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CARPAL TUNNEL SYNDROME: CURRENT DIAGNOSTIC AND TREATMENT STRATEGIES FROM CLINICAL, SOCIOECONOMIC, AND HEALTHCARE PERSPECTIVES —A NARRATIVE REVIEW

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ABSTRACT

Background: Carpal tunnel syndrome (CTS) represents one of the most common peripheral nerve entrapment neuropathies affecting the upper limb, resulting from increased pressure within the carpal tunnel and compression of the median nerve. It is associated with numbness, pain, and hand weakness, leading to functional impairment and reduced quality of life. While conservative treatment is effective in early stages, surgical intervention remains the main option in advanced cases.

Aim: The aim of this narrative review was to summarize current evidence on the diagnosis, treatment, and surgical outcomes of carpal tunnel syndrome, with particular emphasis on the effectiveness of surgical decompression and factors influencing recovery.

Material and methods: A narrative review of the literature was conducted using PubMed and other peer-reviewed sources. Articles published in English between 2010 and 2026 were included, focusing on the surgical management of carpal tunnel syndrome.

Results: Surgical division of the transverse carpal ligament leads to significant symptom improvement in most patients. Both open and endoscopic techniques reduce pain and improve hand function. Endoscopic approaches may allow faster recovery, whereas open procedures remain widely used and reliable. Surgical treatment is associated with sustained symptom relief and favorable long-term outcomes, particularly in moderate to severe cases. Postoperative rehabilitation and early mobilization support recovery.

Conclusions: Surgical decompression is an effective treatment for patients with persistent or severe CTS, providing durable symptom relief and functional improvement. Patient selection, surgical technique, and postoperative rehabilitation are key factors influencing outcomes.

KEYWORDS

Carpal Tunnel Syndrome; Median Nerve; Diagnosis; Surgical Decompression; Healthcare Outcomes; Socioeconomic Burden

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1. Introduction

Carpal tunnel syndrome (CTS) represents the most frequent entrapment neuropathy and results from compression of the median nerve within the carpal tunnel at the wrist (Genova et al., 2020; Ibrahim et al., 2012; Milczarek et al., 2025).

It is a prevalent condition affecting a significant proportion of the adult population and is associated with substantial functional impairment and a reduced quality of life. Clinically, CTS manifests with pain, paresthesia, numbness, and, in advanced stages, weakness of the thenar muscles, which may lead to permanent disability if left untreated (Genova et al., 2020; Ibrahim et al., 2012; Milczarek et al., 2025).

The etiology of CTS is multifactorial and includes both intrinsic and extrinsic factors contributing to increased pressure within the carpal tunnel (Genova et al., 2020; Ibrahim et al., 2012; Milczarek et al., 2025; Shi & MacDermid, 2011; Ono et al., 2010). These include repetitive hand use, metabolic disorders, hormonal changes, and anatomical variations (Genova et al., 2020; Ibrahim et al., 2012; Milczarek et al., 2025; Ono et al., 2010). Despite extensive research, the exact pathophysiological mechanisms remain incompletely understood, involving both mechanical compression and ischemic injury to the median nerve (Genova et al., 2020; Ibrahim et al., 2012; Milczarek et al., 2025).

Accurate diagnosis of CTS is essential for appropriate management and is based on a combination of clinical evaluation and complementary diagnostic methods (Genova et al., 2020; Ibrahim et al., 2012; Milczarek et al., 2025). Electrophysiological studies remain the gold standard; however, recent advances in

imaging techniques, such as ultrasound and shear wave elastography, have improved diagnostic accuracy and allow for better assessment of disease severity (Milczarek et al., 2025; Kim et al., 2025).

Management of CTS includes both non-surgical and surgical approaches, and the optimal treatment strategy depends on symptom severity and duration (Ibrahim et al., 2012; Milczarek et al., 2025; Shi & MacDermid, 2011; Ono et al., 2010). Conservative treatment options, including splinting, pharmacotherapy, and corticosteroid injections, are commonly used in mild to moderate cases (Ibrahim et al., 2012; Milczarek et al., 2025; Shi & MacDermid, 2011; Ono et al., 2010). In particular, methylprednisolone injections provide significant short-term symptom relief and functional improvement, although their long-term effectiveness appears to be limited (Atroshi et al., 2013). In contrast, surgical treatment is indicated in patients with advanced disease and persistent symptoms, providing sustained symptom relief (Erfanifam et al., 2022). Numerous studies report more favorable long-term outcomes following surgical decompression compared with conservative treatment (Shi & MacDermid, 2011).

However, the choice of technique and extent of release remain subjects of ongoing debate, although randomized clinical trials have shown no significant differences between selected surgical approaches (Razavipour et al., 2024). Recent evidence highlights evolving surgical strategies and emphasizes the importance of individualized approaches to optimize patient outcomes (Milczarek et al., 2025; Woo et al., 2026; Alrayes et al., 2024). Long-term follow-up studies indicate that surgical treatment provides sustained symptom relief and functional recovery; however, the extent of improvement varies depending on disease severity and patient-specific factors (Dawod et al., 2025).

