New Therapeutic Vistas in Carpal Tunnel Syndrome Management

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Abstract:

Carpal tunnel syndrome (CTS) represents the most common entrapment neuropathy, affecting approximately 8% of the adult population worldwide. This review examines the pathophysiological mechanisms of CTS and provides a critical evaluation of contemporary interventional approaches that bridge the gap between conservative treatment and surgical management. Particular emphasis is placed on emerging techniques such as ultrasound-guided hydrodissection (HD), prolotherapy, platelet-rich plasma, and hyaluronic acid injections. A systematic analysis of randomised controlled trials and meta-analyses was conducted to evaluate the efficacy, safety, and long-term outcomes of these interventions. The evidence suggests that ultrasound-guided techniques offer significant advantages over blind injections, with dextrose prolotherapy and platelet-rich plasma demonstrating promising results for long-term symptom management. This review provides clinicians with evidence-based recommendations for the appropriate selection of interventional techniques based on disease severity and patient-specific factors, potentially reducing the need for surgical intervention in selected patients.

Key words: Carpal Tunnel Syndrome (CTS), Neuropathy, Emerging Interventional Approaches.

Introduction

Carpal tunnel syndrome (CTS) represents the most prevalent entrapment neuropathy, affecting approximately 8% of the adult population.[1] Characterised by compression of the median nerve as it traverses the carpal tunnel, CTS presents with a classic constellation of symptoms including paraesthesia, numbness, and pain in the median nerve distribution, often accompanied by diminished grip strength and fine motor dexterity.[2,3] The condition significantly impacts the quality of life and work productivity, with economic implications extending beyond direct healthcare costs to include lost workdays and decreased occupational performance.[4]

The management landscape for CTS has traditionally been dichotomised between conservative approaches and surgical intervention. Conservative management typically includes splinting, activity modification, oral anti-inflammatory medications, and local corticosteroid injections.[5] While these approaches may provide temporary relief, their long-term efficacy remains limited, particularly in moderate to severe cases.[6] Conversely, surgical decompression, while generally effective, carries inherent risks including scar formation, pillar pain, and prolonged recovery periods.[7]

The gap between these conventional treatment paradigms has spurred interest in minimally invasive interventional techniques that may provide more durable relief than conservative management while avoiding the morbidity associated with surgery. These intermediate interventions, including ultrasound-guided hydrodissection (HD), prolotherapy, platelet-rich plasma (PRP) injections, and hyaluronic acid applications, represent an evolving frontier in CTS management.[8,9]

This review aims to critically examine the pathophysiological mechanisms underlying CTS and provide a comprehensive analysis of contemporary interventional approaches based on current evidence from randomised controlled trials and meta-analyses. By synthesising this information, we seek to establish evidence-based recommendations for the appropriate selection and implementation of these techniques in clinical practice.

Pathophysiology of CTS

Anatomical considerations

The carpal tunnel is a fibro-osseous canal bounded dorsally by the carpal bones and ventrally by the transverse carpal ligament (TCL). This confined space houses the median nerve and nine flexor tendons – the flexor pollicis longus and eight flexor digitorum superficialis and profundus tendons.[10] The median nerve, positioned superficially beneath the TCL, is particularly vulnerable to compressive forces within this restrictive environment (Figure 1).

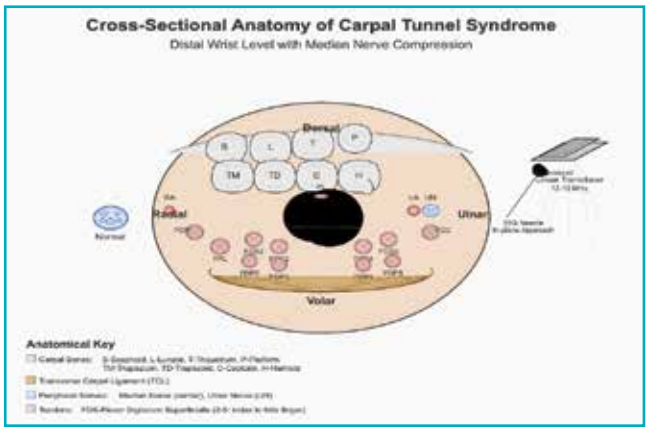

Figure 1: Anatomical site of carpal tunnel with compression of median nerve (Drawn by Dr. Abhishek Dixit using Python Software).

