CARPAL TUNNEL SYNDROME: A NARRATIVE REVIEW

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DOI: - 10.48047/ecb/2023.12.si5a.0538

INTRODUCTION

Carpal tunnel syndrome (CTS) is a popular medical condition which is one of the most common forms of median nerve compression. Any disorder that reduces the cross-sectional area of carpal tunnel or increase the volume in the tunnel may result rise in pressure in carpal canal and compress the structures passing through the canal. The median nerve is squeezed or compressed as it travels through the wrist, causing CTS[1]. The American Academy of Orthopedic Surgeons (AAOS) describes CTS as "a symptomatic median nerve compression at the wrist level[2]". Most cases of carpal tunnel syndrome are idiopathic[3]. The prevalence of CTS is between 4% to 5% worldwide, and patients between their ages of 40 to 60 years being the most easily subjected group[1]. Additionally, women are susceptible than men to experience CTS. The symptoms of carpal tunnel syndrome have been estimated to be bilateral up to 73% of cases, although they may not manifest concurrently[2]. The distribution of median nerve is thumb, index, middle finger, and the radial side of the ring finger that experiences pain, numbness, and tingling sensations. Grip strength and hand function are also affected. Clinical classification of symptoms severity includes mild, moderate, and severe[4]. Obesity, Prolonged wrist activity, pregnancy, genetics, and rheumatoid arthritis are potential causes of CTS[1].

CAUSES

LOCAL	REGIONAL	SYSTEMIC
1.Inflammatory: e.g. Tenosynovitis, Histoplasma fungal infection, Hypertrophic synovium **2. Trauma:** e.g. Colle's fracture, Dislocation of one of the carpal bones **3**. **Tumors** e.g. Haemangioma, Cyst, Ganglion, Lipoma, Neuroma etc. **4.Anatomical anomalies:** e.g., Thickened transverse carpal ligament, Bony abnormalities, Abnormal muscle bellies, Persistent median artery etc.	**1**.Osteoarthritis **2.** Rheumatoid arthritis **3**.Amyloids **4**.Gout	**1.** Diabetes **2**. Obesity **3**. Hypothyroidism **4**. Pregnancy **5**. Menopause **6**. SLE **7**.Scleroderma **8**.Dermatomyositis **9**. Renal failure **10**. Hemodialysis **11**. Acromegaly **12.** Myeloma **13**. Sarcoidosis **14.** Leukemia **15**. Alcoholism

CLINICAL PRESENTATION

Classic symptom of Carpal Tunnel Syndrome is pain in the hand, unpleasant tingling, or numbness in the distribution of the median nerve (thumb, index, middle finger, and the radial side of the ring finger), decrease in grip strength and hand function. Patients sometimes describe a remarkable phenomenon known as "flick sign" in which flicking and shaking their wrist reduces symptoms[5]. Symptoms are typically worst at night, and clumsiness is described during the daytime activities requiring restriction of wrist flexion. Clinical history and symptoms included any kind of paresthesia or pain in the whole or part of the palm innervated by the median nerve, mainly at night or on waking up. These symptoms may be raised on specific body postures or repeatedly forcing of the fingers and wrist, and the discomfort may radiate proximally. Changing posture, rubbing, or shaking (flick sign) the hand may mitigate these symptoms. Other symptoms may include weakness or loss of manual dexterity[6].

Additionally, many patients describe symptoms that are not related to the median nerve distribution. Some patients may present with atypical signs of CTS, such as "writer's cramp" or fatigue, cold sensitivity in the fingers (presumably reflecting the median nerve's supply of sympathetic fibres to part of the forearm and hand), or numbness in the third finger only[7].When performing nerve conduction testing, patients may occasionally appear with no symptoms but thenar atrophy and denervation can be visible[6]. In some cases, patients only have symptoms after strenuous activity, usually get benefit from conservative therapy including changing their work activities, this condition is known as "Dynamic Carpal Tunnel Syndrome[7]".

PATHOMECHANICS

The carpal tunnel, bounded by the transverse carpal ligament and defined as the concave arch of the carpus, where the median nerve travels with the flexor tendons[8]. The narrowest region is located about 2.0 to 2.5 cm distal to the origin of the canal and corresponds to the region where constriction deformity of the median nerve is reported[9].

Normally, the median nerve enters the carpal tunnel slight radially to the midline. The thenar branch can separate within carpal tunnel, however it usually separates from the median nerve distal to the transverse carpal ligament (TCL), Sensory branches of median nerve supply the three radial digits and the radial half fourth digit[8].