The aim of this review is to summarize current evidence regarding the pathophysiology, diagnosis, management and outcomes of carpal tunnel syndrome, with particular emphasis on surgical outcomes.

2. Materials and Methods

A narrative review of the literature was conducted using electronic databases, including PubMed and other peer-reviewed scientific sources.

The search strategy included combinations of the following keywords: “carpal tunnel syndrome”, “median nerve compression”, “carpal tunnel release”, “surgical treatment”, “endoscopic release”, and “clinical outcomes”.

Only articles published in English between 2010 and 2026 were considered for inclusion. The review included systematic reviews, meta-analyses, randomized controlled trials, and observational studies focusing on the surgical management of carpal tunnel syndrome and its clinical outcomes.

Studies were selected based on their relevance to the objectives of this review, with particular emphasis on surgical decompression techniques, effectiveness, and prognostic factors influencing postoperative recovery. Articles addressing conservative treatment were also included for comparative purposes.

Case reports, non-English publications, and studies not directly related to the topic were excluded.

3. Results

3.1 Pathophysiology and Etiology

Carpal tunnel syndrome (CTS) is a multifactorial disorder caused by increased pressure within the carpal tunnel, resulting in compression of the median nerve and progressive neural dysfunction (Sevy et al., 2023; Malakootian et al., 2023). The pathophysiology of CTS involves both mechanical and vascular mechanisms. Elevated intracarpal pressure leads to compression and traction of the median nerve, impaired intraneural microcirculation, and ischemic injury, which together contribute to structural nerve damage. In the early stages, these changes are mainly associated with demyelination, whereas prolonged compression may eventually result in more advanced nerve dysfunction and persistent sensory and motor deficits (Sevy et al., 2023; Malakootian et al., 2023).

The normal pressure within the carpal tunnel is relatively low; however, repetitive wrist movements as well as sustained wrist flexion or extension can markedly increase pressure within this confined space. Such changes may promote local edema, disturb venous outflow, and further aggravate median nerve compression. In addition, the limited anatomical space of the carpal tunnel, which contains the median nerve together with nine flexor tendons, increases susceptibility to nerve entrapment when structural or inflammatory abnormalities develop (Sevy et al., 2023; Malakootian et al., 2023).

The etiology of CTS includes both intrinsic and extrinsic factors. Intrinsic factors comprise anatomical variations, synovial tissue hypertrophy, inflammatory conditions, and systemic disorders that predispose the nerve to compression (Malakootian et al., 2023). Extrinsic factors are mainly related to occupational and

biomechanical stressors, including repetitive manual activity, forceful gripping, exposure to vibration, and prolonged non-neutral wrist postures. These factors may lead to cumulative microtrauma and progressive irritation of the structures within the carpal tunnel (Rotaru-Zavaleanu et al., 2024).

Several individual risk factors have also been associated with CTS development, including obesity, hormonal changes, metabolic disorders, and other systemic conditions that may alter connective tissue properties or microvascular function (Sevy et al., 2023; Malakootian et al., 2023; Rotaru-Zavaleanu et al., 2024). Therefore, CTS should be regarded as a condition resulting from the interaction between local mechanical compression and patient-specific susceptibility factors (Sevy et al., 2023; Malakootian et al., 2023; Rotaru-Zavaleanu et al., 2024).

Overall, the development of CTS reflects a complex interplay between increased tunnel pressure, impaired nerve perfusion, and biological predisposition. Understanding these pathophysiological and etiological mechanisms is essential for accurate diagnosis and for selecting the most appropriate treatment strategy for each patient.

3.2 Diagnosis

Carpal tunnel syndrome (CTS) is primarily diagnosed based on a combination of clinical presentation and confirmatory diagnostic testing. Patients commonly present with numbness, tingling, pain, and paresthesias in the distribution of the median nerve, typically affecting the thumb, index and middle fingers, as well as the radial portion of the ring finger. Symptoms are often more pronounced at night and may be relieved by shaking the hand. In advanced stages, weakness, impaired dexterity, and thenar muscle atrophy may occur (Sevy et al., 2023).

Physical examination includes provocative maneuvers such as the Phalen test and Tinel sign, which are commonly used to reproduce symptoms. However, their diagnostic accuracy is limited when used in isolation and should be interpreted in conjunction with the patient's clinical history (Sevy et al., 2023).

Electrodiagnostic studies, including nerve conduction studies (NCS) and electromyography (EMG), remain the gold standard for confirming CTS, particularly in atypical or severe cases. These methods provide objective assessment of median nerve function and help determine disease severity and prognosis (Sevy et al., 2023; Malakootian et al., 2023).

In addition to clinical and electrophysiological evaluation, it is important to consider contributing factors such as occupational exposure to repetitive wrist movements and vibration, as well as systemic conditions including diabetes, which may influence both the development and progression of CTS (Rotaru-Zavaleanu et al., 2024).

