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Carpal Tunnel Syndrome: An Integrated Review of Risk Factors, Diagnostic Strategies and Management Pathways

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Abstract

Carpal Tunnel Syndrome (CTS) is one of the most frequently encountered peripheral nerve compression disorders and is associated with considerable functional, occupational and socioeconomic consequences. The condition develops when the median nerve is subjected to compression within the anatomically restricted carpal tunnel at the wrist. Although CTS has been extensively studied, its clinical presentation, underlying mechanisms and optimal diagnostic pathway remain multifactorial and sometimes challenging. This review presents an integrated analysis of the major factors involved in CTS by synthesizing evidence related to anatomy, epidemiology, risk factors, pathophysiology, clinical manifestations, diagnostic methods and treatment strategies.

The review highlights that CTS should not be understood as a condition caused by a single mechanical factor. Instead, it represents the interaction of anatomical constraints, increased intracarpal pressure, repetitive mechanical loading, nerve ischemia, systemic conditions and individual susceptibility. Clinical history and physical examination remain important in the initial assessment, while nerve conduction studies provide objective information regarding median nerve dysfunction. Imaging modalities such as ultrasonography and magnetic resonance imaging may provide additional anatomical and structural information in selected situations.

Management should be individualized according to symptom severity, functional impairment, duration of disease and evidence of nerve damage. Conservative treatment may be appropriate for mild and moderate presentations, whereas surgical decompression becomes an important option when symptoms persist or neurological impairment progresses. The present review proposes an integrated diagnostic and management perspective that emphasizes the relationship between risk identification, clinical evaluation, objective testing and severity-based treatment selection.

Keywords: Carpal Tunnel Syndrome, Median Nerve, Entrapment Neuropathy, Diagnosis, Nerve Conduction Studies, Ultrasonography, Carpal Tunnel Release

1. Introduction

Carpal Tunnel Syndrome (CTS) is a compressive neuropathy involving the median nerve at the level of the wrist. The condition commonly produces numbness, tingling, discomfort and functional difficulty in the hand, particularly in areas supplied by the median nerve. In more advanced cases, persistent compression may contribute to reduced grip function, weakness and wasting of the thenar musculature.

CTS represents an important clinical problem because its effects extend beyond pain and sensory disturbance. The disorder

may interfere with occupational activities, repetitive manual work and daily tasks. Its occurrence has also been associated with repetitive wrist activity, exposure to vibration and various systemic or physiological conditions.

The reviewed literature indicates that CTS is not a uniform disorder with a single cause. Instead, the development of symptoms may result from the interaction between mechanical stress, anatomical characteristics, increased pressure within the carpal tunnel, impaired circulation of the nerve and systemic susceptibility. The purpose of this review is to provide an integrated perspective on CTS by examining the relationship between risk factors, pathophysiological mechanisms, clinical presentation, diagnostic strategies and management decisions.

2. Review Method and Scope

This paper is designed as a comparative narrative review based primarily on two published review articles concerning CTS. Rather than reproducing the organization of either source, the information has been reorganized into an integrated framework.

The review focuses on the anatomical basis of median nerve compression, epidemiology and functional burden, occupational and medical risk factors, pathophysiological mechanisms, clinical manifestations, diagnostic approaches, conservative and surgical management, and an integrated diagnostic-management framework.

3. Anatomical Basis of Carpal Tunnel Syndrome

The carpal tunnel is an anatomically confined passage at the wrist. Its boundaries are formed by the carpal bones, while the transverse carpal ligament forms the relatively rigid roof. Within this restricted anatomical space, the median nerve travels together with the flexor tendons.

This anatomical arrangement is fundamental to understanding CTS. Because the available space is limited, an increase in tissue volume, fluid accumulation or structural alteration may increase pressure on the median nerve. Similarly, changes in wrist position may influence the dimensions and pressure characteristics of the tunnel.

Anatomical variation may also contribute to differences in clinical presentation. Variations involving the median nerve and its branches can influence sensory and motor symptoms. The sensory distribution commonly includes the thumb, index finger, middle finger and the radial portion of the ring finger. Persistent or severe compression can also affect motor branches responsible for thumb function.

4. Epidemiology and Functional Impact

CTS is recognized as one of the most common entrapment neuropathies. The reviewed literature describes a substantial burden in the general population and indicates that the condition occurs more frequently in women than men in many populations. CTS can occur at different ages but is commonly reported in middle-aged adults.

The impact of CTS should not be measured only by the presence of sensory symptoms. Functional impairment can influence grip strength, fine hand movements and occupational performance. Repetitive manual work may become increasingly difficult as symptoms progress.

An important clinical consideration is that symptom severity and the degree of nerve dysfunction may not always correspond directly. Therefore, clinical decision-making should not rely exclusively on reported pain intensity. Functional status, neurological examination and objective evidence of nerve impairment should also be considered.