Persistent compression will lead to fibrosis, which will obstruct nerve gliding. Damaged or scarred mesoneurium will cause the nerve to adhere to adjacent tissues. As the nerve tries to move from the fixed location and it may be stretched during movement[10].

The radial and ulnar arteries, which are close to the flexor retinaculum, give blood to the median nerve. These blood arteries direct the median nerves companion nutritional branches distally via carpal tunnel. The perineurium's inner cells and the endothelial cells of the endoneural micro vessels make up the blood-nerve barrier. Elevated pressure will cause a breach in the blood-nerve barrier within the vasculature, which leads to an accumulation of proteins and inflammatory cells[10]. Increased permeability, results rise in endoneurial fluid pressure and development of an intra-fascicular edema, this may cause a miniature closed compartment syndrome[11]. The vascular contribution to inflammation and delayed axonal transport will vary between patients but may be particularly relevant in patients with other vascular problems or prolonged exposure to static loading[12]. Changes in the microvascular structure of the nerve, aggravated by metabolic problems may result in reduction in the endoneurial blood flow and oxygen tension which may increase susceptibility of median nerve compression, particularly in diabetic patients[13]. Furthermore, they exhibit pericyte loss thickening of the base membrane, endothelial hypertrophy, and hyperplasia[14].

The development of CTS may also be caused by hypertrophy of the synovial tissue in the flexor tendons which increase the pressure inside the carpal tunnel[15]. Tenosynovitis has been identified in several histological and biochemical studies as a closely associated risk factor for the onset of idiopathic CTS[16]. Increase in fibroblast density, collagen fibre size, vascular proliferation, and type III collagen in the synovial connective tissue develop in response towards this injury[17].

ASSESSMENT

HISTORY

Obtaining a reliable history is the key of making a diagnosis of CTS . This includes description of the Symptoms, Intensity, Frequency, Aggravating factors (particularly posture and activity), and Relieving factors[18,19].

OBSERVATION

One must observe the atrophy of thenar eminence. A superficial muscle found on the lateral aspect of the thenar mass, the abductor pollicis brevis is innervated by the median nerve. Elevated carpal tunnel pressure and acute inflammation have traditionally been implicated in development of carpal tunnel syndrome[20]. This can be evaluated by comparing the profiles of both thenar eminences. Atrophy of thenar muscle can be observed in moderate to severe CTS[21]. A finding of thenar atrophy with symptoms of CTS is sufficient to confirm the presence of moderate to severe CTS, while its absence does not exclude the presence of CTS[10].

PROVOCATIVE TESTING

Using a provocative manoeuvre to elicit the symptoms of CTS is a routine component of a physical therapy clinical examination. One form of provocation is positional[10]. All are based on stressing an already compromised median nerve in order to exacerbate the symptoms of numbness, pain, and paraesthesia. The wrist-flexion test (Phalen's test), the median nerve percussion test (Tinel's sign), and the median nerve compression test are the three provocative tests that are used most frequently. The tourniquet test also called as Provocative test, is seldom used because of its high false-positive rate[22,23].

Phalen's Test- Traditionally, it is conducted by holding the forearms straight up, while the elbows lying on the exam table. The wrists is allowed to drop into flexion with the assistance of gravity for 30 to 60 seconds (Fig. 1.A). Numbness or tingling in the median nerve distribution is considered a positive test for median nerve. In this position, it is believed that the median nerve is compressed between the proximal edge of the transverse carpal ligament, the underlying flexor tendons and radius[24]. The carpal canal is more constricted and under more pressure with wrist extension than with wrist flexion. This position can also exacerbate CTS symptoms and forms the basis of another provocative test, the reverse Phalen's manoeuvrer[25]. The sensitivity has ranged from as low as 10% to as high as 88% , whereas the specificity has ranged from 47% to 100% [26].

Fig 1.A. Phalen's Test

Durkan Test-

An increase in pressure applied directly to the median nerve is the premise for the carpal compression test, credited to Durkan, who described it in 1991[10]. To perform this test, the examiner applies gentle sustained pressure with his or her thumb over the carpal canal. Paresthesia in the median nerve distribution, which disappears after the pressure is relieved, within 30 seconds is considered a positive test[21]. Some authors have reported this to be one of the most valuable provocative tests (64% sensitivity and 83% specificity).

Nerve percussion test-

The median nerve percussion test, also known as Tinel's sign, is carried out by lightly tapping the median nerve at the wrist from proximal to distal. If the patient feels tingling in the distribution of median nerve, a positive response is noted .The examiner must perform this test gently because the use of too much force can produce paresthesia in a normal, healthy median nerve. Furthermore, the literature reports a wide range of sensitivity and specificity. The sensitivity ranges from 26% to 79% and the specificity ranges from 40% to 100%[26].

