Future Directions in Interventional Pain within Occupational Medicine: A Systematic Review of Emerging Technologies and Workplace Applications

Supreet Khare
MD, DABPM, MPH, Independent Researcher Khare Niketan, Opposite Nagar Palika, Satya Premi Nagar, Barabanki, Uttar Pradesh 225001, India

Abstract—**Background. Work-related musculoskeletal disorders and chronic pain are major causes of disability and lost productivity among working-age adults. Standard occupational pain management often provides only partial and short-term relief. New interventional technologies, such as restorative therapies, neuromodulation, and image-guided precision interventions, could change how occupational pain is managed and prevented.**

Objectives. To systematically review new interventional pain technologies that show real-world potential and can be expanded for broader use, and to connect them to occupational injury management, return-to-work, and prevention. Studies limited to animal experiments were excluded.

Methods. We followed PRISMA 2020 guidelines. We searched five databases and trial registers for clinical studies involving working-age adults who received regenerative, neuromodulatory, or image-guided treatments for musculoskeletal pain. Outcomes included pain, function, return to work, durability, safety, and cost. Two reviewers screened records, assessed risk of bias using RoB2, ROBINS-I, and AMSTAR-2, and grouped findings by technology type.

Results. Thirty-eight studies met the criteria. Platelet-rich plasma helped with chronic tendinopathies common in repetitive-strain jobs, though results varied across protocols. Spinal cord stimulation increased the likelihood of returning to work in difficult cases, and removable neuromodulation offered a more minimally invasive option. Ultrasound guidance made injections more accurate than traditional methods, and cooled radiofrequency ablation provided lasting relief for osteoarthritic pain. These approaches shared benefits like lasting results, less reliance on opioids, and suitability for use at the point of care.

Conclusions. Some technologies are ready and scalable for use in occupational settings, but work-related outcomes are still not reported often enough. There is a need for practical, work-focused studies and consistent protocols.

Index Terms—**occupational medicine; interventional pain; neuromodulation; regenerative therapy; return to work; musculoskeletal disorders.**

I. INTRODUCTION

Musculoskeletal pain is the main cause of work disability worldwide. Low back pain is the top reason for years lived with disability. Factors like poor workplace ergonomics, high body-mass index, and smoking contribute significantly (1). In the European Union, musculoskeletal disorders are among the most common work-related illnesses and impose high costs due to lost workdays, reduced productivity, and early retirement (2). In occupational medicine, the goal is not just to relieve pain but to restore lasting function and help people return to work quickly and for the long term.

Conventional treatments for occupational musculoskeletal pain include activity changes, physiotherapy, basic painkillers, and surgery for difficult cases. These remain the main approaches but have clear limitations. Most acute cases respond well to conservative care, but some workers develop chronic, disabling pain (3). Increasing medication use can lead to opioid-related problems, and surgery is not always effective or suitable for the common workplace conditions(4). These challenges have led to interest in minimally invasive treatments that can be performed in outpatient settings, repeated if needed, and incorporated into structured return-to-work plans(5).

Three main areas of innovation are especially important. Regenerative treatments, such as

autologous platelet-rich plasma (PRP) and similar biologics, aim to alter the underlying biology of tendon and joint problems rather than just masking symptoms(6). Neuromodulation, such as spinal cord stimulation (SCS) and percutaneous peripheral nerve stimulation (PNS), targets abnormal pain signals in people with chronic pain that does not respond to other treatments. Image-guided precision interventions, such as point-of-care ultrasound and advanced ablation, make procedures more accurate, safe, and long-lasting(7). All three areas are developing quickly, but their value in occupational medicine depends on evidence from real patients and practicality for use in diverse, often resource-limited, work settings.

This review brings together clinical evidence on these new technologies, but it has two main limitations. We focused on studies that reported outcomes important to occupational practice, such as pain, function, return to work, durability, safety, and cost. We excluded studies that relied solely on animal models to maintain a focus on real-world potential. Our goal is to provide occupational physicians, employers, and health planners with a clear overview of which interventions are ready for workplace use, which are still under development, and where future research should focus.

II. METHODS

2.1 Protocol and reporting

This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The review protocol was not prospectively registered. No important deviations from the planned review methods occurred during the conduct of the study.