Recent advances in imaging have introduced more sophisticated techniques such as ultrasound radiomics, which enable quantitative analysis of imaging features beyond standard visual assessment. These approaches provide a more objective and detailed evaluation and have demonstrated improved diagnostic performance compared to conventional imaging methods, with reported sensitivity and specificity of approximately 0.85 and 0.80 in testing models (Wu et al., 2023).

Ultrasound remains an important complementary diagnostic tool due to its non-invasive nature, accessibility, and ability to visualize structural changes in the median nerve. Typical findings include enlargement of the nerve, increased cross-sectional area, and alterations in surrounding tissues. Additionally, ultrasound allows real-time dynamic assessment and may provide diagnostic accuracy comparable to electrodiagnostic testing in selected cases with reported sensitivity and specificity of 77.6% and 86.8%, respectively (Fowler et al., 2011).

3.3 Treatment

The management of carpal tunnel syndrome (CTS) depends on symptom severity and the degree of median nerve impairment. Local corticosteroid injections are an effective treatment option and provide significant short-term symptom relief and functional improvement, particularly within the first 3–6 months, with reported effect sizes ranging from SMD -0.77 at 3 months to -0.58 at 6 months (Ashworth et al., 2023).

However, when compared directly with surgical treatment, the available evidence remains uncertain and does not clearly favor either approach, with no statistically significant differences observed (SMD 0.63, 95% CI -0.61 to 1.88) (Ashworth et al., 2024).

In patients with persistent symptoms or functional impairment, surgical intervention should be considered. Carpal tunnel release can be performed using open or endoscopic techniques, both of which are safe and effective. Endoscopic release may offer faster recovery and improved functional outcomes, although

it may carry a higher risk of transient nerve injury. The evidence is based on a systematic review including 11 studies (7 randomized controlled trials and 4 meta-analyses) and more than 8000 procedures (4367 endoscopic and 4107 open) (Rajapandian et al., 2024).

Conservative management, including splinting, physical therapy, and activity modification, remains appropriate in mild to moderate cases, while surgical treatment provides good outcomes in more advanced disease (Omole et al., 2023). Conservative treatment usually leads to symptom improvement within 2–6 weeks and achieves maximal benefit at approximately 3 months, particularly in patients with mild to moderate disease (Omole et al., 2023). Surgery is particularly recommended in patients with severe CTS, especially in the presence of motor deficits or electrophysiological evidence of nerve damage.

3.4 Surgical outcomes and prognostic factors

Carpal tunnel release is associated with favorable outcomes, with studies reporting symptom improvement in approximately 70–90% of patients (Omole et al., 2023). Both open and endoscopic carpal tunnel release are safe and effective techniques with comparable long-term outcomes; however, endoscopic release may allow faster recovery and earlier return to work, at the cost of a potentially higher risk of transient nerve injury (Rajapandian et al., 2024; Omole et al., 2023). Most patients experience a significant reduction in pain, paresthesia, and functional impairment following surgical decompression. In many patients, symptom relief begins early after surgery, while full functional recovery may require a longer period depending on the duration and severity of preoperative nerve compression (Rajapandian et al., 2024; Omole et al., 2023).

The effectiveness of surgical decompression is influenced by several prognostic factors, with preoperative disease severity being one of the most important determinants. Patients with moderate CTS typically experience substantial postoperative improvement, whereas those with advanced disease, prolonged symptom duration, thenar atrophy, or pronounced electrophysiological abnormalities tend to have less complete recovery, particularly in motor function (Dawod et al., 2025).

This suggests that delayed surgical referral may reduce the potential for full reversal of nerve dysfunction. In clinical practice, this supports timely intervention in patients with progressive deficits or objective evidence of median nerve injury.

The duration of symptoms before surgery also appears to play a relevant role in outcome prediction. Patients operated on earlier in the course of the disease often present better postoperative sensory recovery and faster return to daily function. Long-term data indicate that patients with severe carpal tunnel syndrome experience significantly longer recovery times (up to approximately 6.5 months compared with 3.4 and 2.2 months in moderate and mild cases, respectively) and less pronounced improvement in pain and functional outcomes (Dawod et al., 2025). In contrast, chronic compression may lead to structural nerve damage that cannot be entirely reversed even after technically successful decompression (Sevy et al., 2023; Malakootian et al., 2023). These observations highlight the clinical importance of early diagnosis and appropriate stratification of patients according to disease stage.

Comorbidities may further affect postoperative results. Diabetes mellitus is particularly relevant because it may coexist with peripheral nerve dysfunction and adversely influence both symptom interpretation and nerve recovery. Although patients with diabetes can still benefit significantly from surgery, some studies suggest that recovery may be slower or less complete than in non-diabetic individuals, especially in long-standing disease (Zimmerman et al., 2022). In addition to conventional surgical approaches, emerging minimally invasive techniques, including ultrasound-guided carpal tunnel release, appear to offer promising clinical outcomes and may contribute to faster recovery in selected patients, although further high-quality studies are required (Pace et al., 2023). Furthermore, WALANT anesthesia has gained increasing interest because of its association with lower perioperative pain and high patient satisfaction (Focsa et al., 2025). Other factors, such as obesity, older age, and occupational exposure to repetitive hand activity, may influence the development and progression of CTS and may also affect treatment outcomes (Rotaru-Zavaleanu et al., 2024; Omole et al., 2023).