Compression mechanisms

The pathophysiology of CTS involves a cascade of events initiated by increased pressure within the carpal tunnel. Normal pressure ranges from 2-10 mmHg, but can exceed 30 mmHg in CTS patients, particularly during wrist flexion or extension.[11] This elevated pressure leads to several pathophysiological changes:

1. **Vascular compromise:** Initial compression affects venous outflow from the epineurial veins of the median nerve, leading to venous stasis, oedema, and subsequent ischaemia. The compression of the vasa nervorum results in the accumulation of metabolic toxins in the affected segment.[12]

2. **Lymphatic obstruction:** Prolonged compression impairs lymphatic drainage, which normally occurs through vessels located outside the epineurium, further exacerbating local oedema and intraneural pressure.[13]

3. **Demyelination and axonal injury:** Persistent ischaemia leads to focal demyelination, particularly affecting large, myelinated fibres, resulting in slowed nerve conduction. If compression continues, axonal degeneration may occur, leading to permanent neurological deficits.[14]

4. **Mechanical disruption:** Beyond vascular effects, direct mechanical forces impair axonal transport and disrupt the nerve's gliding mechanisms. The median nerve normally exhibits longitudinal excursion during wrist and finger movements. Reduced nerve mobility due to fibrosis and adhesions represents a critical factor in symptom development and persistence.[15]

5. **Neurogenic inflammation:** Compression triggers the release of inflammatory mediators including substance P, calcitonin gene-related peptide, and pro-inflammatory cytokines, perpetuating a cycle of inflammation, oedema, and increased pressure.[16]

Role of nervi nervorum

An important pathophysiological consideration is the impact on nervi nervorum, the free nerve endings supplying the connective tissue sheaths of the main nerve. These structures mediate nociception from the nerve itself and play a critical role in neurogenic inflammation. Compression of nervi nervorum contributes significantly to pain symptomatology in CTS, even before notable conduction abnormalities in the main trunk.[17]

This understanding provides a mechanistic rationale for HD techniques that aim to separate the nerve from surrounding structures, potentially relieving pressure on these pain-mediating nerve fibres.

Progression and Severity Classification

CTS typically progresses through three stages: (1) intermittent symptoms with reversible conduction changes, (2) persistent symptoms with demonstrable sensory and motor deficits, and (3) severe, constant symptoms with muscle atrophy and significant electrophysiological abnormalities.[18] This progression correlates with pathophysiological changes from transient ischaemia to demyelination and ultimately axonal loss. Severity classification guides treatment approaches, with early intervention potentially preventing progression to irreversible neural damage. Electrodiagnostic findings typically correlate with severity:

- **Mild:** Prolonged sensory latencies with normal motor studies
- **Moderate:** Abnormal sensory and motor latencies
- **Severe:** Absence of sensory responses and prolonged motor latencies with reduced amplitude[19]

The cross-sectional area (CSA) of the median nerve on ultrasound represents another important parameter for severity assessment and treatment monitoring, with values greater than 12 mm^2 considered abnormal.[20]

Emerging Interventional Approaches

Ultrasound-guided HD

HD represents a novel technique involving the injection of fluid to separate the nerve from surrounding structures, thereby potentially addressing both mechanical compression and vascular compromise.[21]

Mechanisms of action

HD operates through several proposed mechanisms:

1. **Mechanical separation:** Creating a fluid plane between the median nerve and adjacent structures, reducing direct compression[22]

2. **Improvement in nerve gliding:** Decreasing the gliding resistance of the median nerve, which is considered a principal patho-mechanical factor in CTS[22]

3. **Relief of nervi nervorum compression:** Releasing pressure on the pain-mediating nerve fibres supplying the main nerve[23]

4. **Restoration of vascular flow:** Improving microcirculation by separating the nerve from compressive structures and reducing venous congestion[23]