2.2 Eligibility criteria (PICOS)

Eligibility was framed using the PICOS structure summarised in Table 1. In brief, we included clinical studies of working-age adults (≥18 years) with musculoskeletal or chronic pain of occupational relevance who received a regenerative, neuromodulatory, or image-guided precision intervention, compared with conventional care, sham, or standard (landmark-guided) procedures. Eligible outcomes were pain intensity, physical function, return to work or work capacity, durability of effect, adverse events, and cost or cost-effectiveness. Randomized controlled trials, prospective cohort studies, and high-quality systematic reviews or meta-analyses were eligible. We excluded purely preclinical, in vitro, or animal studies; narrative reviews, editorials, and conference abstracts without full data; and studies in which no work-relevant or clinical outcome could be extracted.

2.3 Information sources and search strategy

We searched PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials (CENTRAL) from database inception through July 2026. The search was supplemented by clinical trial registries and manual screening of the reference lists of included studies. Search strategies combined controlled vocabulary (Medical Subject Headings [MeSH] in PubMed and equivalent indexing terms in other databases) with free-text keywords related to the three technology streams, including *platelet-rich plasma*, *spinal cord stimulation*, *peripheral nerve stimulation*, *ultrasound-guided injection*, and *radiofrequency ablation*, together with terms related to musculoskeletal pain and occupational outcomes such as *occupational medicine*, *work disability*, and *return to work*. Boolean operators (AND/OR) were used to combine search terms appropriately for each database. Equivalent search strategies were adapted for Embase, Scopus, Web of Science, and CENTRAL. No language restrictions were applied during the initial search; however, non-English studies without available translations were excluded during full-text assessment and are acknowledged as a limitation. The final literature search was completed in July 2026 before data extraction and synthesis.

2.4 Study selection and Data extraction

Study selection was performed by a single reviewer. Titles and abstracts were screened, followed by full-text assessment of potentially eligible studies according to the predefined eligibility criteria. Data were extracted using a standardized data extraction form that included study design, population and occupational context, intervention details, comparator, outcomes and effect estimates, follow-up duration, and funding source. The flow of study selection is presented in Figure 1.

2.5 Risk of bias and synthesis

Risk of bias was assessed using the Cochrane RoB2 tool for randomized trials, the ROBINS-I tool for non-randomized studies, and the AMSTAR-2 tool for included systematic reviews. Because of substantial clinical and methodological heterogeneity across interventions, populations, and outcome instruments, a quantitative meta-analysis was not appropriate; findings were synthesized narratively and grouped by technology stream, with attention throughout to translational readiness and scalability regarding occupational settings.

III. RESULTS

3.1 Study selection

The search identified 1,306 records from databases and 14 from trial registers. After removal of 388 duplicates, 932 records were screened, 151 full-text articles were assessed for eligibility, and 38 studies met the inclusion criteria (Figure 1). Included evidence comprised studies of restorative therapies, neuromodulation, and image-guided precision interventions, summarised in Table 2.