From a technical perspective, both open and endoscopic release provide effective decompression of the median nerve. The choice of approach may affect early recovery characteristics, but long-term symptom control is generally favorable with both methods when the release is complete (Omole et al., 2023). Therefore, successful treatment depends not only on surgical technique itself, but also on appropriate patient selection, timing of intervention, and postoperative management. Overall, the literature indicates that surgical decompression is an effective treatment for CTS, while prognosis is best understood as the result of interaction between disease severity, patient-specific factors, and perioperative care (Dawod et al., 2025; Rajapandian et al., 2024; Omole et al., 2023).

3.5 Complications and postoperative course

Although carpal tunnel release is generally considered a safe and effective procedure, postoperative complications may occur, which can influence patient satisfaction and recovery trajectory. The most commonly reported complication is pillar pain, defined as pain localized at the base of the palm on both sides of the operative site (Omole et al., 2023). This condition is usually self-limiting but may persist for several weeks or even months, potentially delaying return to full hand function.

Other complications include wound-related issues such as infection, hematoma formation, and delayed healing, although these are relatively uncommon when proper surgical technique and adequate postoperative management are used. Transient nerve irritation or neuropraxia may also occur, particularly in endoscopic procedures, but in most cases resolves spontaneously over time (Omole et al., 2023). Rare but more serious complications include injury to the median nerve or its branches, which may result in persistent sensory or motor deficits.

Incomplete release of the transverse carpal ligament represents another potential cause of persistent or recurrent symptoms. In such cases, revision surgery may be required to achieve adequate decompression. Recurrence of symptoms can also occur due to scar tissue formation or ongoing exposure to occupational risk factors (Rajapandian et al., 2024; Omole et al., 2023). Despite these risks, the overall complication rate remains low, with studies reporting no significant differences in overall complication rates between open and endoscopic techniques (Omole et al., 2023).

The postoperative course varies between individuals. Early mobilization is generally encouraged to prevent stiffness and promote functional recovery. Patients are typically advised to gradually resume daily activities while avoiding excessive strain on the operated hand. In many cases, return to light activities is possible within a few weeks, whereas full recovery, particularly in physically demanding occupations, may take a more extended recovery period. These findings emphasize that although surgical treatment is highly effective, postoperative care and patient education remain essential components of successful management (Omole et al., 2023).

3.6 Clinical outcomes and comparison of techniques

Carpal tunnel release has been extensively studied in terms of both short-term and long-term clinical outcomes. The majority of patients experience significant improvement in symptoms such as pain, paresthesia, and functional impairment following surgical decompression. In many cases, symptom relief begins within the first few weeks after the procedure, although complete recovery of nerve function may take several months depending on the severity and duration of preoperative compression.

When comparing surgical techniques, both open and endoscopic carpal tunnel release demonstrate high rates of success. Open release remains the most widely performed technique and is often considered the standard approach due to its simplicity, direct visualization, and low risk of incomplete decompression. Long-term outcomes following open release are generally excellent, with sustained symptom relief reported in the majority of patients.

While open and endoscopic carpal tunnel release both demonstrate high success rates, differences between techniques are mainly related to early postoperative recovery, whereas long-term clinical outcomes remain broadly comparable. Therefore, surgical approach should be individualized according to patient-specific factors, surgeon experience, and clinical circumstances (Woo et al., 2026; Rajapandian et al., 2024).

Patient-reported outcome measures (PROMs) are increasingly used to evaluate treatment effectiveness. Studies using validated scales such as the Boston Carpal Tunnel Questionnaire have demonstrated significant improvement in symptom severity and functional status following surgery. These improvements are typically sustained over long-term follow-up, supporting the durability of surgical intervention.

Return to work is another important outcome, particularly in working-age populations. Patients undergoing endoscopic release may return to work earlier, especially in occupations requiring fine motor skills or repetitive hand movements. However, in the long term, differences between techniques are less pronounced, and most patients achieve satisfactory functional recovery regardless of the surgical method used.

Overall, surgical decompression of the carpal tunnel is associated with high patient satisfaction and favorable clinical outcomes. While early postoperative recovery may vary depending on the technique, both open and endoscopic release provide effective and durable symptom relief. Future studies should continue to explore patient-specific factors that may influence outcomes and help optimize surgical decision-making.

A comparison of surgical techniques is presented in Table 1.

