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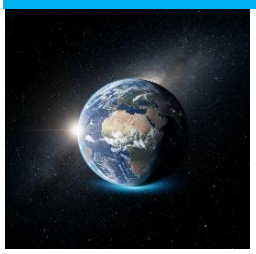

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Management of Carpal Tunnel Syndrome: Surgical vs Conservative approach

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Abstract

Introduction and Purpose: Carpal Tunnel Syndrome (CTS) is the most common peripheral neuropathy, causing significant functional impairment and socioeconomic burden. Relative effectiveness of conservative versus surgical interventions remains debated due to heterogeneity in study designs. This study aims to systematically review randomized controlled trials (RCTs) published from 2009 onwards to evaluate the comparative efficacy and durability of these treatment strategies in adult patients.

Material and Method: A systematic search was performed in PubMed, Scopus, Web of Science, and the Cochrane Library for RCTs published between 2009 and 2022. The review included adults with clinically or electrophysiologically confirmed CTS. Analyzed interventions included conservative treatments, such as splinting, corticosteroid injections, perineural dextrose, platelet-rich plasma (PRP), manual therapy and surgical release techniques. Primary outcomes extracted included symptom severity and functional status (BCTQ), pain intensity, and neurophysiological parameters.

Results: Conservative therapies, particularly corticosteroids and manual therapy, demonstrate significant short-term (1–3 months) symptom relief often comparable to surgery. Perineural dextrose and PRP show superior mid-term efficacy compared to steroids. Surgical decompression provides superior long-term durability (>6 months) with significantly lower recurrence rates and a reduced need for subsequent interventions.

Conclusions: Conservative management serves as an effective first-line option for mild-to-moderate CTS, providing fast relief. Emerging regenerative injections offer better durability than traditional steroids. Nevertheless, surgical release remains the definitive treatment for

ensuring long-term remission, particularly in severe cases. Therapy should be individualized, prioritizing non-invasive methods initially while reserving surgery for lasting anatomical correction.

Key words: carpal tunnel syndrome (CTS), surgical management, surgical approach, conservative treatment, conservative therapy, comparison, nerve hydrodissection, platelet-rich plasma, corticosteroid injection, manual therapy

1. Introduction

Carpal Tunnel Syndrome (CTS) is regarded as the most frequent peripheral canalicular nerve entrapment disorder of the upper extremities, accounting for approximately 90% of all nerve compression syndromes. It is defined as an entrapment neuropathy caused by compression of the median nerve inside the restricted area of the carpal tunnel at the wrist [1,2,3]. Neurological deficiency distal to the lesion is the effect of three factors such as: internal space reduction, limited tissue movement and upsurge of pressure in internal or external canal [4,5,6]. Typical pressure gradient gets disturbed enough to impede the axonal transport, even resulting in a complete transport block [7]. Constant mechanical and ischemic deterioration contributes to the development of intraneural edema, fibrosis, and thus - demyelination, ultimately causing axonal degeneration [8,9,10]. What is more, the dorsal root ganglia (DRG), lacking a blood-nerve barrier, get prone to biochemical irritation and together with neurogenic inflammation and activation of glial cells of the spinal cord can explain the bilateral presentation of CTS, as well as extraterritorial pain frequently recognized in clinical practice [7,9,10]. The common nocturnal aggravation of CTS symptoms is further worsened by a couple of factors: redistribution of the interstitial fluid into distal limbs due to recumbent position, absence of fluid clearance related to the lack of muscle pump and sustained wrist flexion which increases the compartmental pressure [11]. These continuous structural changes in the connective tissue, impact the longitudinal gliding of the nerve, maintaining a cycle of mechanical irritation and