5. **Disruption of adhesions:** Breaking fibrous connections that restrict nerve movement[23]

Technical approaches

Two primary approaches have been described for ultrasound-guided HD:

1. **In-plane approach:** The needle is positioned in-plane with the ultrasound transducer, perpendicular to the long axis of the nerve. The tissues above and below the nerve are hydrodissected sequentially. This can be performed from either the ulnar or radial side, with some evidence suggesting the radial approach may offer more prolonged pain relief.[24]

2. **Out-of-plane approach:** The needle is advanced parallel to the long axis of the nerve, with the probe initially perpendicular and then parallel to the nerve. This facilitates HD of longer nerve segments but may be technically more challenging.[25]

Comparative studies suggest the in-plane ulnar approach may be more effective than out-of-plane or blind injections in terms of symptom improvement and electrophysiological outcomes.[26]

Efficacy and safety

Multiple randomised controlled trials have demonstrated the efficacy of ultrasound-guided HD. Wang *et al.* conducted a study with 64 patients randomised to HD or control groups, finding improvements in both functional and electrophysiological parameters in the HD group.[27] Similarly, Wu *et al.* demonstrated that HD with 5 mL normal saline was superior to subcutaneous injection above the carpal tunnel, supporting the mechanical separation hypothesis.[28]

A systematic review by Yang *et al.* concluded that ultrasound-guided injections yielded favourable results for symptom severity and functional status compared to conventional approaches.[29] The safety profile appears excellent, with nerve damage being exceptionally rare due to the polyfascicular architecture of peripheral nerves and real-time visualisation provided by ultrasound guidance.[30]

Long-term outcomes are encouraging, with a retrospective study by Li *et al.* reporting effective outcomes in 88.6% of patients after a mean follow-up of 1-3 years. Notably, the number of injections required correlated with initial severity, with mild, moderate, and severe grades requiring an average of 1.7, 2.4, and 2.6 injections, respectively.[31]

Injectate Options for Interventional Approaches

The evolution of interventional management has seen experimentation with various injectates, each with unique properties and proposed mechanisms of action (Table 1).

Injectate	Mechanism of Action	Key Evidence	Advantages	Limitations
Normal saline	• Mechanical separation of nerve from surrounding tissues • Promotion of blood flow • Reduction of nerve compression	Wu *et al.* 2019[28]	• Cost-effective • Minimal side effects • Safe for repeat injections	• Limited durability • Primarily mechanical effect • Less effective than bioactive injectates
Corticosteroids	• Anti-inflammatory effect • Reduction of local oedema • Inhibition of fibroblast activity and collagen formation	Babaei-Ghazani *et al.* 2018[33]	• Rapid onset of action • Strong evidence base • Effective for acute symptoms	• Limited long-term efficacy • Potential for tissue atrophy with repeated use • Risk of tendon weakening • Particulate steroids pose risk of neural damage
Dextrose 5% (D5W)	• Inhibition of TRPV1 receptors • Reduction of neurogenic inflammation • Correction of perineural glycopenia • Modulation of nerve hyperexcitability	Wu *et al.* 2017[39] Wu *et al.* 2018[40]	• Superior long-term outcomes • Non-toxic to neural tissue • Safe for repeat injections • May promote tissue healing	• Slower onset of action • May require multiple treatments • Mechanism not fully elucidated
Platelet-rich plasma (PRP)	• Delivery of growth factors (TGF-β, PDGF, VEGF) • Promotion of tissue repair and regeneration • Modulation of inflammatory response	Wu *et al.* 2017[43] Raeissadat *et al.* 2018[44]	• Long-lasting effects • Potential regenerative properties • Autologous nature reduces reaction risk • May reduce need for surgery	• Preparation complexity • Higher cost • Standardisation challenges • Requires special equipment
Hyaluronic acid	• Anti-adhesion properties • Anti-inflammatory effect • Promotion of nerve regeneration • Enhancement of nerve gliding	Su *et al.* 2021[46] Elawamy *et al.* 2020[47]	• Rapid onset of action • Natural component of human tissues • Improves tissue hydration and gliding • Favourable safety profile	• Higher cost • Variable molecular weights available • Less durable than PRP or D5W
Ozone (O_2-O_3)	• Improved tissue oxygenation • Enhancement of cellular metabolism • Anti-inflammatory properties • Reduction of oxidative stress	Bahrami *et al.* 2019[50]	• Potent anti-inflammatory effect • Antimicrobial properties • Improvement in tissue oxygenation	• Limited standardisation • Specialised equipment required • Variable concentration protocols • Less robust evidence base

Table 1: Comparison of different injectates for carpal tunnel syndrome.