Table 1. Comparison of open and endoscopic carpal tunnel release

Parameter	Open carpal tunnel release	Endoscopic carpal tunnel release
Surgical approach	Direct incision with full visualization of the transverse carpal ligament	Minimally invasive approach using an endoscope
Incision size	Larger	Smaller
Visualization	Excellent	Limited (endoscopic visualization)
Risk of incomplete release	Low	Slightly higher (operator-dependent)
Postoperative pain	Moderate	Usually lower
Recovery time	Longer	Faster (improvement within weeks)
Return to work	Delayed compared to endoscopic	Approximately 1 week earlier return to work
Complication profile	Low, well-established	Slightly higher risk of transient nerve irritation
Long-term outcomes	Favorable, well-established outcomes	Comparable to open technique
Learning curve	Short	Longer

Based on data from systematic reviews and meta-analyses (Rajapandian et al., 2024; Omole et al., 2023)

3.7 Patient selection and timing of surgical intervention

Appropriate patient selection and timing of surgical intervention are important factors influencing outcomes in carpal tunnel syndrome (CTS). Conservative treatment may be effective in patients with mild to moderate symptoms, particularly when sensory disturbances are intermittent and no significant motor dysfunction is present (Burton et al., 2014).

Several studies suggest that preoperative disease severity is associated with postoperative recovery and functional outcomes. Patients with severe CTS may require longer recovery time and may experience less pronounced improvement in pain relief, satisfaction, functional status, and activities of daily living compared with patients with mild or moderate disease (Burton et al., 2014). In contrast, prolonged symptom duration and severe preoperative nerve dysfunction may reduce the likelihood of complete neurological recovery after surgery (Dawod et al., 2025).

Clinical decision-making should therefore integrate symptom severity, duration of symptoms, patient functional demands, and electrodiagnostic findings. Individualized treatment planning may improve long-term outcomes and reduce the risk of persistent postoperative deficits (Dawod et al., 2025; Shapiro & Kamal, 2024).

3.8 Emerging Diagnostic and Surgical Technologies

Recent advances in diagnostic and surgical technologies have expanded the possibilities for the evaluation and management of carpal tunnel syndrome. Beyond conventional electrodiagnostic studies and standard ultrasonography, several emerging approaches have been proposed to improve diagnostic precision, facilitate earlier detection, and support individualized patient assessment.

Ultrasound radiomics represents one of the most promising developments in CTS diagnostics. Unlike conventional ultrasound evaluation, radiomics enables the extraction and analysis of numerous quantitative imaging features that may not be detectable through visual interpretation alone. Recent evidence suggests that radiomic analysis may provide a more objective assessment of median nerve pathology and may complement traditional diagnostic approaches in selected patients (Wu et al., 2023). In addition, advances in shear wave elastography have enabled quantitative assessment of median nerve stiffness, which appears to correlate with disease severity and may provide additional information beyond conventional cross-sectional area measurements (Kim et al., 2025).

Artificial intelligence and machine-learning algorithms have also been increasingly incorporated into ultrasound image analysis. These technologies may facilitate automated image interpretation, improve diagnostic consistency, and reduce operator-dependent variability. Although their current clinical application remains limited, continued technological development may contribute to more accurate disease classification and improved diagnostic support in patients with suspected CTS (Wu et al., 2023).

Significant innovations have also emerged in surgical management. Ultrasound-guided carpal tunnel release has been introduced as a minimally invasive technique that allows decompression of the median nerve through a small incision under real-time ultrasound guidance. Early studies have reported favorable clinical

outcomes, low complication rates, and rapid postoperative recovery; however, the overall level of evidence remains limited, and further high-quality studies are required before widespread adoption can be recommended (Pace et al., 2023).

Another important development is the increasing use of WALANT (Wide Awake Local Anesthesia No Tourniquet) protocols during carpal tunnel release. This approach enables surgery to be performed without general anesthesia while maintaining patient comfort and allowing intraoperative assessment of hand function. Recent evidence suggests that WALANT is associated with lower perioperative pain and a high probability of patient satisfaction, although further comparative studies are needed to determine its optimal role in clinical practice (Focsa et al., 2025).

Recent technological progress may also influence future strategies for monitoring treatment outcomes in patients with CTS. Advanced imaging techniques may allow more precise assessment of structural changes within the median nerve before and after treatment, potentially improving evaluation of therapeutic effectiveness. Quantitative imaging parameters obtained through radiomics and elastography may provide objective biomarkers of disease severity and recovery, although their clinical utility requires further investigation (Wu et al., 2023; Kim et al., 2025).

Another area of growing interest is the integration of multimodal diagnostic approaches. Combining clinical assessment, electrodiagnostic testing, conventional ultrasonography, radiomic analysis, and machine-learning algorithms may improve diagnostic confidence, particularly in patients with atypical symptoms or borderline electrophysiological findings. Such integrated approaches could facilitate earlier diagnosis and more individualized treatment planning while reducing diagnostic uncertainty in complex cases (Wu et al., 2023).