neurological decline [7,8]. Clinical manifestation of CTS can be described as pain, numbness, tingling, and night-time burning aches, commonly along the palmar distribution of the first three fingers and the radial half of the fourth finger [1,2,12,13,14]. When left untreated, CTS can lead to severe outcomes of thenar eminence atrophy, notable loss of hand function, and irreversible median nerve impairment [4,5,6,12]. CTS is related to a significant economic and social burden. Depending on particular studies its impact is estimated from 1–5% up to 7 to 16% of adults, with women being three times more predisposed than men, peaking in incidence between the ages of 45-54 or 40-60 [1,2,3,15]. Even though the majority of cases (approximately 80%) are idiopathic, CTS is also related to certain systemic conditions such as diabetes mellitus, rheumatoid arthritis, obesity, as well as repetitive strain injuries or pregnancy. All of them may increase intraneural pressure or the probability of symptomatic response [2,8,16,17,1819]. The management scope of CTS can be divided into conservative treatments - usually suggested for benign or moderate cases, and surgical intervention, generally reserved for patients with severe symptoms, thenar muscle atrophy, or failure of conservative therapy [2,13]. Conservative approach includes wrist immobilization using splints or orthoses, physiotherapy, systemic pharmacotherapy (diuretics, Vitamin B6), and local/oral corticosteroid administration [20,21]. Furthermore, emerging non-operative methods such as neuromobilization (nerve and tendon mobilization), hydrodissection, acupuncture, and shock-wave therapy; have gained popularity as non-invasive alternatives. However, their effectiveness requires further scientific verification [4,21]. Despite the consistency (80-90%) of good to excellent long-term results of surgical treatment by carpal tunnel release, 10–20% of patients experience unsatisfactory outcomes. Therefore, choosing a sufficient therapeutic approach remains a complex issue, especially when taking the significantly higher cost of surgery into consideration [22]. In addition, the scientific literature presents contrary evidence regarding the optimal therapeutic strategy [23,24,25,26]. Despite the wide range of available conservative and surgical treatment options for cCTS, the relative effectiveness of these interventions remains unclear due to heterogeneity of study designs, outcomes, and follow-up durations, thereby justifying a systematic synthesis of randomized controlled trials.

Research objective: Comparison of conservative and surgical methods of CTS management.

2. Epidemiology, Prevalence, and Risk Factors of Carpal Tunnel Syndrome (CTS)

2.1 Prevalence and distribution

Depending on particular studies, estimated prevalence of CTS in the general adult population ranges from 1-1,5% [2,18,19] to 7-16% [2,3]. CTS often presents bilaterally, which has been reported in 60-74% of patients [9,10].

Demographic and Occupational Factors

The incidence of CTS indicates a considerable female predominance, typically three times more prevalent in women than in men [1,15]. Some studies document up to 10 times higher prevalence of CTS in women [27]. Women aged 40 to 60 years appear to have the highest risk of developing CTS, with the peak incidence generally falling between 45 and 54 years of age [2,18,19,27]. The smaller relative cross-sectional area of the carpal tunnel in women (9.0) compared to men (11.3) seems to be related to observed female susceptibility in CTS [28]. Overrepresentation of females in occupations with a higher risk of CTS cannot be omitted when discussing such predominance [29]. CTS is generally categorized as an occupational hazard. Occupations requiring repetitive hand motion, such as those held by production workers, material movers, and office administrative staff, are considered as high-risk [30]. Furthermore, white race seems to be more susceptible to CTS [27].

2.2 Risk factors

While approximately 65-80% of CTS cases are idiopathic, numerous factors contribute to the syndrome by either increasing pressure or causing tissue changes within the carpal tunnel [2,3,18,19].

Key risk factors including: diabetes mellitus (DM), obesity, age, sex, anatomical or developmental changes in the carpal tunnel; could also influence the development of CTS. [2,15,31]. Furthermore, DM's higher risk of CTS is akin to hyperglycemia-related glycosylation and inflammation of tendons [32]. Inflammatory diseases such as Rheumatoid Arthritis (RA) can also relate to the formation of CTS, as synovial hyperplasia (infiltrating pannus) physically restricts the canal [33]. Pregnancy-related fluid retention and/or edema as well as Hypothyroidism are also associated risk factors [7].

In addition, frequent, repetitive wrist activity is also a confirmed risk factor, as it can

dramatically increase the interstitial fluid pressure, especially during extension - up to tenfold increase [2,15,31,34].