Abbreviations: TRPV1: Transient Receptor Potential Vanilloid 1; TGF-β: Transforming Growth Factor Beta; PDGF: Platelet-derived Growth Factor; VEGF: Vascular Endothelial Growth Factor.

Corticosteroids

Corticosteroid injections remain the most widely studied intervention for CTS. Their anti-inflammatory properties reduce swelling within the carpal tunnel, potentially alleviating pressure on the median nerve.[32] While traditionally administered using anatomical landmarks, ultrasound-guided corticosteroid injections have demonstrated superior efficacy.

A meta-analysis by Babaei-Ghazani *et al.* examining 10 randomised controlled trials (n=633) found ultrasound-guided corticosteroid injections provided significantly greater improvement in symptom severity compared to landmark-guided injections (standardised mean difference [SMD]=-0.82; 95% CI, -1.14 to -0.50; $p < 0.001$).[33] However, the duration of benefit appears limited, with effects typically waning after 3-6 months.[34]

The choice of corticosteroid may influence outcomes and safety profiles. Triamcinolone acetonide, a commonly used particulate steroid, carries a risk of permanent nerve injury if accidentally injected intraneurally. Conversely, dexamethasone sodium phosphate, a non-particulate steroid, may offer a more favourable safety profile while maintaining efficacy.[35]

Dextrose prolotherapy (5% dextrose in water, D5W)

Dextrose prolotherapy has emerged as a promising approach for CTS, particularly for its potential neuromodulatory and regenerative properties. D5W is iso-osmolar, minimising irritation to neural structures while potentially offering therapeutic benefits.[36]

The mechanism of action remains incompletely understood but may involve inhibition of transient receptor potential vanilloid receptor-1 (TRPV1), blocking the release of substance P and calcitonin gene-related peptide, key mediators in neurogenic inflammation.[37] Additionally, chronic neuropathic pain may reflect relative glycopenia around affected nerves, with dextrose potentially correcting this metabolic imbalance.[38] Wu *et al.* conducted a pivotal randomised controlled trial comparing 5 mL of D5W against placebo in 54 patients with mild-to-moderate CTS. At 6-month follow-up, the dextrose group demonstrated significantly greater improvements in the Boston Carpal Tunnel Syndrome Questionnaire symptom severity score (-0.8 ± 0.5 vs -0.2 ± 0.4; $p < .001$) and functional status score (-0.7 ± 0.6 vs -0.1 ± 0.3; $p < .001$).[39]

In a subsequent study comparing D5W to triamcinolone injection, Wu *et al.* found superior long-term outcomes with dextrose. While both treatments showed initial efficacy, the dextrose group-maintained improvements at 4-6 months, whereas the steroid group demonstrated regression toward baseline.[40]

Dosage considerations may be relevant, with Lin *et al.* demonstrating that 4 mL of D5W provided better efficacy than 1 mL or 2 mL volumes based on symptom relief and functional improvement at 1-, 4-, and 12-weeks post-injection.[41]

Platelet-rich plasma (PRP)

PRP represents an autologous concentration of platelets containing numerous growth factors, including transforming growth factor-β, platelet-derived growth factor, and vascular endothelial growth factor. These bioactive components potentially promote tissue repair and nerve regeneration.[42]

Wu *et al.* conducted a randomised controlled trial comparing single ultrasound-guided PRP injections against night splinting in 60 patients with mild-to-moderate CTS. At 6-month follow-up, the PRP group demonstrated significantly greater improvements in pain, symptom severity, functional status, and CSA of the median nerve.[43]