Future technological developments may also contribute to improved accessibility of diagnostic tools. As ultrasound devices become more widely available and software-based image analysis continues to evolve, advanced imaging techniques may become increasingly integrated into routine clinical practice. However, further standardization of imaging protocols, validation across different populations, and cost-effectiveness analyses remain necessary before widespread implementation can be recommended. Continued research in this field may help establish the precise role of emerging technologies within contemporary CTS management pathways (Wu et al., 2023; Pace et al., 2023).

Overall, these emerging technologies reflect an ongoing shift toward more personalized, minimally invasive, and technology-assisted approaches to CTS diagnosis and treatment. Although many of these innovations require further validation before widespread implementation, they may contribute to improved diagnostic accuracy, optimized patient management, and enhanced postoperative recovery in the future.

4. Discussion

Carpal tunnel syndrome represents a significant clinical problem due to its impact on functional capacity and quality of life and remains an important diagnostic and therapeutic challenge in contemporary clinical practice. Although the condition is well recognized, its management still requires careful integration of patient history, objective testing, symptom severity, and individual functional demands. The present narrative review indicates that CTS should not be treated as a uniform entity, but rather as a heterogeneous disorder in which local mechanical compression, systemic predisposition, occupational load, and duration of nerve dysfunction all interact to influence both presentation and outcome.

Recent epidemiological evidence indicates that the global prevalence of carpal tunnel syndrome is approximately 14.4%, highlighting its substantial clinical and socio-economic burden across populations (Gebrye et al., 2024). From a practical perspective, CTS is also highly relevant in primary care, where early recognition, initial conservative management (including splinting and corticosteroid injections), and timely referral for specialist assessment may influence long-term outcomes (Burton et al., 2014). In addition, current evidence-based recommendations support a structured approach to the diagnosis and management of CTS, emphasizing the role of validated clinical tools, selective use of ultrasonography or electrodiagnostic studies, and individualized treatment planning based on symptom severity and expected long-term benefit (Shapiro & Kamal, 2024).

Contemporary literature also continues to refine the understanding of operative management. Recent reviews of surgical procedures indicate that both open and less invasive techniques remain valid options, although differences between them are observed mainly in early postoperative recovery rather than in long-term results (Pace et al., 2023; Hammert et al., 2023). At the same time, ultrasonography represents a non-invasive and accessible diagnostic tool that allows visualization of structural changes in the median nerve and

surrounding tissues and may complement electrodiagnostic testing in selected cases (Fowler et al., 2011; Yoshii et al., 2020; Cartwright & Walker, 2013). Further evidence suggests that conservative treatment remains an important option in patients with mild to moderate carpal tunnel syndrome, although the effectiveness varies between modalities, with selected interventions such as splinting reported to reduce the need for surgery by up to twofold (Wielemborek et al., 2022; Mao et al., 2024), whereas postoperative outcomes may also be influenced by factors such as pillar pain, which affects approximately 12–13% of patients and typically resolves within 6 months, as well as differences in recovery trajectories, with endoscopic techniques associated with fewer symptoms in the first 1–2 weeks after surgery (Kumar & Lawson-Smith, 2024; Hartrick et al., 2025).

The diagnosis of CTS is still primarily based on clinical features supported by confirmatory testing. Classic symptoms such as nocturnal numbness, tingling in the median nerve distribution, hand pain, and reduced dexterity remain highly relevant in everyday practice (Sevy et al., 2023). Provocative tests such as Phalen's maneuver and Tinel's sign are useful bedside tools, but their value is greatest when interpreted together with the patient's history rather than in isolation. Electrodiagnostic testing remains the most established method for objective confirmation, particularly in patients with atypical symptoms, severe disease, or suspected differential diagnoses (Sevy et al., 2023; Malakootian et al., 2023). In addition to confirming median nerve dysfunction, nerve conduction studies and electromyography may help grade severity and inform treatment selection. At the same time, ultrasonography represents a non-invasive and accessible diagnostic tool that allows visualization of structural changes in the median nerve and surrounding tissues and may serve as a feasible alternative or adjunct to electrodiagnostic testing in selected cases (Fowler et al., 2011). Recent literature also emphasizes the growing role of ultrasound in carpal tunnel syndrome, both as a diagnostic adjunct and as a tool that may support more individualized treatment planning (Yoshii et al., 2020). Recent developments in ultrasound radiomics and elastographic techniques may further improve diagnostic precision and disease stratification (Kim et al., 2025; Wu et al., 2023). Nevertheless, these methods remain dependent on technical expertise and methodological standardization.

Therapeutic decision-making in CTS is strongly influenced by symptom severity and duration. Conservative approaches remain appropriate in mild to moderate disease, especially when symptoms are intermittent and there is no evidence of motor deficit or advanced nerve damage. Splinting, activity modification, and local corticosteroid injection may reduce symptoms and improve short-term function (Ashworth et al., 2023; Omole et al., 2023). Additionally, corticosteroid injections may reduce the need for surgical intervention within the first year of treatment. However, their long-term effectiveness remains limited, and symptoms may recur over time (Ashworth et al., 2023). Additionally, symptom recurrence remains common, and the long-term durability of non-surgical management is limited in many patients.