2.3 Genetic predispositions

Other studies strongly suggest a significant role of genetic factors in CTS. Familial morbidity of CTS (FCTS) can be detected in 17% up to 39% of cases, often expressing as a high incidence rate of bilateral CTS [35].

Genetic susceptibility is linked to single-nucleotide variations (polymorphisms) in genes managing three key processes: collagen synthesis, collagen degradation, and protection against oxidative stress effects in connective tissues. Among specific gene variants we can highlight:

COL1A1 (Type I collagen): variants such as rs1800012 may cause overproduction of type I collagen, changing connective tissue mechanics and increasing CTS risk, especially in women [36].

COMP (Cartilage Oligomeric Matrix Protein): mutations in this gene have been identified as the cause of familial bilateral CTS, inherited in an autosomal-dominant manner [31,37]

TTR (Transthyretin): mutations are associated with CTS, as the syndrome can be one of the first manifestations of familial amyloidosis [38].

Glutathione S-transferases (GSTs): The GSTM1-null variant is linked to a twofold increase in CTS risk [39].

3. Materials and methods

3.1 Study design

This study is a systematic review of randomized controlled trials evaluating conservative and surgical treatment options for CTS.

3.2 Study eligibility

Randomized controlled trials evaluating conservative or surgical treatment strategies for CTS in adult patients were eligible for inclusion. Studies, published from 2009 onwards, were required to enroll adults diagnosed with CTS based on clinical assessment, electrodiagnostic

testing, or a combination of both, and to report clinically relevant outcomes such as symptom severity, functional status, pain, or electrophysiological parameters. Trials including both idiopathic cases and patients with associated systemic conditions were considered.

Studies were excluded if they were non-randomized, observational in design, case reports, narrative reviews, conference abstracts, or if they focused exclusively on diagnostic methods or anatomical aspects without evaluation of treatment effects.

3.3 Information sources and search strategy

A literature search was conducted in PubMed, Scopus, Web of Science, and the Cochrane Library (CENTRAL). Search terms related to CTS and its treatment were used. Studies published from January 2009 onwards were considered eligible in order to reflect contemporary treatment strategies and clinical practice. The search was limited to studies involving adult human participants. Reference lists of relevant review articles were screened to identify additional eligible trials.

3.4 Study selection and data extraction

Titles and abstracts were screened for eligibility, followed by full-text assessment of potentially relevant articles. Study selection was performed by two reviewers, with disagreements resolved by discussion. Data were extracted using a standardized approach, including study characteristics, participant demographics, intervention and comparator details, follow-up duration, and reported outcomes.

4. Results

4.1 Characteristics of included studies

The included randomized controlled trials were published between 2011 and 2022 and enrolled adult patients diagnosed with CTS. Most studies included patients with mild to moderate CTS, although several trials also enrolled patients with severe or persistent symptoms following previous conservative treatment. Sample sizes ranged from small single-center trials to larger controlled studies.

Diagnosis of CTS was based on clinical assessment, electrodiagnostic testing, or a combination of both. Follow-up duration varied across studies and included short-term (≤3 months), mid-term (3–6 months), and longer-term (>6 months) assessments. The most frequently reported outcomes were symptom severity and functional status measured using the Boston Carpal Tunnel Questionnaire (BCTQ) [40–44,46–48,51–57], followed by pain intensity [42–45,49–54], nerve conduction study parameters [47–50,53], and the need for subsequent surgical intervention [58–62]. The characteristics of the included randomized controlled trials, including CTS characteristics, treatment type, sample size, and follow-up duration, are summarized in Table 1.

