REVIEW ARTICLE

Ortopedia *Traumatologia* **Rehabilitacja**
© MEDSPORTPRESS, 2017; 1(6); Vol. 19, 1-8
DOI: 10.5604/15093492.1232629

Carpal Tunnel Syndrome: Symptoms, Causes and Treatment Options. A Literature Reviev

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SUMMARY

Carpal Tunnel Syndrome (CTS) is the most common form of entrapment neuropathy. Several authors have investigated the anatomical and pathophysiological features of CTS and have identified several parameters that, in combination, play a significant role in its pathophysiology. Advancement in biological research on CTS has enabled the advent of efficient diagnostic techniques such as provocative tests and nerve conduction studies. Sophisticated technologies, such as magnetic resonance imaging (MRI) and ultrasonography (US), have facilitated the diagnosis of CTS. This review article aims at consolidating the relevant medical literature pertaining to the symptoms, pathophysiology, clinical diagnosis and treatment strategies of CTS. It also compares the various methods of diagnosis and discusses their benefits and disadvantages. Finally, it sheds light on the conservative vs. surgical approach to treatment and compares them. While the surgical approach has proved to be more efficient relative to the conservative methods of steroid injections and splinting, many studies have demonstrated both advantages and adverse effects of the surgical methods. Surgical options and complications are discussed in detail. This article comprehensively summarizes all medical aspects of CTS to update medical professionals' knowledge regarding the disease.

Key words: entrapment, neuropathy, median nerve, carpal tunnel syndrome, treatment

BACKGROUND

Carpal Tunnel Syndrome, first studied by Paget in 1954, is a common entrapment neuropathy, affecting about 3.8% of the population [1,2]. An entrapment neuropathy is a kind of neuropathy caused due to pressure inside anatomical structures that are not flexible. Sustained or high pressure in the carpal tunnel impedes microcirculation in the median nerve, leading to decreased action potentials, demyelination in the nerve and axonal degeneration. CTS is defined as a symptomatic compression neuropathy of the median nerve in the wrist [3].

EPIDEMIOLOGY AND SOCIOECONOMIC EFFECTS

One in every five subjects generally reports pain, numbness and a tingling sensation in the hands. A clinical examination and electrophysiology testing may confirm the presence of this form of neuropathy. Annual incidence rates of 276:100,000 have been reported. CTS is more prevalent in females than in males, with a frequency of 9.2% in females and 6% in men [3]. The average age is 40 to 60 years [3]. In Europe 60% of work-related disorders were attributed to CTS. Some activities such as fish processing are associated with an approximately 73% rate of occurrence of CTS among the employees. Diabetic patients have a prevalence rate of 14% and 30% without and with diabetic neuropathy, respectively, whilst the prevalence of CTS during pregnancy has been reported to be around 2% [3].

The UK demonstrates the highest number of CTS cases (7-19%), whereas in the US, the prevalence is 5% [3]. The median number of leaves due to CTS is the highest in UK, at 27 days. In the US in 1995, nearly 400,000–500,000 CTS patients underwent surgery, which incurred an economic cost of $2 billion. This imposes a severe burden on the National Health Service to render patient care in terms of diagnosis, physician time and treatment options.

ANATOMY AND PATHOPHYSIOLOGY

The carpal tunnel comprises of a bony duct-like structure consisting of carpal bones the roof of which is the fibrous but rigid transverse carpal ligament. The carpal tunnel is made of nine flexor tendons and the median nerve, which enters the tunnel in the midline or slightly radial to it [4]. The pain and paraesthesia are experienced by the CTS patients in the 3 radial digits and the radial half of the fourth digit, which are supplied by the sensory branches. The palm generally remains unaffected in CTS, since the cutaneous skin of the palm is supplied by the palmar sensory cutaneous branch of the median nerve, which is about 6 cm proximal to the transverse carpal ligament (TLC) [4].

Idiopathic CTS is defined as increased pressure within the carpal tunnel leading to obstruction to the blood flow, which is a result of mismatch between the size of the median nerve and the components of the tunnel [5]. The pathophysiology of CTS can be attributed to a combination of parameters such as mechanical stress, increased pressure, and ischemic injury to the nerve.