5. Risk Factors and Predisposing Conditions

5.1 Occupational and Mechanical Factors

Repeated wrist movements, prolonged wrist flexion or extension and exposure to vibration are frequently associated with CTS. Occupations involving repetitive manual activity may therefore increase mechanical stress on the structures within the carpal tunnel. Mechanical exposure, however, may interact with pre-existing anatomical or systemic susceptibility rather than acting as the sole cause.

5.2 Physiological and Systemic Factors

Several medical and physiological conditions have been associated with an increased likelihood of CTS, including:

- Obesity
- Pregnancy
- Diabetes
- Hypothyroidism
- Menopause
- Renal dysfunction
- Rheumatoid and inflammatory conditions
- Fluid balance alterations

These factors may influence tissue volume within the tunnel, fluid distribution or the vulnerability of the median nerve.

5.3 Structural Factors

Previous injury to the wrist, fractures and post-traumatic structural changes may alter the shape or available space within the carpal tunnel. Tumours or other space-occupying lesions may also contribute to compression in selected cases. Overall, the evidence supports a multifactorial risk model rather than a single-cause model of CTS.

6. Pathophysiology: From Mechanical Stress to Nerve Dysfunction

6.1 Increased Intracarpal Pressure

Pressure within the carpal tunnel is influenced by wrist position. Flexion and extension can increase pressure within the confined space. Repetitive or prolonged mechanical stress may therefore contribute to repeated compression of the median nerve.

6.2 Demyelination and Nerve Dysfunction

Repeated mechanical compression may initially affect the myelin surrounding nerve fibres. Demyelination can interfere with normal nerve conduction and contribute to sensory symptoms such as tingling and numbness. If compression continues, more significant nerve dysfunction may occur.

6.3 Vascular and Ischemic Effects

Persistent pressure may interfere with microcirculation and contribute to ischemic injury. Alteration of the blood-nerve barrier may result in edema and further increase pressure within the nerve. This can create a progressive cycle of mechanical compression, vascular disturbance, edema, increased pressure and further nerve dysfunction.

6.4 Nerve Tethering and Tissue Changes

Chronic compression may interfere with the ability of the median nerve to glide normally during wrist movement. Fibrotic changes and altered surrounding tissues may increase traction on the nerve. Changes in synovial tissue and inflammation of structures surrounding the tendons may further reduce the available space within the carpal tunnel.

7. Clinical Presentation and Progression

The classical symptoms of CTS include:

- Tingling
- Numbness
- Pain or discomfort
- Reduced hand function
- Reduced grip strength

Symptoms frequently involve the thumb, index finger, middle finger and radial aspect of the ring finger. Nocturnal symptoms are commonly reported, and some patients obtain temporary relief by shaking or moving the hand.

7.1 Early Phase

Symptoms are often intermittent and may be particularly noticeable during the night. Tingling and numbness may improve temporarily after changing hand position.

7.2 Intermediate Phase

Symptoms may begin to occur during the day, particularly during repetitive activity or prolonged wrist positioning. Functional difficulty may become more apparent.

7.3 Advanced Phase

Persistent nerve compression may result in sensory loss, weakness and thenar muscle wasting. At this stage, functional impairment may be substantial. This progression emphasizes the importance of early recognition before prolonged nerve damage develops.

8. Diagnostic Approach

An effective diagnosis of CTS should combine clinical and objective information rather than depend entirely on a single test.

8.1 Clinical History

A detailed clinical history should investigate:

- Location of symptoms
- Duration and frequency
- Nocturnal symptoms
- Activities that provoke symptoms
- Repetitive work exposure
- Exposure to vibrating equipment
- Medical conditions associated with CTS
- Functional limitations

8.2 Physical Examination

Common clinical tests include Phalen's test, in which wrist flexion is used to determine whether symptoms are provoked in the median nerve distribution, and Tinel's sign, in which tapping over the carpal tunnel may reproduce paresthesia. These tests are useful but should not be interpreted as independently definitive.

8.3 Nerve Conduction Studies

Nerve conduction studies provide objective information about median nerve function. They can help identify delayed conduction across the carpal tunnel and provide an indication of physiological severity. Their advantages include objective assessment of median nerve dysfunction, estimation of disease severity and assistance in distinguishing CTS from other neuropathies. Clinical interpretation remains important because false-positive and false-negative results can occur.

8.4 Ultrasonography

Ultrasonography can provide structural information about the median nerve. Features such as enlargement of the nerve, flattening and structural changes within the tunnel may support the diagnosis. Ultrasound may be useful when anatomical visualization or an additional non-invasive assessment is desirable.

8.5 Magnetic Resonance Imaging

MRI provides more detailed anatomical information and may assist in selected cases where structural abnormalities, tissue changes or unusual pathology are suspected. Because of cost and availability considerations, MRI may not be necessary for every patient with suspected CTS.