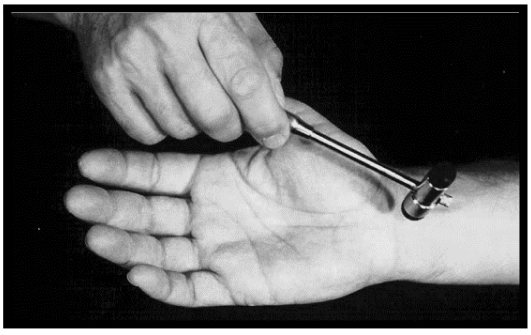


Fig 1. B. Tinel's Sign/ Nerve Percussion Test

SENSORY EVALUATION

The majority of CTS symptoms are sensory, thus objective sensory testing should be appropriate in both diagnosing the condition and evaluating response to intervention. Experimental studies developed on median nerve compression have shown that vibration and light touch thresholds are impacted early in nerve compression but altered 2-point discrimination is a late finding[23].

MOTOR EVALUATION

Thenar muscle strength is evaluated for the presence of thenar muscle atrophy in patients with carpal tunnel syndrome (Fig 3). The abductor pollicis brevis muscle strength is assessed by evaluating the patient's ability to abduct the thumb away from the palm. Typically, this is conducted using a graded manual muscle test (0, nothing; 1, trace; 2, full-range gravity-eliminated movement; 3, full-range against-gravity movement; 4, some resistance; 5, normal)[27].

Fig 3. Thenar Muscle Atrophy

NERVE CONDUCTION STUDIES

The 2016 American Academy of Orthopedic Surgeon clinical guidelines states that the electrodiagnostic testing (EDX) could be used in diagnosis of carpal tunnel syndrome[4]. EDX measures sensory and motor nerve conduction speed, conduction consistency along the nerve and the strength of action potential[28]. The sensory component of the median nerve is affected much earlier than the motor component and in early stages of CTS. The median nerve is stimulated 13 cm proximal to the recording electrodes after the electrode is placed near the base of ring finger to detect sensory nerve conduction delay. Surface electrodes are used to evaluate the velocity of the transmission of the motor nerve from elbow to wrist[6]. Median nerve conduction studies are the gold standard diagnostic tests with sensitivity between 49% to 84% and specificity of 95% to 99% [21].

OUTCOME MEASURES

1.Boston carpal tunnel questionnaire
2.Brigham & Women's carpal tunnel questionnaire

MANAGEMENT

There are two types of treatment for CTS: Surgical and Non-surgical. The level of the symptoms determines the treatment that is most appropriate for carpal tunnel syndrome patients. Mild CTS patients are advised to use nonsurgical therapies whereas surgery is advised for patients who have moderate to severe symptoms[3].

NON-SURGICAL TREATMENT

Non-surgical or "Conservative treatment", which include a variety of options like Splinting, Corticosteroid injections, Non-steroids anti-inflammatory drugs, B6 vitamin, Diuretics, Ultrasound therapy, Ergonomic positioning, Orthosis, Manual therapy intervention, lidocaine patches and Acupuncture are hypothesized to reduce carpal tunnel pressure, improve circulation and venous outflow from nerve, reduce presence of inflammatory mediator, increase tunnel dimension to restore nerve conduction[3].

Splinting

Splinting has become the first line therapeutic choice for CTS among non-operative treatment options. Splints are typically prescribed for night-time use but may also be utilized during daytime hours based on patient work and activity demands[29]. By keeping the wrist in a neutral position, splints decrease the extremes of wrist flexion and extension, which have been shown to increase pressure within the carpal tunnel .The majority of splints fails to extend beyond the distal palmar crease, but some do so on aim to maintain extended position of metacarpophalangeal joints. This improves tunnels dimension and reduces compression by preventing the lumbrical muscles from retracting proximally, theoretically relieving strain on tendons and nerve movement through tunnel[30] (Fig.4) .