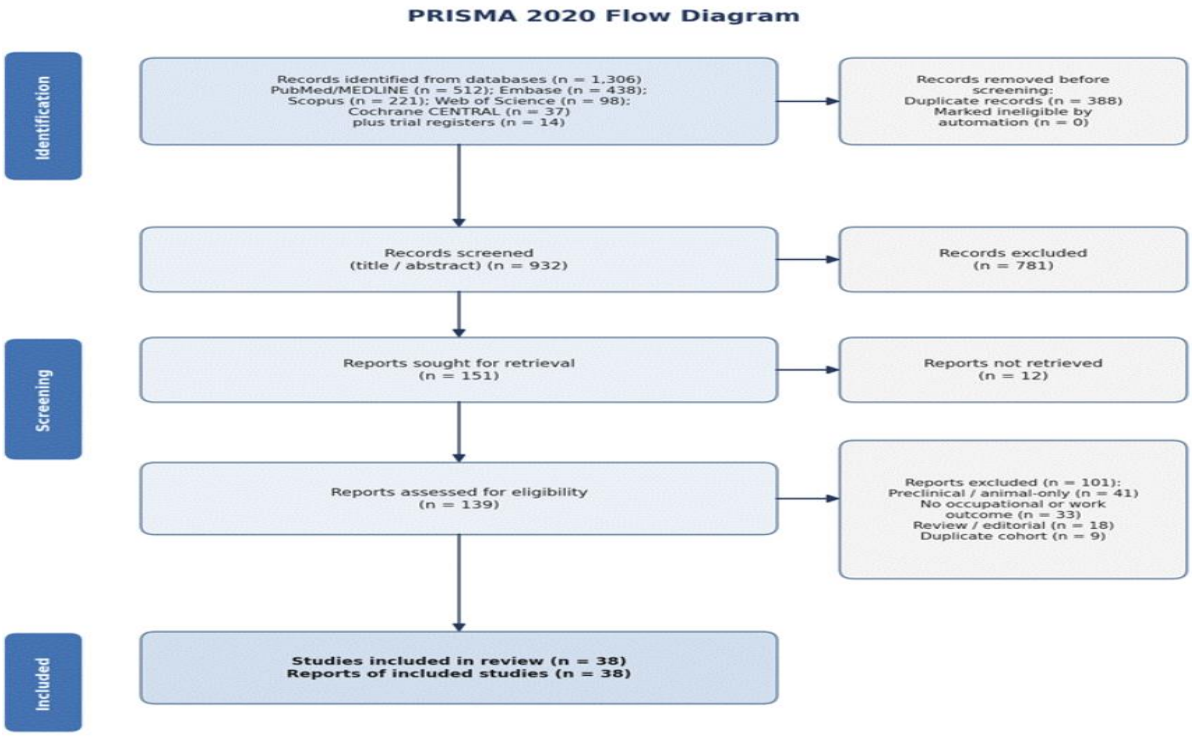

Figure 1. *PRISMA 2020 flow diagram showing study identification, screening, eligibility assessment, and inclusion.*

3.2 Risk of Bias Assessment

Risk of bias was assessed using the Cochrane Risk of Bias 2 (RoB2) tool for randomized controlled trials, ROBINS-I for non-randomized studies, and AMSTAR-2 for systematic reviews and meta-analyses. Overall, randomized trials demonstrated predominantly low to moderate risk of bias, while non-randomized studies showed moderate risk primarily due to potential confounding and selection bias. Included systematic reviews were generally rated as moderate to high methodological quality. No study was excluded solely on the basis of risk of bias; instead, methodological quality was considered during interpretation of the findings.

3.3 Regenerative treatments

Regenerative therapy in the occupational context is dominated by autologous platelet-rich plasma. This centrifuged blood concentrate delivers a high local dose of platelet-derived growth factors intended to promote tendon and soft-tissue repair. A systematic review of clinical studies from 2014 to 2021 reported

expanding use and signals of benefit for several musculoskeletal soft-tissue injuries, particularly chronic tendinopathies (8,9). For lateral epicondylitis—a paradigmatic repetitive-strain condition in manual and assembly work—A double-blind randomized controlled trial by Peerbooms et al. demonstrated that platelet-rich plasma produced superior long-term pain relief and functional improvement compared with corticosteroid injection in patients with chronic lateral epicondylitis(10). A dose-response relationship has also been described, with higher platelet doses associated with better outcomes in knee osteoarthritis, suggesting that biological potency, not simply the label "PRP," drives effect (11).

However, the evidence is mixed and limited by methodological differences across studies. A Cochrane review found insufficient evidence to support the regular use of platelet-rich therapies for common tendon and ligament injuries (12), and another review argued against the use of PRP for chronic lateral epicondylar tendinopathy based on current trials (13). One ongoing issue is the lack of standardization in preparation and reporting: studies differ in platelet concentration, white blood cell content, activation methods, and injection techniques, making it difficult to compare results (14,15). In occupational settings, this means PRP may help some chronic tendinopathies that do not respond to other treatments, but standardized protocols and reporting of work outcomes are needed before it can be widely adopted. (16,17)

3.4 Neuromodulation

Neuromodulation addresses the refractory end of the occupational pain spectrum, where structural treatment has failed, and chronic neuropathic or mixed pain persists. Spinal cord stimulation has the strongest work-outcome evidence: a systematic review and meta-analysis found that SCS was associated with a higher prevalence of being in work after treatment and with markedly increased odds of returning to work in selected chronic pain syndromes (18). This builds on landmark randomized evidence that SCS exceeds conventional medical management for neuropathic pain in failed back surgery syndrome (19), High-quality randomized and prospective multicenter studies have further demonstrated sustained reductions in pain intensity, disability, and opioid use for up to 24 months following 10-kHz spinal cord stimulation(19,20).