Similarly, Raeissadat *et al.* compared PRP to corticosteroid injections in 41 patients, finding comparable short-term outcomes but superior long-term efficacy with PRP at 10-week follow-up.[44]

Hyaluronic acid (HA)

HA has gained attention for its potential anti-adhesion, anti-inflammatory, and nerve regeneration properties. As a glycosaminoglycan naturally present in human tissues, HA may improve nerve gliding mechanics while modulating inflammatory responses.[45]

Su *et al.* conducted a randomised trial comparing HA to normal saline in CTS patients, demonstrating superior outcomes in the HA group regarding symptom severity, functional status, and electrophysiological parameters.[46] Similarly, Elawamy *et al.* found that HD with HA offered more rapid onset of pain relief and better median nerve conduction compared to HD with normal saline alone over a 6-month follow-up period.[47]

When compared directly to corticosteroids, a study by Alsaeid demonstrated that HA significantly outperformed dexamethasone in terms of Boston Carpal Tunnel Questionnaire scores, electrophysiological studies, and sonographic parameters at 1 week, 1 month, 3 months, and 6 months post-intervention.[48]

Ozone therapy

Ozone therapy represents an emerging approach for various musculoskeletal disorders, including CTS. The proposed mechanisms include improved tissue oxygenation, enhanced cellular metabolism, anti-inflammatory effects, and reduction of oxidative stress.[49]

Bahrami *et al.* conducted a randomised controlled trial of 40 patients with mild or moderate CTS, comparing ozone injection to corticosteroid. At 10-week follow-up, the ozone group demonstrated superior improvements in functional scales and visual analog scale scores.[50]

However, when compared directly to corticosteroid injection in another study, both treatments showed improvement in symptom severity and pain at 6 and 12 weeks, but electrophysiological parameters improved significantly only in the corticosteroid group.[51]

Comparative Efficacy of Different Injectates

Wu *et al.* conducted a comparative study of commonly used injectates in patients with severe CTS (CSA > 15 mm^2).

Intervention	Symptom Improvement	Functional Improvement	Electrophysiological Improvement	Sonographic Improvement	Onset of Action	Duration of Effect	Recommended for
Conservative Management							
Splinting	+	+	+/-	-	Slow (weeks)	Temporary	Mild CTS, initial management
Oral NSAIDs	+	+/-	-	-	Moderate (days)	Short-term	Acute symptoms, mild CTS
Intermediate Interventions							
US-guided corticosteroid injection	+++	++	++	+	Rapid (days)	3-6 months	Moderate CTS, acute symptoms
US-guided D5W HD	++	+++	++	++	Moderate (1-2 weeks)	6+ months	Mild to moderate CTS, patients seeking durability
US-guided PRP injection	++	+++	++	+++	Moderate (1-2 weeks)	6+ months	Moderate to severe CTS, failed conservative treatment
US-guided HA injection	+++	++	++	++	Rapid (days)	3-6 months	Moderate CTS, patients needing rapid relief
US-guided ozone therapy	++	++	+	+	Moderate (1-2 weeks)	3-4 months	Alternative for patients with contraindications to other treatments
Surgical Approaches							
Endoscopic release	++++	++++	+++	+++	Delayed (weeks)	Long-term/ permanent	Severe CTS, failed conservative/ interventional approaches
Open release	++++	++++	+++	+++	Delayed (weeks)	Long-term/ permanent	Severe CTS, recurrent CTS, complicated cases

Table 2: Comparative efficacy of interventional approaches for carpal tunnel syndrome.

Rating scale: - = no effect; + = minimal effect; ++ = moderate effect; +++ = significant effect; ++++ = maximum effect

Abbreviations: US: Ultrasound; D5W: 5% Dextrose in Water; PRP: Platelet-Rich Plasma; HA: Hyaluronic Acid; CTS: Carpal Tunnel Syndrome; NSAIDs: Non-steroidal Anti-inflammatory Drugs.