Fig 4. Splints

Steroid Injections

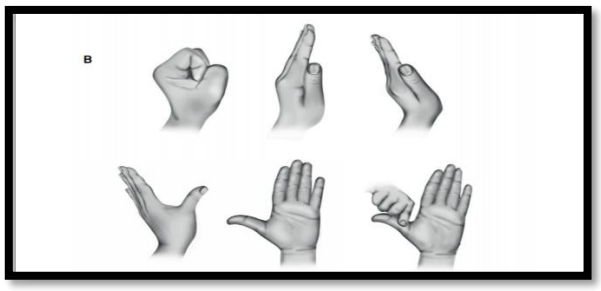
Despite being more invasive than other non-operative techniques, Corticosteroid injections (CSI) are frequently used to treat CTS. The purpose behind CSI is to relieve pressure in the carpal tunnel by reducing the inflammation of the tenosynovium that runs through tunnel[29]. Complication rates from corticosteroid injections in the carpal tunnel are rare, with local injection site pain being the most common in roughly 13% of patients[2].

Hand Therapy

Hand therapy aims to enhance nerve and tendon excursion, improve axonal transport and nerve conduction by easing the gliding of nerves and tendons within the carpal tunnel[31]. Several authors claim that gliding exercises reduce symptoms by preventing, or stretching adhesions between the tendons and median nerve, reducing tenosynovial edema, enhancing venous return and therefore lowering pressure within carpal tunnel[32,33]. Basically, the exercises involve a sequence of finger and wrist movements for tendon and Median nerve gliding[34] (Figures 5 A and B).

Fig 5.A Tendon Gliding Exercise

5 .B Nerve Gliding Exercise



PHYSICAL FACTORS INVOLVED IN THE TREATMENT OF CTS-

The Following Physical Factors are usually integrated in therapeutic courses-

1. Considering on the disease stage, the extent of symptoms, the selectivity of the treated tissues according to their water percentage and the patient's individual tolerance, either exogenous heat by means of paraffin, or endogenous heat by ultra-high frequency therapy (UHFT) is applied. Paraffin wax is applied for 15-20 minutes at a temperature of about 50° C. UHFT is applied with minimal to moderate heat sensation. About 2-3 cm is the distance from patient's skin to the electrodes. 8-10 minutes are required to complete the procedure. Thermal procedures are used for analgesia, reduction of

paresthesia, stiffness, and improvement of nervous conduction and atrophy[2].

2. Laser therapy is used to alleviate symptoms like pain and paraesthesia. One of the first procedure was the use of laser therapy for the treatment of CTS . The use of both low- and high-intensity laser beams using the corresponding dose regimen is appropriate[32].
3. Using the low-frequency ultrasound with intensity of 0.8 to 1.0 W/cm2 is beneficial for deeper impact. The duration of the procedure is six minutes[2].
4. Iontophoresis is a technique for combining potassium iodide's fibrinolytic effect and analgesic effects. The hydrophile pillow is surrounded by the negative electrode and the 5% solution of potassium iodide. To prevent burning and pain sensation, the intensity of the current is dosed subjectively (up to 10 mA). The procedure requires 20 minutes[2].
5. Another method of treating CTS pain is acupuncture. When properly administered, its anaesthetic effect is comparable to that of topical corticosteroid administration[33].
6. Shockwave therapy (SWT) is one of the non-invasive and evidence-based physical approach to treat CTS. It is locally applied, pneumatically generated shock waves with low frequency (5-20 Hz) and pressure of 1-5 bar. The therapeutic course consists of 1-2 treatments per week of 4-6 procedures. When the CTS is related to occupational overload, it is more effective in the young and early stages of the condition[2].

SURGICAL TREATMENT

Surgical treatment of CTS consists of the division of the transverse carpal ligament which reduces the pressure on the median nerve by increasing the space in the carpal tunnel[6]. Open release and Endoscopic release are two different types of surgical techniques used to treat CTS. The open carpal tunnel release (OCTR) surgery has been modified by the application of epineurotomy and new incision techniques as the mini-open release[34]. The mini-open carpal tunnel release is a relatively recent procedure that involves making a 1.5-3.0 cm longitudinal incision parallel to the ring fingers radial border[35].

Surgical intervention includes desensitization, edema management, wound care, education, immobilization, nerve gliding, pain management, sensory retraining, strengthening, and various combination of these intervention[36].

POST OPERATIVE REHABILITATION

Some patients encounter postoperative complications such as: infections, neuromas, scar dehiscence, scar hypersensibility, keloids, or even reflex sympathetic dystrophy. For this reason, therapeutic protocol for the treatment of these postoperative complications, as well as, for prevention of their onset have been elaborated. Immediately following surgery, the patient should begin a rehabilitation programme. The duration and type of rehabilitation treatment depends on the patient's physiologic recovery and the amount of hand and wrist strength[37].