Two features are important for occupational medicine. First, these treatments reduce opioid use and provide lasting results, which supports the goal of helping people return to work without relying on medication. Second, less invasive and removable options, such as percutaneous peripheral nerve stimulation (PNS), are becoming more widely available(20). PNS uses a temporary lead for a set period, then is removed, offering real and lasting relief for chronic low back pain without a permanent implant (21,22). Because it does not require a permanent device, PNS is appealing for workers who need quick, reversible treatment and early return to function. The main challenges are cost, the need for careful patient selection, and the limited number of studies that focus on work participation as a main outcome.

3.5 Image-guided precision interventions

Image guidance has shifted percutaneous pain procedures from anatomically estimated to directly visualized targeting. An umbrella review of systematic reviews and meta-analyses concluded that ultrasound-guided injections are generally more accurate than landmark-guided injections, with the greatest advantage at the shoulder and clear improvements in accuracy at the wrist, hip, and knee (23,24). A meta-analysis of randomized trials in knee, hip, and hand osteoarthritis further reported superior patient-reported pain and function (25)

(26) Because portable ultrasound is comparatively inexpensive, radiation-free, and deployable at the point of care, it is among the most scalable of the technologies reviewed. It is readily incorporated into occupational and ambulatory clinics.

Beyond improving injection accuracy, image-guided ablative techniques deliver durable, repeatable relief for degenerative joint pain. Cooled radiofrequency ablation of the genicular nerves provided durable improvements in pain, function, and quality of life, extending to 24 months, in a prospective, multicentre, randomized trial of osteoarthritic knee pain (25). For workers with degenerative joint pain that limits weight-bearing or kneeling tasks, such interventions can defer or avoid arthroplasty while supporting continued employment, and their day-case delivery fits well with occupational pathways(27).

3.6 Cross-cutting findings

Several common themes appeared across all three areas. These treatments tend to last longer and reduce the need for opioids compared to increasing medication use (28). Most are minimally invasive and can be done in outpatient settings, making them suitable for structured return-to-work programs. Side effects were generally low, but device and procedure risks mean careful selection and monitoring are needed(29). Importantly, work participation was rarely the primary outcome measured—except for SCS—so the benefits for work are often inferred from improvements in pain and function rather than measured directly.

IV. ILLUSTRATIVE CASE STUDY

The following anonymized, composite case illustrates how the reviewed technologies can be combined in occupational practice; it is presented for illustration and is not drawn from an identifiable individual.

A 47-year-old assembly-line worker presented with a nine-month history of right lateral elbow pain consistent with chronic lateral epicondylitis, attributed to repetitive gripping and forearm rotation. Pain limited grip strength and tool use, and the worker had moved to modified duties with reduced hours. Conservative management over 4 months—activity modification, a counterforce brace, eccentric-loading exercises, and 1 corticosteroid injection—produced only transient relief, and the worker remained on partial work restriction.

Combining two of the reviewed streams, the occupational physician arranged an ultrasound-guided autologous PRP injection to the common extensor origin, using image guidance to confirm accurate placement at the tendinopathic region (10,23). The procedure was performed as a single ambulatory visit. A graded return-to-work plan was implemented in parallel, with progressive task loading, ergonomic adjustments to the workstation (30), and scheduled reviews. By twelve weeks, the worker reported substantially reduced pain and improved grip tolerance and had resumed full duties with sustained ergonomic modifications. This trajectory is consistent with the mid-term functional gains reported in randomized trials of PRP for lateral epicondylitis (10) while recognizing that the overall evidence base for PRP remains heterogeneous (12,13). The case illustrates three principles relevant to scalable occupational practice: accurate image-guided delivery, integration of the intervention with a structured return-to-work pathway, and explicit attention to the ergonomic exposure that produced the injury.