Increased Pressure

In CTS, the pressure in the wrist may dramatically rise to about 8-10 fold than the normal pressure of about 2-10 mm of Hg [6]. Studies have shown experimental evidence for a direct relationship between the duration and intensity of pressure and the severity of the neural dysfunction [7].

Nerve injury

Repeated pressure on the nerve causes demyelination of the median nerve at the site of compression and then spread to the whole intermodal segment. A persistent compression may further lead to disturbances in the endoneurial capillary system and culminate in endoneurial oedema.

Ischemic Injury

It has been shown that ischemia in the limbs can increase paresthesias in CTS patients. Three stages of ischemic injury have been identified: increased intrafunicular pressure, capillary degeneration with leakage and oedema and obstruction of arterial flow.

Breakdown in the Blood-Nerve-Barrier

The blood-nerve-barrier is formed by the inner cells of the perineurium and the endothelial cells of endoneurial capillaries, which pass via the median nerve in the carpal tunnel. A rise in the pressure inside the tunnel can cause the vasculature to collapse within this barrier, causing the proteins and inflammatory cells to build up [8]. This could increase the permeability, adding to the increased endoneurial fluid pressure and lead to intra-fascicular oedema. Patients with vascular complications or persistent exposure to static loading are typically vulnerable to a breakdown in the blood-nerve-barrier [8].

Biochemical changes

Mechanical stress on the synovial tissue inside the carpal tunnel can also lead to biochemical changes [5]. Keratin expression is often increased in CTS

patients as compared to normal individuals. Continuous exposure of the tendons to tension can increase the proteoglycan composition of the matrix in the tendon, leading to increased pressure within the carpal tunnel [9]. Tenascin-C is a protein involved in tissue remodeling and has been implicated in the pathogenesis of CTS. Mechanical strain on the flexor synovium controls the production of tenascin-C by the synovial lining [9]. A physical injury to the flexor tendons due to repeated movements of the wrist may cause damage to the synovium and enlarge the carpal tunnel from the inside.

Inflammation

Tenosynovitis, inflammation of the synovial tissue of the flexor tendons, can also lead to high pressure in the carpal tunnel and result in CTS [10]. This has been verified by increased expression of prostaglandin E2 and the vascular endothelial growth factor (VEGF) in synovial biopsy tissue from patients with symptomatic CTS [11]. After the injury, there is a rise in fibroblast density, size of collagen fiber, vascular proliferation, and type III collagen in the synovial connective tissue [12]. This causes formation of constrictive scar tissue around the median nerve, which may subsequently result in nerve tethering.

Role of small fibers

Although most of the literature on compression focused on the big myelinated nerves, the contribution of small fibers is significant and may aid in the comprehension of symptoms of CTS, involving pain in the median nerve. This pain is often caused by aberrant diffusion of the sodium channels into the damaged small C-fibers, resulting in hyperactivity and ectopic discharge induction. Inflammatory mediators, such as tumor necrosis factor TNFa, play a significant role in the symptoms associated with pain CTS [13].

SECONDARY CTS

Many factors such as anomalies of the flexor tendons, synovium, and lesions may raise the pressure inside the carpal tunnel and lead to median nerve compression. Some diseases like diabetes, rheumatoid arthritis, tuberculosis, purulent tenosynovitis, systematic lupus erythematosus, gout or hyperthyroidism may influence the synovium [5].

Diabetes

Diabetic patients may be at high risk of developing CTS. It has been reported to occur in 14% of DM patients without diabetic neuropathies and in up to 30% of the patients with diabetic neuropathies [14]. The prevalence of CTR in patients with Type-2 diabetes has been estimated to be about 4-14 fold higher than in normal individuals [15].

Pregnancy

Pregnancy and labor may cause peripheral nerve disorders, such as CTS, facial nerve palsy, lumbosacral radiculopathy, and femoral neuropathy, of which CTS is the most frequently reported. CTS may occur due to edema associated with fluid retention in the synovium, which exerts pressure on the median nerve.