Comparing normal saline, D5W, PRP, and HA, they found that single doses of PRP, D5W, and HA were significantly more effective than normal saline regarding symptomatic improvement, functional outcomes, and reduction in median nerve cross-sectional area.[52]

For long-term efficacy, PRP and D5W demonstrated greater durability than HA at 6-month follow-up, although PRP showed slightly superior results. For early response, HA demonstrated the most rapid effect at 1-month post-intervention.[53]

This differential temporal response pattern may guide clinical decision-making, with HA potentially preferred for rapid symptom relief, while PRP or D5W may be superior choices for sustained long-term outcomes (Table 2).

Volume Considerations in HD

The optimal volume for HD remains an area of active investigation. Traditional approaches typically utilise larger volumes (5-10 mL) to achieve mechanical separation of the nerve from surrounding structures.[54] However, the minimum required volume for therapeutic effect remains undefined.

Wang *et al.* conducted a randomised trial comparing ultrasound-guided HD with 10 mL of solution (1 mL triamcinolone, 1 mL lidocaine, 8 mL saline) versus 2 mL (1 mL triamcinolone, 1 mL lidocaine). Both groups demonstrated comparable functional and electrophysiological improvements, suggesting volume may not be the primary determinant of efficacy.[27]

Conversely, Lin *et al.* found that ultrasound-guided injection of 4 mL of D5W provided superior efficacy compared to 1 mL or 2 mL volumes based on symptom relief and functional improvement at 1-, 4-, and 12-weeks post-injection.[41] In a subsequent analysis, they demonstrated that higher volumes (4 mL) yielded better nerve mobility and more significant reductions in median nerve cross-sectional area compared to smaller volumes.[55]

This discrepancy may reflect differences in the primary mechanism of action between various injectates. Corticosteroids may exert their effect predominantly through anti-inflammatory properties, with volume playing a lesser role. In contrast, D5W may require sufficient volume to achieve

both mechanical separation and adequate distribution of the dextrose solution to modulate neurogenic inflammation and local metabolism.

Ultrasound-Guided Versus Blind Injections

The role of ultrasound guidance in CTS interventions has been extensively studied, with compelling evidence supporting its superiority over traditional landmark-guided approaches. Chen *et al.* conducted a double-blind randomised controlled trial comparing ultrasound-guided versus direct approach corticosteroid injections in CTS patients. The ultrasound-guided group demonstrated earlier and more profound symptom relief, greater improvements in sensory testing, and superior gains in sensory nerve conduction velocity.[56]

A comprehensive meta-analysis by Babaei-Ghazani *et al.* synthesising data from 10 randomised controlled trials (n=633) found ultrasound-guided injections significantly outperformed landmark-guided approaches in symptom severity improvement (SMD=-0.82; 95% CI, -1.14 to -0.50; $p < 0.001$). While functional status showed a trend favouring ultrasound guidance, this did not reach statistical significance.[33]

The advantages of ultrasound guidance include:

1. **Precise medication delivery:** Ensuring the injectate reaches the intended target[30]
2. **Avoidance of iatrogenic injury:** Minimising risk to neurovascular structures[30]
3. **Confirmation of spread patterns:** Visualising the distribution of injectate around the nerve[30]
4. **Potential diagnostic information:** Providing real-time assessment of neural morphology and surrounding structures[30]
5. **Improved patient satisfaction:** Potentially reducing procedural anxiety and discomfort[30]

The safety profile of ultrasound-guided procedures appears excellent, with nerve injury exceptionally rare due to the polyfascicular architecture of peripheral nerves and real-time visualisation.[30]

HD Versus Surgical Management

For patients with refractory symptoms or severe CTS, surgical decompression has traditionally been considered the gold standard. However, emerging evidence suggests HD techniques may offer a viable alternative in selected cases. Zeng *et al.* directly compared ultrasound-guided HD versus surgery in CTS patients. While both approaches demonstrated efficacy, HD offered several advantages including smaller incision, lower cost, shorter procedural time, and faster recovery.[58]

The decision between interventional approaches and surgery should consider several factors:

1. **Disease severity:** Severe CTS with significant axonal loss and muscle atrophy may necessitate surgical intervention
2. **Failed conservative management:** Patients who have not responded to initial conservative measures
3. **Patient preferences:** Consideration of recovery time, procedural invasiveness, and risk tolerance
4. **Comorbidities:** Medical conditions that may increase surgical risk.
5. **Occupational demands:** Requirements for rapid return to function versus long-term outcome optimisation[59]

For mild to moderate CTS, or in patients with contraindications to surgery, HD with appropriate injectates may offer a reasonable alternative with potentially equivalent long-term outcomes in selected cases.