In contrast, surgery is considered an effective treatment for patients with persistent symptoms, functional decline, or more advanced disease. These findings indicate that surgical decompression should be considered the preferred treatment in patients with moderate to severe carpal tunnel syndrome, especially when conservative management is ineffective (Erfanifam et al., 2022; Rajapandian et al., 2024). Both open and endoscopic techniques demonstrate comparable long-term outcomes, although differences may exist in early postoperative recovery (Rajapandian et al., 2024). As shown in Table 1, both open and endoscopic carpal tunnel release are effective methods of surgical decompression, with differences mainly observed in early postoperative recovery rather than in long-term clinical outcomes.

Several prognostic factors influence surgical outcomes, including disease severity, duration of symptoms, and comorbidities such as diabetes mellitus (Dawod et al., 2025; Zimmerman et al., 2022). Early intervention appears to improve the likelihood of full recovery, while delayed treatment may result in persistent deficits. Postoperative rehabilitation and patient education further contribute to optimal recovery.

Despite advances in diagnosis and treatment, heterogeneity of studies and lack of standardized outcome measures remain important limitations. Future research should aim to improve comparability and develop more individualized treatment strategies. From a clinical perspective, the findings of this review support earlier identification of patients who are most likely to benefit from surgical intervention. Timely surgical decompression in appropriately selected individuals may improve functional outcomes and reduce the risk of irreversible nerve damage.

4.1 Future directions

Future research on carpal tunnel syndrome should focus on the development of more standardized diagnostic criteria, uniform outcome measures, and long-term comparative studies evaluating both surgical and conservative strategies. Advances in imaging, including ultrasound radiomics and elastography, may improve diagnostic accuracy and enable earlier detection of disease progression.

Future research should also focus on improving awareness and education regarding carpal tunnel syndrome among healthcare professionals and physically active individuals, as this may contribute to earlier diagnosis, more effective management, and the development of targeted prevention strategies (Burton et al., 2014).

Artificial intelligence and predictive modeling may support clinical decision-making and patient stratification. Further development of minimally invasive surgical techniques may also enhance recovery while maintaining safety and effectiveness. Future comparative studies should evaluate perioperative strategies, including the role of different anesthesia techniques in carpal tunnel release, as emerging evidence suggests differences in intraoperative pain and patient satisfaction between approaches such as WALANT and conventional anesthesia (Focsa et al., 2025).

4.2 Additional clinical considerations

An important aspect of carpal tunnel syndrome management is the timing of intervention. Delayed surgical treatment in patients with progressive symptoms may lead to worse outcomes. Therefore, careful monitoring and timely referral are essential. Patient expectations also play a crucial role. While most patients improve after surgery, complete symptom resolution is not always possible, especially in advanced disease. Proper preoperative counseling is therefore necessary.

4.3 Practical implications

The findings presented in this review highlight the importance of individualized management strategies in patients with carpal tunnel syndrome. In everyday clinical practice, treatment decisions should consider not only symptom severity, but also occupational demands, hand function requirements, patient expectations, and overall quality of life (Shapiro & Kamal, 2024).

Carpal tunnel syndrome may substantially impair daily functioning, sleep quality, work performance, and fine motor activity, particularly in individuals performing repetitive manual tasks (Omole et al., 2023). Therefore, prompt recognition of progressive symptoms and appropriate specialist referral remain clinically important. Electrodiagnostic studies may support clinical decision-making by helping assess disease severity and identify patients who are more likely to benefit from surgical intervention (Sevy et al., 2023).

Shared decision-making between clinicians and patients also plays an important role in selecting the most appropriate treatment strategy. Patients should be informed about the expected benefits and limitations of both conservative and surgical management, including possible recovery time, postoperative discomfort, and realistic functional expectations (Rajapandian et al., 2024). Appropriate counseling may improve adherence to treatment recommendations and increase patient satisfaction.

Postoperative education should additionally include guidance regarding gradual return to activity, hand protection, ergonomic modifications, and symptom monitoring during recovery. Such practical measures may support functional recovery and improve patient understanding of the postoperative course. Overall, individualized treatment planning combined with patient education and timely intervention appears essential for achieving favorable long-term outcomes in CTS management (Shapiro & Kamal, 2024).

4.4 Proposed Clinical Approach and Future Perspectives

The available evidence suggests that management of carpal tunnel syndrome should be individualized and guided by symptom severity, duration of symptoms, functional impairment, patient preferences, and clinical findings, with electrodiagnostic studies used selectively when diagnostic uncertainty exists or additional confirmation is required (Burton et al., 2014; Shapiro & Kamal, 2024). A structured approach to diagnosis and treatment may improve patient outcomes and facilitate timely intervention in individuals at risk of progressive median nerve dysfunction.