DIAGNOSIS OF CTS

Symptoms

In the early stages of CTS, the patient experiences numbness in the fingers or numbness while holding a phone or newspaper [5]. These symptoms may be a result of transient ischemia of the median nerve. With advancement of the disease, the carpal tunnel volume may be reduced and lead to fibrosis of the median nerve. The patients may experience an unpleasant sensation during thumb movements. Symptoms are often more intense at night than during daytime. Some patients may complain of symptoms like writer's cramp/fatigue and pain in the forearm or shoulder.

Two papers by the Quality Standards Subcommittee of the American Academy of Neurology and American Association of Electrodiagnostic Medicine, American Academy of Neurology and American Academy of Physical Medicine and Rehabilitation define the guidelines for clinical and neurophysiologic diagnosis of CTS [3]. These papers stress the importance of a thorough case history, which must focus on the following: onset of symptoms – which, in the initial stages, primarily include nocturnal paraesthesias, provocative factors – such as hand positions and repetitive movements, working activities like instrument use, vibrating tools, pain location in the cutaneous median nerve region with ascending, sometimes up to the shoulder, or descending radiation, actions which alleviate symptoms – e.g. hand shaking, position changes, and existence of predisposing factors such as diabetes, adiposity, chronic polyarthritis, myxedema, acromegaly or pregnancy [2].

PROVOCATIVE TESTS

The two most widely used diagnostic and provocative tests used to detect CTS are Phalen's test and Tinel's tests [3]. A pain or paraesthesia in the median nerve, on extending the wrist and maintaining this position for 60 seconds, is indicative of positive sign of CTS. Phalen's test has a sensitivity range of 67%

to 83%, whereas its specificity ranges from 40% to 98%. Tinel's test is performed by tapping on the volar surface of the wrist and, if positive, it causes paraesthesia in median nerve-innervated fingers such as thumb, second and middle finger, and the radial side of the ring finger. The sensitivity range of Tinel's test is 48% to 73% and specificity is 30% to 94%. The prognostic and diagnostic value of these tests has been questionable; hence, their use is often coupled with evaluation of the patient's clinical history and other methods of diagnosis such as nerve conduction study (NCS) [16].

Nerve Conduction Studies

NCS lends valuable information about the physiological condition of the median nerve across the carpal tunnel. In NCS, a transcutaneous pulse of electricity, which triggers an action potential in the nerve, excites the nerve. A proximally or distally placed recording electrode detects the wave of depolarization as it passes by the surface electrode. The amplitude of the median nerve segment across the carpal tunnel is compared to a different nerve segment that does not traverse the carpal tunnel, such as the radial or ulnar nerve [6].

Other neurophysiological evaluations

Other types of clinical neurophysiologic evaluation of the median nerve across the wrist include current perception testing, vibrometry threshold testing, questionnaire of symptoms and other quantitative sensory testing. These methods are less sensitive as compared to NCS, since they lack objectivity.

Magnetic Resonance Imaging (MRI)

The diagnosis of CTS is generally based on the symptoms, clinical history and NCS. However, many patients present a normal NCS, which necessitates the use of ultrasound and MRI. MRI is very useful for evaluating the infrequent pathological causes of CTS such as bone deformities, ganglion, hemangioma, which could influence surgical interventions. MRI has a sensitivity range of 96%, whereas the specificity is as low as 33-38%. MRI provides anatomical information rather than details about the nerve dysfunction. Although it is an expensive technique, it is still preferred by many patients. It is often used to evaluate the point of entrapment post failure of Carpal Tunnel Release (CTR) surgery [5]. Enlargement of the cross-sectional area (CSA) of the median nerve at the proximal end of the carpal tunnel, enhanced signal intensity over the median nerve, and palmar bowing of the TCL are typical features of idiopathic CTS [17]. These observations depend on the progression of the disease: proximal enlargement of the CSA and high signal intensity of the median nerve are more significant during the advanced stage of the disease [18]. Enlargement of the median nerve and a high signal intensity on T2-weighted images are suggestive of accumulation of the axonal transportation, myelin sheath degeneration or edema [19].