Table 1. Characteristics of included randomized controlled trials

Author (Year)	**CTS Characteristics**	**Type of treatment**	**Sample size (n)**	**Follow-up duration**
Wu (2017)	Mild–moderate CTS	Perineural dextrose injection	49	6 months
Wu (2018)	Mild–moderate CTS	5% dextrose injection	54	6 months
Raeissadat (2018)	Mild–moderate CTS	PRP injection	50	6 months

Author (Year)	CTS Characteristics	Type of treatment	Sample size (n)	Follow-up duration
Wu (2017)	Mild–moderate CTS	PRP injection	60	6 months
Karimzadeh (2019)	Mild–moderate CTS	Corticosteroid injection	60	3 months
Eltabl (2020)	Mild–moderate CTS	PRP injection vs surgery	45	6 months
Fernández-de-las-Peñas (2015)	Mild–moderate CTS	Manual therapy	120	12 months
Fernández-de-las-Peñas (2017a)	Mild–moderate CTS	Manual therapy	100	12 months
Fernández-de-las-Peñas (2017b)	Mild–moderate CTS	Manual therapy	120	12 months
Jiménez-del-Barrio (2021)	Mild–moderate CTS	Manual therapy	401	6 months
Ijaz (2022)	Mild–moderate CTS	Physiotherapy + neuromobilization	66	6 weeks
Wu (2015)	Mild–moderate CTS	Extracorporeal shock wave therapy	60	3 months

Author (Year)	CTS Characteristics	Type of treatment	Sample size (n)	Follow-up duration
Atthakomol (2018)	Mild–moderate CTS	rESWT	50	6 months
Chen (2015)	Mild–moderate CTS	Pulsed radiofrequency	40	3 months
Fusakul (2014)	Mild–moderate CTS	Low-level laser therapy	50	3 months
Chung (2016)	Mild–moderate CTS	Electroacupuncture	70	3 months
Horng (2011)	Mild–moderate CTS	Nerve vs tendon gliding exercises	48	8 weeks
Wang (2017)	Mild–moderate CTS	Steroid injection + splint	64	6 months
Jarvik (2011)	Mild–moderate CTS	Surgical release	116	12 months
Awan (2015)	Mild–moderate CTS	Surgery vs steroid injection	60	6 months
Ismatullah (2013)	Mild–moderate CTS	Surgery vs steroid injection	66	6 months

Author (Year)	CTS Characteristics	Type of treatment	Sample size (n)	Follow-up duration
Jafari (2018)	Mild–moderate CTS	Surgery vs steroid injection	90	12 months
Zhang (2019)	Mild–moderate CTS	Surgery and steroid injection vs steroid injection alone	80	6 months

rESWT - radial extracorporeal shock wave therapy

4.2 Conservative treatment

4.2.1 Injection therapies

Corticosteroid injections

Local corticosteroid injections were associated with short-term improvements in symptom severity and pain intensity compared with baseline measures or splinting alone [44,45,54,57]. These effects were most pronounced during the first weeks to months following injection. Several trials demonstrated attenuation of treatment effects over time, with symptom recurrence and an increased likelihood of additional treatment during longer follow-up [44,45,57].

Perineural dextrose injections

Perineural dextrose injections demonstrated greater reductions in symptom severity and pain scores compared with corticosteroid injections in short- and mid-term follow-up [40,41] Functional outcomes measured using BCTQ also improved in patients treated with dextrose injections [40,41]. Long-term outcomes beyond one year were inconsistently reported.

Platelet-rich plasma (PRP) injections

PRP injections were associated with improvements in symptom severity and functional outcomes during short- to mid-term follow-up [42,43,45]. However, results varied across

studies with respect to magnitude and duration of effect, reflecting heterogeneity in injection protocols and follow-up duration [42,43].

4.2.2 Manual therapy and physiotherapy

Manual therapy and neurodynamic interventions resulted in improvements in symptom severity, functional status, and pain intensity in several trials [46–50]. Some studies also reported improvements in nerve conduction study parameters following manual therapy–based interventions [47,49]. Combined physiotherapy approaches incorporating neuromobilization techniques demonstrated greater improvements compared with standard physiotherapy alone [50].

4.2.3 Electrotherapy and physical modalities

Electrotherapy modalities, including extracorporeal shock wave therapy, pulsed radiofrequency, and low-level laser therapy, demonstrated beneficial effects on symptom severity and pain reduction during short-term follow-up [51–54]. Functional improvements were reported in selected trials [51,52], while electrophysiological outcomes were inconsistently improved across studies [53,54]. In some trials, short-term outcomes were comparable to those achieved with corticosteroid injections.