The physical therapy treatment goals in the first 2 weeks post-surgery are:

- Edema control
- Sensory evaluation
- Maintain complete finger range of motion
- Prevention of Tendon adhesions
- Intermittent wrist immobilization and protection

Splints-

The patient's wrist is immobilized in a neutral position using a dorsal resting splint. It is crucial to avoid overstretching the wrist with flexion and extension movements during the first 2 weeks following surgery[38]. Using the lightweight thin thermoplastic material, a handmade dorsal resting splint that puts the wrist at 0 ° should be provided if the patient is unable to keep their wrist in a neutral position on their own. The patient is instructed to wear the splint all the time for the first 14 days and taking it off only for medication changes and very carefully supervised gentle wrist exercises should be done for four times daily[39]. After 15 days, the patient is instructed to take the splint off during the day and to wear it exclusively at night for the next 7 days or when engaging in moderately demanding repetitive everyday tasks. Additionally they are also instructed to avoid extreme wrist flexion and heavy lifting during this time.

Fig 6. Dorsal Resting Splint

Recovery of finger range of motion-

The patient is taught to open and close the hand ten times each hour. Each finger should move individually, and in coordination. Different finger gliding exercises are initiated in order to facilitate

isolated excursion of each finger's flexor tendons (flexor superficialis and flexor profundus), which pass through the carpal tunnel. The patient should produce a hook fist with the metacarpophalangeal joints extended but the proximal and distal interphalangeal joints flexed. The patient is instructed to flex the metacarpophalangeal joints as well as the proximal inter phalanges in order to achieve maximum flexor superficialis excursion, but to extend the distal inter phalanges. A closed fist is done to obtain maximum excursion of the flexor profundus and to be integrated into these exercises by flexing its metacarpophalangeal joint while extending its inter phalanx and vice versa. These exercises should be performed in set of 5 repetitions for minimum10 times a day[40]

Retrograde Massage and Increasing Venous Return:

Patient can be advised to perform upper extremity exercises ten times an hour, which involve raising the entire arm above the level of the heart. When the patient has a moderate-to-severe amount of edema, the therapy should start with a targeted lymph drainage massage[40]. Next the fingers, wrist, and forearm should be wrapped in a compression glove stocking, COBAN, or String Wrap to reduce the local edema. Ice application is a technique that is always effective in reducing severe edema and the patient should be advised to apply the ice for no longer than 10 min at a time[42].

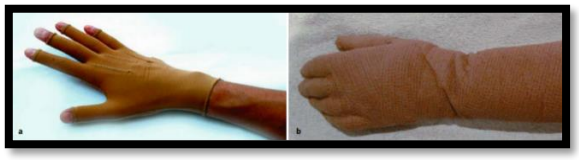


Fig -7. Compression Glove Stocking

Shoulder exercises:

The patient can retain complete shoulder mobility and avoid the development of capsular adhesions by moving the shoulder across all of its planes of motion. At least three times a day, for ten repetitions each should be spent performing all the shoulder exercises[42].

The goals of physical therapy in the third and fourth week from the time of surgery are:

- Complete finger range of motion
- Complete wrist range of motion
- Prevent scar adhesion in soft tissue
- Complete flexor tendon gliding freedom

Scar Treatment; Remodelling, and Desensibilization:

A desensibilization techniques are used to reduce scar hyper sensibility symptoms and gradually increase the patient's tactile tolerance to the area manual vibrator can be used on the scar[39]. It consists of 5 –10 min exercises 3–4 times a day. A scar suction pump, which creates a negative pressure on the scar site and its borders, can be used in the attempt to detach the epidermis from the underlying dermis in order to break up superficial scar adhesions[40, 42].

Fig- 8.A. Manual Vibrator

Fig-8.B. Scar Suction Pump

Wrist Range of Motion Exercises

The patient is recommended to perform range of motion exercises three times a day, alternating between passive and active movements. The exercises consist of having the patient arrive to their maximum range of motion in all the wrist planes of movement and slowly applying a constant but light pressure on the wrist to slowly stretch the scar without overloading the articulation or nerve[43].

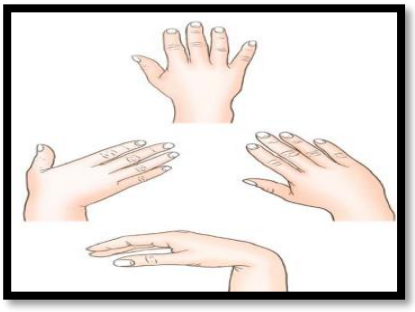


Fig.9. Wrist Range of Motion

Transcutaneous Electric Stimulation (T.E.N.S.) or Microcurrent Stimulation:
The use of long duration and low frequency pulse can provoke a release of local natural opioids, (endorphin), and therefore, diminish pain perception. To have an analgesic effect, T.E.N.S. should be used at least 20 min every hour during the first few days, and then reduced to 20 min every other hour[44].

