescribed in acute CTS due to infection, trauma or hematoma formation. Patients showing evident denervation in median nerve distribution and pronounced sensory loss particularly supported by electrodiagnostic studies are primary candidates for surgical release. Nevertheless patients who fail to respond to conservative methods and should be operated if willing for surgery.

Non-surgical measures

Splinting, activity modification and oral medications:

Wrist immobilisation in night and intermittently during day shows relief in up to 80% patients within days²². Splints are particularly of use to patients who have positive fist test or a positive Phalens test. Splints work primarily by maintaining MCP joint in neutral position keeping the lumbricals out of tunnel. Splint position has been controversial but large scale studies demonstrate carpal tunnel pressure to be lowest with wrist in $2^{\circ} \pm 9^{\circ}$ of extension and $2^{\circ} \pm 6^{\circ}$ of ulnar deviation. Activity modification is an integral part of initial management and is aimed to avoid repetitive strenuous activities. Ergonomic modifications at work place like ergonomic keyboards are supposed to be helpful. Various drugs are used to supplement the physical measures. NSAIDs are primarily used for analgesic and anti-inflammatory purpose. Supplementation with neurotropic vitamins pyridoxine (B6), and methylcobalamin may have a beneficial role. Uncommonly oral steroids and diuretics are prescribed to lower the interstitial fluid pressure with documented benefit in some studies.

Corticosteroid injections

Local corticosteroid injections for CTS have been utilized for years to alleviate symptoms²³. The effectiveness and duration of benefit from these injections have not been clearly outlined. There is very little information as to the optimal corticosteroid to use, dosage, or location of the injection²⁴. It has been demonstrated that reoccurrence of symptoms after corticosteroid injection range from 8% to 100%²³. Much of this depends on severity of symptoms, study design, and outcome measures. Patients with the most severe CTS generally derive the least benefit from steroid injections. Celiker²⁴ performed an unblinded, randomized trial comparing injections to NSAIDs and splinting. During the short follow-up periods, there was no statistical difference between corticosteroid injection alone versus NSAIDs and splinting. The duration of benefit has not been systematically studied. Local corticosteroid injections appear to be superior to oral steroids for up to 3 months. No studies show, however, benefit from steroid injection greater than 3months.

Adjunctive measures

Local ultrasound therapy, laser therapy and iontophoresis are variably prescribed and depending on investigators have shown inconsistent benefits. Primarily they are thought to alter blood flow dynamics and controlling inflammation or its progress.

Surgical release

Carpal tunnel release has been performed by various methods including open method, limited open method and endoscopic methods. Various authors have improvised instrumentations and methods for release with equally good results. The different methods have their own drawbacks and benefits. The main rationale for outpouring of so many methods is to limit the post-operative weakness and recurrence rates and avoid complications. Although the latter have been relatively constant the post-operative weakness due to tendon subluxations following release of carpal ligament (so-called volar wrist pulley) is the main concern and attempts to control the same have yielded variable benefits and is still evolving.

Open release

Traditionally the open release is performed through wrist-palm incision variously described by Milford, Phalen, Inglis, Taleisnik etc.^{25,26,27,28} although the shape of incisions vary, they commonly involve similar deep dissection releasing palmar fascia and carpal ligament longitudinally. Care is taken to avoid injury to motor branch, and palmar cutaneous branch of median nerve. Internal neurolysis, epineurotomy and tenosynovectomy initially performed lead to skin-adhesions, neuro-dermodesis phenomenon, algo-paresthesias and hence internal neurolysis has been definitively abandoned²⁹. With the improved understanding, early diagnosis and increased need for aesthetic surgery 'palm-only' incision technique has evolved whereby incision is given only in the region of palm³⁰. The proximal reference point can be found by flexing the fourth finger towards the distal wrist crease [figure 4]. It is advisable to move lateral to this line for both the cutaneous incision and its underlying exposure. The cutaneous incision line is ulnarly located with respect to the thenar crease and is located 2mm ulnarly to the fourth ray. As soon as the skin is incised, one should be extremely careful to look for branch anomalies that cross over the same incision line. As soon as the proximal margin of the TCL is isolated, sectioning is begun along the fourth ray. The distal half of the TCL is sectioned in layers. One should also be extremely careful when sectioning the midpalmar adipose tissue that surrounds the superficial vascular arch. Therefore, the antebrachial fascia should be sectioned for 2–3 cm. The external margins of the TCL are raised towards the thenar muscles and the median nerve is detached from the TCL; thorough checking of the compression site and the epineurium's thickness should always be done. In majority of cases there is hourglass constriction in the median nerve at the level of hook of hamate (figure 5) while occasionally there is marked compression of the nerve with ecchymosis (figure 6). Optimally, surgery satisfies the criteria of the Three Es: it has a limited impact on health care resources (*economy*); it consists of methods that can be performed with few difficult surgical skills (*efficiency*); and it fairly accomplishes its goals of relief of symptoms and restoration of function (*effectiveness*). A simplified approach to open release of the carpal tunnel, with a short palmar incision, satisfies these criteria.