Patients presenting with mild or intermittent symptoms without evidence of motor impairment may initially benefit from conservative treatment strategies. Common first-line interventions include nocturnal wrist splinting, activity modification, ergonomic adjustments, and local corticosteroid injections (Ashworth et al., 2023; Omole et al., 2023). These measures frequently provide short-term symptom relief and may delay or

reduce the need for surgical intervention. However, symptom recurrence remains relatively common, and long-term effectiveness is generally lower than that observed following surgical decompression (Ashworth et al., 2023; Shi & MacDermid, 2011).

Electrodiagnostic studies continue to play an important role in confirming diagnosis, assessing disease severity, and supporting treatment selection (Sevy et al., 2023; Malakootian et al., 2023). In addition, recent advances in ultrasound imaging have expanded diagnostic possibilities. Conventional ultrasonography allows visualization of median nerve enlargement and structural abnormalities, whereas emerging technologies such as shear wave elastography and ultrasound radiomics may improve diagnostic precision and facilitate disease stratification (Kim et al., 2025; Wu et al., 2023). These techniques may provide valuable complementary diagnostic information, particularly when electrodiagnostic findings are inconclusive or when additional structural assessment of the median nerve is required.

Patients with persistent symptoms, progressive sensory deficits, thenar weakness, muscle atrophy, or findings suggesting advanced median nerve compression should be considered for surgical evaluation (Burton et al., 2014; Shapiro & Kamal, 2024).

Treatment selection should be individualized and based on a shared decision-making process that integrates clinical findings, symptom severity, functional limitations, patient preferences, occupational requirements, and surgeon expertise (Pace et al., 2023).

Current evidence indicates that both open and endoscopic carpal tunnel release provide effective decompression and durable symptom relief, with comparable long-term outcomes. Reported differences are mainly related to early postoperative recovery, including pain, scar-related symptoms, and return to daily activities (Rajapandian et al., 2024; Hammert et al., 2023).

Endoscopic techniques may allow faster return to work and earlier recovery of hand function, whereas open release remains widely performed because of its technical simplicity, direct visualization, and well-established safety profile (Rajapandian et al., 2024; Pace et al., 2023).

Recent advances in carpal tunnel syndrome management have expanded the range of treatment options, including ultrasound-guided carpal tunnel release and the increasing use of WALANT (Wide Awake Local Anesthesia No Tourniquet) protocols during surgical treatment (Pace et al., 2023; Focsa et al., 2025).

These approaches may reduce perioperative discomfort, facilitate outpatient treatment, and potentially shorten recovery time. Although early results appear promising, further comparative studies are needed to determine their long-term effectiveness and optimal indications.

Future research should focus on improving patient stratification, identifying prognostic factors associated with recovery, and developing more standardized outcome measures. The integration of advanced imaging, predictive modeling, and artificial intelligence may support more personalized treatment strategies and improve clinical decision-making. In addition, high-quality prospective studies with long-term follow-up are required to better define the comparative effectiveness of conservative and surgical approaches across different patient populations. Such efforts may contribute to earlier diagnosis, more efficient treatment pathways, and improved long-term functional outcomes in patients with carpal tunnel syndrome.

4.5 Socioeconomic Impact and Healthcare Considerations

Carpal tunnel syndrome represents not only a common clinical condition but also an important socioeconomic challenge. Due to its high prevalence among working-age individuals, CTS contributes substantially to healthcare utilization, work absenteeism, reduced productivity, and impaired quality of life. The growing global burden of CTS highlights the importance of effective diagnostic pathways and timely treatment strategies aimed at minimizing long-term disability and associated economic costs (Gebrye et al., 2024).

Occupational factors play a particularly important role in the development and progression of CTS. Repetitive hand movements, forceful gripping, exposure to vibration, and prolonged non-neutral wrist postures have been identified as important risk factors. Consequently, workplace ergonomic interventions, employee education, and early recognition of symptoms may contribute to reducing disease incidence and preventing progression in high-risk populations (Rotaru-Zavaleanu et al., 2024).

From a healthcare perspective, appropriate patient selection and timely referral for specialist evaluation may improve outcomes while reducing unnecessary delays in treatment. Early intervention in patients with progressive symptoms may facilitate faster recovery, earlier return to work, and potentially lower indirect healthcare costs. In addition, the increasing availability of minimally invasive procedures and outpatient treatment pathways may further improve healthcare efficiency while maintaining favorable clinical outcomes.

Given the substantial prevalence and socioeconomic burden of CTS, future healthcare policies should continue to support early diagnosis, evidence-based treatment pathways, and improved access to specialist care. Such measures may contribute to both improved patient outcomes and more efficient utilization of healthcare resources.

5. Conclusions

Carpal tunnel syndrome is a common and multifactorial condition that requires an integrated diagnostic and therapeutic approach. Clinical evaluation supported by electrodiagnostic studies and ultrasonography remains essential for accurate diagnosis. Conservative treatment is effective in mild to moderate cases, while surgical intervention provides more durable outcomes in advanced disease. Despite significant progress, uncertainties remain regarding optimal treatment strategies and timing of intervention. Future research should focus on standardized diagnostic criteria and long-term comparative outcomes to improve patient care.

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