Median Nerve Gliding Exercises:
These exercises have the goal of facilitating the median nerve to glide through its tunnel and adjacent to the thenar eminence. When the wrist is in extension, the thumb can be passively stretched in order to prevent adhesions from forming between the skin and the median nerve's palmar cutaneous sensitive branch. These exercises are done three times a day and each time for ten repetitions[45].

The physical therapy goals in the fifth week are:
- Gradual recovery of hand and wrist strength
- Rehabilitation of hand and wrist endurance

Strengthening Exercises:
A personalized hand strength recovery program should be set up for each patient according to their Profession, Hand dominance, and Habits. The patient can begin by manipulating Thera-Putty of low resistance and gradually begin low-to-high level resistance exercises within a 1-month time frame (fig.10). In order to get good postoperative results for the hand and wrist one should keep in mind that lifting more than 5 kg for the first 2 months following surgery is not recommended[46]. Hand and wrist exercises can be initiated by performing the isometric exercises and then moving onto isotonic and isokinetic exercises[47].

Figure.10. Strengthening Exercise

The goals six weeks after surgery are:
- Re-cover normal functional use of the entire upper extremity including sensibility, strength, resistance, and dexterity.

Ergonomic advices-
One month following surgery, the patient can begin a work hardening program. The patient is instructed to utilize their hand as much as possible while performing daily tasks to avoid overloading the other articulation. After surgery, patient can gradually start lifting weights against resistance but not over 5 kg for at least 2 months. Only after 2 months can they begin to load and strengthen their involved wrist and upper extremity[48].

REFERENCE

1. Zaralieva A, Georgiev GP, Karabinov V, Iliev A, Aleksiev A. Physical therapy and rehabilitation approaches in patients with carpal tunnel syndrome. Cureus. 2020 Mar 3;12(3).
2. Ashworth N. Carpal tunnel. BMJ. 2014; 349: g6437.
3. Ghasemi-Rad M, Nosair E, Vegh A, Mohammadi A, Akkad A, Lesha E, Mohammadi MH, Sayed D, Davarian A, Maleki-Miyandoab T, Hasan A. A handy review of carpal tunnel syndrome: From anatomy to diagnosis and treatment. World journal of radiology. 2014 Jun 28;6(6):284.
4. Burton C, Chesterton LS, Davenport G. Diagnosing and managing carpal tunnel syndrome in primary care. British Journal of General Practice. 2014 May 1;64(622):262-3.
5. Ibrahim I, Khan WS, Goddard N, Smitham P. Suppl 1: carpal tunnel syndrome: a review of the recent literature. The open orthopaedics journal. 2012;6:69.
6. De Krom MC, De Krom CJ, Spaans F. Carpal tunnel syndrome: diagnosis, treatment, prevention, and its relevance to dentistry. Nederlands tijdschrift voor tandheelkunde. 2009 Feb 1;116(2):97-101.
7. Somaiah A, Roy AJ. Carpal tunnel syndrome. Ulster Med J. 2008;77(1):6-17.
8. Rotman MB, Donovan JP. Practical anatomy of the carpal tunnel. Hand clinics. 2002 May 1;18(2):219-30.
9. Nigro RO. Anatomy of the flexor retinaculum of the wrist and the flexor carpi radialis tunnel. Hand clinics. 2001 Feb 1;17(1):61-4.
10. Mac Dermid JC, Doherty T. Clinical and electrodiagnostic testing of carpal tunnel syndrome: a narrative review. Journal of Orthopaedic & Sports Physical Therapy. 2004 Oct;34(10):565-88.
11. Lundborg G. Intraneural microcirculation. Orthopedic Clinics of North America. 1988 Jan 1;19(1):1-2.
12. Alfonso C, Jann S, Massa R, Torreggiani A. Diagnosis, treatment and follow-up of the carpal tunnel syndrome: a review. Neurological Sciences. 2010 Jun;31(3):243-52.