4.2.4 Acupuncture and exercise-based interventions

Electroacupuncture was associated with reductions in symptom severity and pain compared with splinting during short-term follow-up [55]. Exercise-based interventions, including nerve and tendon gliding exercises, demonstrated improvements in symptoms and functional outcomes, although effect sizes varied and long-term outcome data were limited [56].

4.3 Surgical treatment

4.3.1 Surgery versus conservative treatment

Surgical decompression demonstrated higher rates of sustained clinical improvement compared with conservative treatment during mid- and long-term follow-up [58–61]. While short-term symptom relief was often comparable between surgical and non-surgical interventions [58–60],

surgery was associated with a lower likelihood of symptom recurrence and reduced need for additional interventions [59-62].

4.4 Comparative effectiveness

Overall, conservative treatment modalities were associated with meaningful short-term improvements in symptom severity and functional status, particularly in patients with mild to moderate CTS [40–57]. Surgical treatment was associated with more durable clinical improvement and a lower need for subsequent intervention, especially in patients with persistent or recurrent symptoms [58–62]. A summary of treatment effects and the subsequent need for surgical intervention across different treatment modalities is presented in Table 2.

Table 2. Summary of outcomes by treatment modality

Treatment modality	**Short-term symptom improvement**	**Long-term durability**	**Subsequent need for surgical intervention**
Corticosteroid injection	Yes	Limited	Moderate–high
Perineural dextrose injection	Yes	Moderate	Low
PRP injection	Yes	Moderate	Low–moderate
Manual therapy	Yes	Limited–moderate	Moderate
Electrotherapy modalities	Yes	Limited	Unknown
Acupuncture / exercise	Yes	Limited	Unknown
Surgical treatment	Yes	High	Lowest

5. Discussion

This systematic review synthesized evidence from randomized controlled trials published from 2009 onwards evaluating contemporary conservative and surgical treatment strategies for CTS. The findings indicate that while a wide range of non-surgical interventions provide meaningful short-term symptom relief and functional improvement, surgical decompression remains associated with more durable clinical benefit and a lower likelihood of subsequent intervention in selected patients.

5.1 Conservative treatment and patient-centered outcomes

Across included trials, conservative treatment modalities—including injection therapies, manual therapy, electrotherapy, acupuncture, and exercise-based interventions—were consistently associated with improvements in symptom severity and functional status, particularly in the short term. These findings are clinically relevant, as they support the role of conservative management as a first-line strategy, especially for patients with mild to moderate CTS who prioritize symptom relief while avoiding invasive procedures.

Injection therapies demonstrated variable durability of effect. Corticosteroid injections provided rapid symptom improvement, which may be beneficial for patients seeking short-term relief or temporary functional recovery. However, attenuation of treatment effects over time and symptom recurrence were frequently observed, suggesting that corticosteroids may serve as a temporizing rather than definitive intervention. In contrast, perineural dextrose injections and platelet-rich plasma (PRP) therapies showed more sustained benefits in several trials, with improvements in both symptoms and function. Although these findings are promising, heterogeneity in treatment protocols and limited long-term follow-up warrant cautious interpretation.

Manual therapy and neurodynamic interventions resulted in clinically meaningful improvements in pain and function, and in some cases electrophysiological parameters. These approaches may be particularly valuable for patients preferring non-invasive treatment options or those for whom injections or surgery are contraindicated. Importantly, combined physiotherapy approaches appeared to enhance outcomes, underscoring the potential benefit of multimodal conservative care tailored to individual patient needs.

Electrotherapy modalities and adjunctive physical treatments, such as extracorporeal shock wave therapy, pulsed radiofrequency, laser therapy, acupuncture, and exercise programs, were associated with short-term symptom improvement. However, evidence regarding their long-term effectiveness and impact on disease progression remains limited. From a patient perspective, these modalities may offer symptomatic relief with minimal risk, but expectations regarding durability of benefit should be appropriately managed.