Clinical Recommendations

Based on the current evidence, several practical recommendations emerge for the interventional management of CTS:

1. Ultrasound guidance is preferred over blind or landmark-guided injections for all interventional procedures, offering superior precision, safety, and potentially improved outcomes.
2. The in-plane ulnar approach generally provides optimal results for HD, although the radial approach may offer longer pain relief in some cases.
3. Injectate selection should be tailored to patient-specific factors:
   - For rapid symptomatic relief: Corticosteroids or hyaluronic acid
   - For durable long-term results: D5W or PRP
   - For patients with contraindications to other injectates: Normal saline
4. Volume considerations suggest 4-5 mL may represent an optimal balance for HD, particularly when using D5W, though this may vary based on injectate type.
5. Disease severity influences treatment selection:
   - Mild CTS: Conservative management initially; if unsuccessful, consider D5W or HA HD
   - Moderate CTS: Consider ultrasound-guided interventions as first-line therapy; PRP or D5W may offer optimal long-term results
   - Severe CTS: Surgical intervention is typically preferred; in patients declining surgery or with contraindications, multiple sessions of HD (particularly with PRP) may provide benefit
6. Combination approaches may offer synergistic benefits, such as initial corticosteroid injection for rapid relief followed by D5W or PRP for long-term management,

though evidence for such sequential therapy remains limited.

7. Safety considerations favour non-particulate steroids (dexamethasone) over particulate options (triamcinolone) when corticosteroids are selected, due to reduced risk of intraneural injection complications.

8. Monitoring response should include patient-reported outcomes (Boston Carpal Tunnel Questionnaire), objective measures (grip strength, sensory testing), and where available, serial ultrasound assessment of median nerve CSA and mobility.

Future Directions

Several areas warrant further investigation to refine our understanding and optimisation of interventional approaches for CTS:

1. Comparative effectiveness research directly contrasting various injectates in large, well-designed randomised controlled trials with extended follow-up periods

2. Identification of predictive factors for response to specific interventions, potentially including ultrasound parameters, electrodiagnostic findings, or symptom characteristics

3. Exploration of combination therapies utilising sequential or simultaneous application of different injectates or techniques

4. Standardisation of techniques including optimal needle approach, volume, concentration, and post-procedural recommendations

5. Investigation of regenerative approaches beyond PRP, potentially including stem cell therapies or nerve growth factors

6. Development of novel injectates specifically designed to address the pathophysiological mechanisms of CTS

7. Cost-effectiveness analyses comparing interventional approaches to conventional management strategies

Conclusion

The management of CTS continues to evolve, with ultrasound-guided interventional techniques offering a promising middle ground between traditional conservative measures and surgical decompression. Current evidence supports the efficacy and safety of HD techniques utilising various injectates, each with unique properties and potential advantages.

Ultrasound guidance significantly enhances precision and outcomes compared to landmark-guided approaches. Among available injectates, dextrose prolotherapy and PRP demonstrate particular promise for durable long-term outcomes, while hyaluronic acid may offer more rapid symptomatic relief.

Patient selection remains crucial, with disease severity, prior treatment response, comorbidities, and patient preferences informing the appropriate intervention strategy. For mild to moderate CTS, ultrasound-guided HD may provide a viable alternative to surgery in many cases, potentially reducing healthcare costs and recovery time while maintaining comparable outcomes.

As our understanding of CTS pathophysiology continues to deepen, and interventional techniques are further refined, the management paradigm will likely continue shifting toward minimally invasive, targeted approaches that address the underlying mechanisms of neural compression and dysfunction.

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