13. Dahlin LB. Aspects on pathophysiology of nerve entrapments and nerve compression injuries. Neurosurgery Clinics of North America. 1991 Jan 1;2(1):21-9.
14. Samii A, Unger J, Lange W. Vascular endothelial growth factor expression in peripheral nerves and dorsal root ganglia in diabetic neuropathy in rats. Neuroscience letters. 1999 Mar 12;262(3):159-62.
15. Aboonq MS. Pathophysiology of carpal tunnel syndrome. Neurosciences Journal. 2015 Jan 1;20(1):04-9.
16. Phalen GS. The Carpal-Tunnel Syndrome: seventeen years'experience in diagnosis and treatment of six hundred fifty-four hands. Jbjs. 1966 mar 1;48(2):211-28.
17. Sud V, Tucci MA, Freeland AE, Smith WT, Grinspun K. Absorptive properties of synovium harvested from the carpal tunnel. Microsurgery: Official Journal of the International Microsurgical Society and the European Federation of Societies for Microsurgery. 2002;22(7):316-9.
18. Carmeliet P, Ferreira V, Breier G, Pollefeyt S, Kieckens L, Gertsenstein M, Fahrig M, Vandenhoeck A, Harpal K, Eberhardt C, Declercq C. Abnormal blood vessel development and lethality in embryos lacking a single VEGF allele. Nature. 1996 Apr;380(6573):435-9.
19. Ettema AM, Amadio PC, Zhao C, Wold LE, An KN. A histological and immune histochemical study of the subsynovial connective tissue in idiopathic carpal tunnel syndrome. JBJS. 2004 Jul 1;86(7):1458-66.
20. Bland JD. The value of the history in the diagnosis of carpal tunnel syndrome. The Journal of Hand Surgery: British & European Volume. 2000 Jan 1;25(5):445-50.
21. Katz JN, Larson MG, Sabra A, Krarup C, Stirrat CR, Sethi R, Eaton HM, Fossel AH, Liang MH. The carpal tunnel syndrome: diagnostic utility of the history and physical examination findings. Annals of Internal Medicine. 1990 Mar 1;112(5):321-7.
22. Palumbo CF, Szabo RM. Examination of patients for carpal tunnel syndrome: Sensibility, provocative, and motor testing. Hand clinics. 2002 May 1;18(2):269-77.
23. Gilliatt RW, Wilson TG. A pneumatic-tourniquet test in the carpal-tunnel syndrome. The Lancet. 1953 Sep 19;262(6786):595-7.
24. Gellman HA, Gelberman RH, Tan AM, Botte MJ. Carpal tunnel syndrome. An evaluation of the provocative diagnostic tests. The Journal of Bone and Joint surgery. American Volume. 1986 Jun 1;68(5):735-7
25. Phalen GS. The Carpal-tunnel Syndrome: Clinical Evaluation of 598 Hands. Clinical Orthopaedics and Related Research (1976-2007). 1972 Mar 1;83:29-40.
26. Werner RA, Bir C, Armstrong TJ. Reverse Phalen's maneuver as an aid in diagnosing carpal tunnel syndrome. Archives of physical medicine and rehabilitation. 1994 Jul 1;75(7):783-6.
27. Williams TM, Mackinnon SE, Novak CB, McCabe S, Kelly L. Verification of the pressure provocative test in carpal tunnel syndrome. Annals of plastic surgery. 1992 Jul 1;29(1):8-11.
28. Muscles testing and function with posture and pain; Florence Peterson Kendall; et al; 5th edition; 2005; 262.
29. Skirven, T.M., Osterman, A. L., Fedorczyk, J.,& Amadio, P.C. rehabilitation of the hand and upper extremity. 2-volume set (6th ed.) Mosby.2011.
30. Weiss AP, Akelman E. Carpal tunnel syndrome: a review. Rhode Island Medicine. 1992 Jun 1;75(6):303-6.
31. Ostergaard PJ, Meyer MA, Earp BE. Non-operative treatment of carpal tunnel syndrome. Current reviews in musculoskeletal medicine. 2020 Apr;13(2):141-7.
32. Weiss ND, Gordon L, Bloom T, So Y, Rempel DM. Position of the wrist associated with the lowest carpal-tunnel pressure: implications for splint design. The Journal of bone and joint surgery. American volume. 1995 Nov 1;77(11):1695-9.
33. Kim SD. Efficacy of tendon and nerve gliding exercises for carpal tunnel syndrome: a systematic review of randomized controlled trials. Journal of physical therapy science. 2015;27(8):2645-8.
34. Martins RS, Siqueira MG. Conservative therapeutic management of carpal tunnel syndrome. Arquivos de neuro-psiquiatria. 2017;75:819-24.
35. Yang CP, Hsieh CL, Wang NH, Li TC, Hwang KL, Yu SC, Chang MH. Acupuncture in patients with carpal tunnel syndrome: a randomized controlled trial. The Clinical journal of pain. 2009 May 1;25(4):327-33.
36. Akalin E, El Ö, Peker Ö, Senocak Ö, Tamci S, Gülbahar S, Çakmur R, Öncel S. Treatment of carpal tunnel syndrome with nerve and tendon gliding exercises. American journal of physical medicine & rehabilitation. 2002 Feb 1;81(2):108-13.
37. Mintalucci DJ, Leinberry CF. Open versus endoscopic carpal tunnel release. Orthopedic Clinics. 2012 Oct 1;43(4):431-7.