Ultrasonography

The importance of ultrasound (US) assessment as a diagnostic tool in evaluation of CTS is related to the fact that it can effectively measure thickening of the median nerve, flattening of the nerve within the tunnel and bowing of the flexor retinaculum (FR).

In a study designed to evaluate the diagnostic precision of US, Keles et al compared 35 wrists with NCS to 40 normal wrists and discovered that FR increased considerably in the NCS positive wrists relative to the normal [20]. Data obtained for Japanese populations have demonstrated that the diagnostic sensitivity and specificity were 67% and 97%, respectively, when the mean carpal nerve area (average of the areas measured at the distal edge of the TCL, the hook of the hamate, and the wrist crease) was used as the diagnostic criterion. Furthermore, when this criterion was combined with the results of NCSs, the sensitivity and specificity were 84% and 94%, respectively. US can be universally employed when a standardized procedure is used, because the measurements thus obtained are found to be reproducible, regardless of whether an experienced or inexperienced employee performs the evaluation, after a short orientation.

TREATMENT OPTIONS

The treatment strategies for CTS are classified into two types: conservative and surgical.

Conservative Treatment

Conservative treatment is usually provided to patients with mild to moderate symptoms. These options include corticosteroids, oral and transvenous steroids, vitamins B6 and B12, nonsteroidal anti-inflammatory drugs (NSAIDs), yoga, carpal bone mobilization and the use of hand splints. It has been demonstrated that patients benefited considerable with conservative treatment, albeit, in the short term, while their long term advantages are still a matter of controversy. Other conservative treatment methods such as splinting, exercise, chiropractic treatment or magnetic therapy have not shown any significant symptomatic recovery relative to controls.

Steroid Administration

Administration of steroids as a treatment modality for CTS has been a subject of debate. While one study showed that steroidal injection generated significant clinical enhancement in symptoms one month after the injection, another experiment showed no such difference beyond one month [21]. Although corticosteroid treatment is effective in ameliorating such symptoms as edema and inflammation, it is accompanied by side effects such as reduction of mechanical strength of the tendon, causing further degradation [22]. Some authors have reported that NSAID's, pyridoxine and diuretics are no longer efficacious in comparison to a placebo in relieving the signs of CTS [23].

Local Injection

A combination of local injection in the wrist and a local anesthetic into the carpal tunnel can be employed in CTS patients with mild to moderate symptoms. Recent reviews have studied the impact of local corticostreoid injections and demonstrated that this type of treatment lends a much greater recovery rate at one month compared to the placebo [22,23]. Local corticosteroid injection for carpal tunnel syndrome provides greater clinical improvement in symptoms at one month after injection compared to placebo. Significant symptom relief beyond one month has not been demonstrated. Also it has been proven that two or more local corticosteroid injections do not provide significant added clinical benefit compared to one injection [24]. Median nerve injury is the most serious complication and may present as shooting pain at the injection time along with other sensory distortion, motor weakness and muscle atrophy. Appropriate needle positioning is vital for preventing nerve injury. The patient should not be heavily sedated and should be encouraged to report any experience of numbness/paresthesia during the procedure immediately [25].