9. Differential Diagnosis

Symptoms similar to CTS can occur in several other conditions. Differential diagnosis may therefore include:

- Cervical radiculopathy
- Proximal median nerve compression
- Peripheral neuropathy
- Pronator syndrome
- Thumb carpometacarpal disorders
- De Quervain tendinopathy
- Other neurological conditions

10. Management Strategies

Management should be based on symptom severity, functional limitations, duration of disease and evidence of neurological damage.

10.1 Conservative Management

Conservative approaches may be appropriate in mild or moderate cases and may include:

- Wrist splinting
- Modification of aggravating activities
- Ergonomic changes
- Reduction of vibration exposure
- Physical therapy
- Nerve-gliding exercises
- Selected pharmacological approaches
- Corticosteroid treatment in appropriate clinical situations

Conservative treatment can improve symptoms, particularly when the condition is identified before significant neurological damage develops. Continued clinical evaluation remains important because short-term symptom improvement does not necessarily indicate complete resolution.

10.2 Surgical Management

Carpal tunnel release aims to reduce pressure on the median nerve by dividing the transverse carpal ligament and increasing the available space within the tunnel. Surgery may be considered when conservative management fails, symptoms persist, neurological deficits progress, severe nerve dysfunction is identified, or significant weakness or muscle wasting develops.

The two broad approaches described in the reviewed literature are open carpal tunnel release and endoscopic carpal tunnel release. The choice of technique depends on clinical circumstances, surgeon experience and patient-specific factors.

11. An Integrated Diagnostic and Management Framework

Based on the synthesis of the reviewed literature, the following conceptual pathway is proposed:

1. Step 1: Identify Symptoms – pain, tingling, numbness or functional difficulty suggesting possible median nerve involvement.
2. Step 2: Assess Risk Profile – evaluate repetitive work, vibration exposure, obesity, pregnancy, diabetes, thyroid disorders and previous wrist injury.
3. Step 3: Clinical Evaluation – perform detailed history and physical examination, including provocative tests where appropriate.
4. Step 4: Consider Differential Diagnoses – evaluate whether symptoms may originate from cervical, proximal nerve or systemic neurological disorders.
5. Step 5: Objective Assessment – use nerve conduction studies when confirmation or severity assessment is required and consider ultrasonography or MRI in selected cases.
6. Step 6: Classify Severity – assess sensory symptoms, functional impairment and evidence of nerve injury.
7. Step 7: Select Treatment – mild or moderate cases may be managed conservatively, while persistent, progressive or severe cases may require consideration of surgical decompression.
8. Step 8: Follow-up – monitor symptom improvement, functional recovery and recurrence.

12. Discussion

The combined literature indicates that CTS should be considered a dynamic and multifactorial condition. Mechanical exposure alone cannot explain all cases, and systemic disease alone does not account for the anatomical and occupational patterns observed in clinical practice.

One important finding from the reviewed literature is the relationship between pathophysiology and management. Early-stage symptoms may primarily reflect potentially reversible changes associated with increased pressure and nerve irritation. Prolonged compression, however, may lead to structural and physiological nerve damage. This provides a rationale for escalating treatment when symptoms persist or neurological impairment becomes progressive.

Another important consideration is the distinction between diagnosis and testing. Clinical symptoms provide essential information about the patient's experience, while nerve conduction studies provide physiological evidence of nerve dysfunction. Imaging can provide anatomical information. These approaches should be regarded as complementary rather than competing methods.

The review also highlights an occupational perspective. Repetitive work and exposure to vibration may increase mechanical stress, but prevention should focus on modifying the interaction between the individual and the working environment rather than assuming that all repetitive work inevitably causes CTS.

Future research may benefit from developing more individualized models that combine clinical symptoms, occupational exposure, anatomical variation, electrophysiological findings and functional outcomes.

13. Conclusion

Carpal Tunnel Syndrome is a common and multifactorial compression neuropathy involving the median nerve at the wrist. Its development is associated with the interaction of anatomical constraints, mechanical stress, increased pressure, vascular changes, tissue alterations and systemic susceptibility.

The diagnosis of CTS should not depend on a single symptom or test. A structured approach involving patient history, clinical examination, differential diagnosis and objective testing provides a more comprehensive basis for decision-making.

Conservative treatment remains appropriate for many mild and moderate cases, particularly when risk factors can be modified. Persistent symptoms, progressive neurological impairment and severe nerve dysfunction may require surgical decompression.

The integrated framework presented in this review emphasizes that effective CTS management begins with understanding the relationship between risk factors, pathophysiological mechanisms, diagnostic evidence and disease severity. This perspective may support more systematic clinical assessment and more individualized treatment decisions.

References

1. Genova A, Dix O, Saefan A, Thakur M, Hassan A. Carpal Tunnel Syndrome: A Review of Literature. Cureus. 2020;12(3):e7333. doi:10.7759/cureus.7333.

2. Ibrahim I, Khan WS, Goddard N, Smitham P. Carpal Tunnel Syndrome: A Review of the Recent Literature. The Open Orthopaedics Journal. 2012;6(Suppl 1:M8):69–76. doi:10.2174/1874325001206010069.