38. Charles Giangarra, Robert Manske. Clinical orthopaedic rehabilitation a team approach, fourth edition.Elsevier Mosby 2018.
39. Keilani MY, Crevenna R, Fialka-Moser V. Postoperative Rehabilitation von Patienten mit Karpaltunnelsyndrom [Postoperative rehabilitation of patients with carpal tunnel syndrome]. Wien Med Wochenschr. 2002;152 (17-18):479-80. German. doi: 10.1046/j.1563-258x.2002.01137.x. PMID: 12385074.
40. Nazarieh, Mahshid & Hakakzadeh, Azadeh & Ghannadi, Shima & Maleklou, Faezeh & Tavakol, Zahra & Alizadeh, Zahra. (2020). Non-Surgical Management and Post-Surgical Rehabilitation of Carpal Tunnel Syndrome: An Algorithmic Approach and Practical Guideline. Asian Journal of Sports Medicine. In Press. 10.5812/asjsm.102631.
41. Multanen J, Uimonen MM, Repo JP, Häkkinen A, Ylinen J. Use of conservative therapy before and after surgery for carpal tunnel syndrome. BMC Musculoskelet Disord. 2021 May 26;22(1):484. doi: 10.1186/s12891-021-04378-3. PMID: 34039330; PMCID: PMC8157685.
42. Sawan, Salah A., Sayed Mahmoud, Hayam M., and Hussien, Maha M. 'Effect of Different Physical Therapy Modalities on Post-operative Recovery Following Transverse Carpal Ligament Release: A Randomized Controlled Trial'. 1 Jan. 2013: 75 – 82
43. Cantero-Téllez R, Garcia-Orza S, Cuadros-Romero (2016) Physiotherapy and Occupational Therapy Evidence-based Intervention after Carpal Tunnel Release: Literature Review. J Nov Physiother 6:296. doi:10.4172/2165-7025.1000296
44. Koca I, Boyaci A, Tutoglu A, Ucar M, Kocaturk O. Assessment of the effectiveness of interferential current therapy and TENS in the management of carpal tunnel syndrome: a randomized controlled study. Rheumatol Int. 2014 Dec;34(12):1639-45. doi: 10.1007/s00296-014-3005-3. Epub 2014 Apr 12. PMID: 24728028.
45. Tamaru Y, Yanagawa A, Matsugi A. Sensory Nerve Conduction Velocity Predicts Improvement of Hand Function with Nerve Gliding Exercise Following Carpal Tunnel Release Surgery. J Clin Med. 2021 Sep 13;10(18):4121. doi: 10.3390/jcm10184121. PMID: 34575232; PMCID: PMC8470096.
46. Yoo WG. Effect of the release exercise and exercise position in a patient with carpal tunnel syndrome. J Phys Ther Sci. 2015 Oct;27(10):3345-6. doi: 10.1589/jpts.27.3345. Epub 2015 Oct 30. PMID: 26644707; PMCID: PMC4668198.
47. Peter A. Nathan, Kenneth D. Meadows, Richard C. Keniston, Rehabilitation of carpal tunnel surgery patients using a short surgical incision and an early program of physical therapy, The Journal of Hand Surgery, Volume 18, Issue 6,1993, Pages 1044-1050, ISSN 0363-5023, https://doi.org/10.1016/0363-5023(93)90401-N.
48. O'Connor D, Page MJ, Marshall SC, Massy-Westropp N. Ergonomic positioning or equipment for treating carpal tunnel syndrome. Cochrane Database Syst Rev. 2012 Jan 18;1(1):CD009600. doi: 10.1002/14651858.CD009600. PMID: 22259003; PMCID: PMC6486220.
49. Riccardo Luchetti, Peter Amadio. Carpal Tunnel Syndrome. Springer Berlin, Heidel berg. February 2010.
50. Kisner Carolyn and lynn Allen Colby. Therapeutic Exercise: Foundations and techniques. 6th ed. Davis.2012