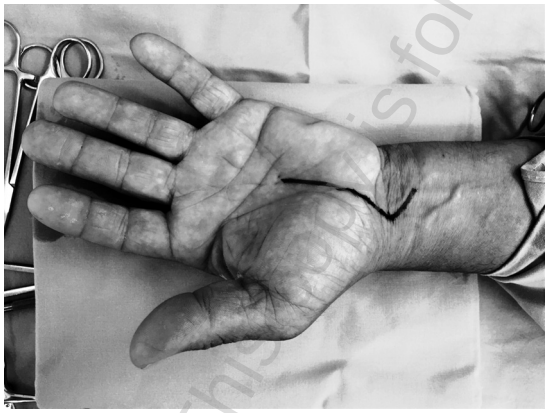
Splinting

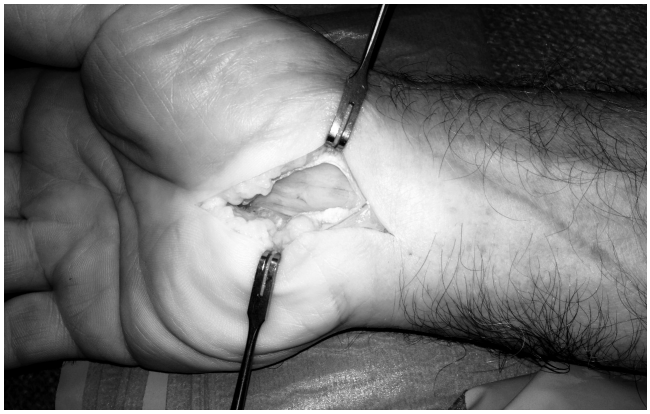
Wearing a splint at a neutral angle aids in decreasing the repetitive flexion and eases the swelling in the soft tissue and tenosynovitis. The basic premise for wrist splinting is the assumption that CTS symptoms worsen with activity and improve with rest. When applied within three months of onset of the disease, splinting has been proven to be an efficacious treatment option. Splinting provided symptomatic relief and improved sensory and motor nerve conduction velocities at long-term follow-up when the splints were worn almost every night [26,28].

SURGERY

Surgery for CTS involves carpal tunnel release (CTR), in which the transverse carpal ligament (TCL) is cut to create more space in the carpal tunnel and reduce the pressure (Fig 1). Long-term beneficial outcomes following CTR are seen in approximately 70–90% of the patients [3]. CTR is a suitable option for diabetic patients with CTS and peripheral neuropathy. In the most recent literature, surgery has been proven to be a better treatment strategy for CTS as compared to splinting and other conservative treatment options [29]. There are several kinds of CTR based on the surgical techniques used: conventional open carpal tunnel release (OCTR), mini-OCTR, and endoscopic carpal tunnel release (ECTR). The limited incision technique arose in the 1990's as a response to endoscopic surgical techniques. The purpose of a smaller incision is to improve the cosmetic result of the surgery while still allowing direct visualization of the relevant anatomy (Fig 2). With the minimal approach, the palmar fascia remains intact, decreasing the incidence of post-operative pain.

A

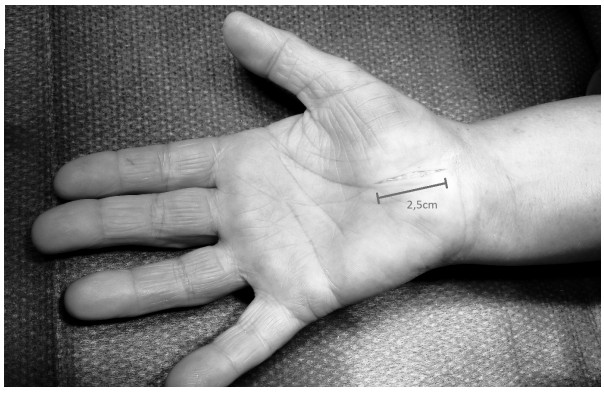


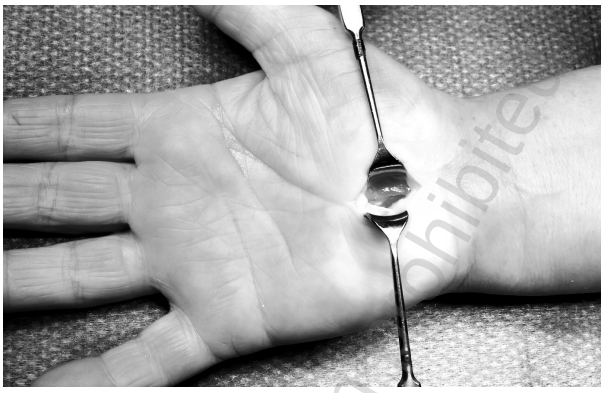


B

Fig. 1a,1b. Classic open carpal tunnel release surgery (CTR), in which the transverse carpal ligament is divided