5.2 Surgical treatment and durability of benefit

Surgical decompression demonstrated higher rates of sustained clinical improvement compared with conservative treatment during mid- and long-term follow-up. While short-term outcomes were often comparable between surgical and non-surgical approaches, surgery was associated with a lower likelihood of symptom recurrence and reduced need for subsequent intervention. These findings support surgical treatment as an effective option for patients with persistent symptoms, recurrent disease, or insufficient response to conservative management.

Importantly, comparisons of different surgical techniques did not demonstrate consistent superiority of one approach over another, suggesting that surgical expertise, patient selection, and perioperative management may be more influential determinants of outcome than the specific technique employed.

5.3 Clinical implications and patient benefit

From a patient-centered perspective, the findings of this review support a stepwise and individualized approach to CTS management. Conservative treatments offer meaningful symptom relief with low risk and may improve quality of life in the short term, making them appropriate initial options for many patients. Surgical intervention, while more invasive, provides more durable symptom control and functional improvement, which may be particularly important for patients with ongoing impairment, occupational demands, or reduced quality of life despite conservative therapy.

Shared decision-making should incorporate patient preferences, symptom severity, functional limitations, and expectations regarding treatment durability. Clear communication regarding

the likely course of symptom improvement and the potential need for future intervention is essential to optimize patient satisfaction and outcomes.

5.4 Limitations

This review has several limitations. Despite inclusion of randomized controlled trials only, considerable heterogeneity was present in terms of intervention protocols, outcome measures, and follow-up duration. Long-term data were limited for several conservative treatment modalities, particularly newer injection therapies. Additionally, the absence of placebo-controlled surgical trials limits interpretation of the absolute magnitude of surgical benefit.

5.5 Contribution of the present review

By focusing exclusively on randomized controlled trials published from 2009 onwards, this review provides an up-to-date synthesis of contemporary treatment strategies for carpal tunnel syndrome. Unlike broader reviews that include older studies with outdated techniques, the present analysis reflects current clinical practice and highlights the relative benefits and limitations of modern conservative and surgical interventions. This approach offers clinically relevant insights to support informed treatment decisions and patient-centered care in everyday practice.

6. Conclusion

Based on the systematic review of the provided scientific literature, the following conclusions are drawn regarding the management of CTS:

Efficacy Hierarchy: While a diverse array of non-surgical interventions, ranging from splinting and corticosteroids to manual therapy delivers meaningful short-term symptom relief and functional recovery, surgical decompression is unequivocally associated with superior long-term durability. Surgery significantly reduces the likelihood of symptom recurrence and the necessity for subsequent therapeutic interventions, making it the definitive standard for severe or uncontrollable cases.

Emerging Conservative Paradigms: The literature identifies perineural dextrose injections (hydrodissection) and platelet-rich plasma (PRP) as highly effective conservative alternatives. These modalities demonstrate mid-term benefits that often surpass traditional corticosteroid injections, likely due to their regenerative and neuro-modulatory mechanisms rather than

simple anti-inflammatory effects. They represent a viable option for patients seeking to delay or avoid surgery.

Clinical Algorithm: The optimal therapeutic strategy is stage-dependent. Conservative management is supported as the first-line approach for mild-to-moderate CTS, prioritizing symptom relief and functional preservation. However, for patients with persistent symptoms or advanced neuropathy, the transition to surgical release should be timed appropriately to prevent irreversible neurological impairment. The choice of therapy must be a shared decision, balancing the patient's preference for non-invasiveness against the need for definitive, long-lasting decompression.

7. Author contribution

Conceptualization: KG, MD; methodology: KG, JS; validation: HA, ZK; formal analysis: MD, JS; resources: KG, MD; data curation: JS,KK; writing - original draft preparation: KG, MD, ZK; writing - review and editing: HA, KK; visualization: ZK; supervision: HA, KK.
All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflicts of interest.

10. Declaration of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used Gemini by Google for the purpose of refining the academic English language of the manuscript in order to maintain clarity, consistency and adherence to scientific writing standards, as well as additional linguistic refinement in order to provide proper English grammar, style and clarity in the presentation of the results. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.

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