Limited open carpal tunnel release: Modification instrumentation, light source, availability of magnification lead to development of techniques similar to endoscopic carpal tunnel release. Using a 'palm-

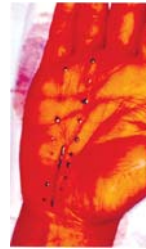


Figure 4: Surface marking of the Incision; in line with the ring finger.

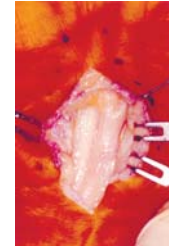


Figure 5: Hourglass constriction of the nerve at the level of hook of hamate which is classically located 1 cm distal to the proximal border of transverse carpal ligament.



Figure 6: Marked compression of the median nerve with ecchymosis.

only' mini incision (<2 cms) distal end of carpal ligament is released under direct vision followed by proximal release using variously designed guides^{30,31}. Some authors use double approach with proximal and distal mini-incisions³². The distal incision is made between the hamate and the proximal palmar crease and has a longitudinal course of about 1.5–2 cm in the direction of the axis of the fourth finger. The proximal transverse incision is about 1 cm in length, just above the crease of the wrist, between the flexor carpi ulnaris and the palmaris longus. By means of distal incision the distal part of the transverse carpal ligament can be reached. A U-shaped incision is made at the distal base of the anti-brachial fascia and a probe is inserted, which comes out of the distal edge of the transverse carpal ligament. The transverse ligament is sectioned and the effective opening of the carpal canal is ascertained by a direct view and the *geyser-effect* obtained from the saline solution injected at pressure into the incisions.

Endoscopic technique

The technique was developed to ameliorate some complications like scar tenderness, prolonged healing time, pillar pain and weakened grip strength. Single and dual portal techniques have been described³³. In single portal technique (figure 7) carpal ligament release is performed through a portal placed midway between FC and FCR. With wrist extended and endoscopic blade assembly aligned to ring finger distal edge of ligament is identified and sectioned from distal to proximal in controlled fashion. Dual portal technique³⁴ involves same proximal portal with a distal portal deep to TCL. Endoscopic technique should not be performed in patients with wrist stiffness, proliferative synovitis and space occupying lesions that obliterate the view of canal.



Figure 7: Endoscopic carpal tunnel release.

Outcome analysis

To address the primary concern of choosing treatment modality it has been found that surgical treatment for CTS is more effective than conservative method or injection technique^{35,36}. Especially with long term benefit the surgical technique fared superior to injection method which gives relief only in short term. While comparing endoscopic to open carpal tunnel release it was found that there is no significant difference in the outcome between the treatment groups however overall satisfaction was lower in the endoscopic patients following 5% rate of revision surgery^{37,38}. Wrist immobilization following carpal tunnel release has not been found to be any benefit and hence active motion exercises of the wrist and fingers are encouraged post-operatively in nearly all patients³⁹.

Various complications have been reported following any method of carpal tunnel release; however the frequencies of each differ depending on the technique used. Commonly encountered complications are injuries to motor and/ or palmar cutaneous branch of median nerve, hypertrophic scar formation, pillar pain, injury to superficial palmar arch, incomplete carpal tunnel release, tendon adhesions, infection, wound hematoma, finger stiffness, reflex sympathetic dystrophy, weak grip strength and recurrence. The most common complication following open carpal tunnel release surgery is pillar pain followed by laceration of the palmar cutaneous branch of median nerve. Incomplete release is the most frequently reported complication of endoscopic release.

Recurrent carpal tunnel syndrome has been reported to occur in 7-20% patients⁴⁰. This is a difficult problem to deal with as compared to the primary CTS and the results are often dismal. Revision surgery involves neurolysis of median nerve, fat or muscle transfer and vein wrapping^{41,42}.

SUMMARY

Carpal tunnel syndrome is a common problem with a reported prevalence of around 5% in general population. The primary etiology is varied but idiopathic form is the most common. A thorough history and physical examination is an absolute requirement to establish the diagnosis and rule out related and unrelated disorders. Neurophysiological studies are often used to confirm the diagnosis and is considered gold standard. Carefully chosen patients for nonsurgical treatment (splinting, medications and steroid injections) and surgical carpal tunnel release yields good results. The results of open carpal tunnel release compared to limited open methods are comparative considering the benefits and disadvantages of each. Endoscopic carpal tunnel release has also yielded comparative results however the rate repeat surgery is higher and definite superiority is yet to be established.

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- Editorial: Tobacco & Health
- Functional Impairment in Elderly
- Nephrotoxic Potential of Herbal Drugs
- Health-related Quality of Life amongst Sikkim Population
- Symposium : Anorectal Disorders : Current Management