A





B

Fig. 2a,2b. Minimal-incision open carpal tunnel decompression

Endoscopic Carpal Tunnel Release (ECTR) is conducted as either a single portal surgery [30] or a dual portal technique [31]. ECTR is a more useful technique in accomplishing decompression of the median nerve. However, its efficiency relative to the less invasive OCTR for recovery from CTS post surgery is still a matter of debate [29]. The advantage of ECTR over OCTR is that by partitioning the TCL from inside. The skin and muscle above are preserved, potentially reducing post-surgery morbidity, expediting recovery and return to work, and maintaining grip strength. The risk of any major injuries to nerves, vessels, or tendons was shown to be lower in an ECTR group (0.19%) relative to a OCTR group (0.49%) [29]. OCTR has been shown to cause complications such as hypertrophic scar, infection and scar tenderness, which is lesser in ECTR. ECTR also shows faster recovery in patients undergoing the surgery in the first 2 weeks, with faster relief from pain and faster improvement in functional activities. However, at 1 year, both ECTR and OCTR appear to be evenly efficient.

There is no strong evidence supporting the need for replacement of standard open carpal tunnel release by existing alternative surgical procedures for the treatment of carpal tunnel syndrome. The decision to apply endoscopic carpal tunnel release instead of open carpal tunnel release seems to be guided by the surgeon's and patient's preferences [27].

While infrequent, there are complications in both the open and endoscopic techniques [32,33]. The most common complication is an inadequate division of the transverse carpal ligament, which can be due to inappropriate exposure of the transverse carpal ligament or lack of surgeon experience [33]. This complication occurs in both approaches. Other complications include injuries to the recurrent motor and palmar cutaneous branches of the median nerve, laceration of the median and ulnar trunk, vascular injuries of the superficial palmar arch, painful scar formation, postoperative wound infection, and complex regional pain syndrome.

When comparing the complications of open versus endoscopic techniques, there is increased risk of nerve injury during endoscopic carpal tunnel release [34]. This can be due to limited exposure of the carpal ligament before ligation. Other complications occur at the same rate with the different techniques [35]. Studies have reported that the endoscopic technique had less occurrence of painful scar formation and an earlier return to work [36]. Both types of carpal tunnel releases had similar rates of reoperation [35].

CONCLUSION

Clinical messages:

1. Carpal Tunnel Syndrome is the most prevalent form of entrapment neuropathy, giving rise to increased pressure in the tunnel.
2. It is more common in females than in males, with average age of 40-60 years. Diabetic patients have been reported to be highly susceptible to CTS. Pregnancy and labor have also been associated with a high risk of CTS.
3. Pathophysiology of CTS involves several factors such as mechanical injury, nerve injury, ischemic injury, and involvement of small fibers, inflammation, biochemical changes, which act in a concerted fashion.
4. Certain diseases can affect the synovium and can result in secondary CTS.
5. In early stages of CTS, patients may experience numbness in the fingers, whereas in later stages, nocturnal pain may be more severe than daytime pain.
6. Although provocative tests have been widely used to detect CTS, their utilization and diagnostic va-

lue are questionable. They need to be used in conjunction with the patient's clinical history and nerve conduction analysis.
7. Although, NCS provides valuable information about the median nerve, the use of more transparent methods such as MRI or ultrasound could be helpful.
8. The use of conservative treatment of CTS, such as steroid injections and splinting, although effective, is questionable, considering the adverse effects.
9. In comparison to the conservative treatment, surgery has been proven to be more efficacious.
10. There is no strong evidence supporting the need for replacement of standard open carpal tunnel release by existing alternative surgical procedures.

ACKNOWLEDGMENTS

Grant KEGA 071UK-4/2016

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Liczba słów/Word count: 4512 **Tabele/Tables:** 0 **Ryciny/Figures:** 2 **Piśmiennictwo/References:** 36

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Otrzymano / Received *14.08.2016 r.*
Zaakceptowano / Accepted *30.09.2016 r.*