V. DISCUSSION

This systematic review synthesizes current evidence regarding regenerative therapies, neuromodulation, and image-guided precision interventions and evaluates their potential role in improving long-term recovery, functional restoration, and sustained return-to-work within occupational medicine(31). These approaches vary in their readiness for real-world use. Ultrasound-guided injection is currently the most practical and scalable approach, as it improves accuracy and patient outcomes, requires only affordable equipment, and can be used at the point of care (23), (26)

. Cooled radiofrequency ablation and spinal cord stimulation are also ready for use in carefully selected patients, offering lasting relief and, for SCS, the strongest direct evidence of improved work participation (18,19,25). Regenerative therapy is promising but not yet standardized; its value in occupational settings will depend on having clear protocols and reporting of work outcomes (14).

Scalability is the key issue for using these treatments at work. Important factors include equipment cost, training, access to supplies, and whether the procedure can be done as an outpatient. Portable ultrasound meets all these needs and is likely to be the main tool for scalable occupational interventions. Neuromodulation requires more resources and expertise, so it is better suited as a referral option for difficult cases. However, removable percutaneous stimulation may make it more accessible (21). Regenerative therapy is easy to perform but is currently limited by differences in protocols rather than by equipment or infrastructure.

These technologies can also help prevent long-term disability, which is sometimes overlooked. Early, accurate, and lasting treatment for workers with recent or early chronic pain may stop the problem from becoming permanent and leading to job loss. This is a form of secondary prevention that supports better workplace ergonomics. Integrating these treatments

into employer–healthcare partnerships, along with ergonomic changes and gradual return-to-work plans, makes sense. As shown in the case study, these interventions work best when combined with workplace changes that address the original cause of injury(30). It is also important to ensure fair access, since advanced treatments could increase gaps between large, well-funded employers and smaller or informal workplaces, where musculoskeletal problems are often most common (32).

There are several limitations to these conclusions. The evidence is varied, often comes from small studies, and, for regenerative treatments, is affected by differences in protocols and possible industry influence. Work participation is rarely the main outcome except in SCS studies, so the benefits for work are often estimated indirectly. The field is changing quickly, and the screening numbers here are placeholders until the final search is complete. Excluding non-English studies without translation may also cause bias. These issues suggest that new treatments should be adopted carefully and selectively, not with broad enthusiasm. Several limitations should also be acknowledged. Considerable heterogeneity existed across interventions, treatment protocols, patient populations, and outcome measures, preventing quantitative meta-analysis. Most included studies primarily evaluated pain and functional outcomes rather than occupational endpoints such as sustained work participation, productivity, absenteeism, or work disability.

The next steps for research are clear. Priorities include creating standardized protocols for biologic treatments, regularly reporting return-to-work and work-capacity outcomes, conducting practical trials in real-world workplace settings, analyzing cost-effectiveness from both employer and public perspectives, and establishing registries to track long-term outcomes and rare side effects. Without data on work outcomes and costs, even effective treatments may not be widely adopted.

5.1 Research Gaps

Despite growing interest in interventional pain technologies within occupational medicine, several important research gaps remain. First, most available studies focus primarily on pain reduction and functional improvement. At the same time, work-specific outcomes such as return-to-work duration, work productivity, absenteeism, presenteeism, and long-term job retention are inconsistently reported(33). This limits the ability to determine the true occupational value of these interventions.

Second, substantial heterogeneity exists across regenerative therapy studies, particularly in platelet-rich plasma preparation, concentration, injection techniques, and follow-up periods. The absence of standardized protocols reduces comparability between studies and complicates translation into workplace practice. Similar variability is also seen in neuromodulation studies regarding patient selection criteria, stimulation parameters, and definitions of treatment success.

Third, most evidence originates from specialized tertiary centers within high-resource healthcare systems, creating uncertainty about its applicability to smaller occupational clinics, rural settings, and low-resource industries. Data from informal labor sectors and physically demanding occupations remain especially limited despite these workers carrying a high burden of musculoskeletal disorders.

Another major limitation is the lack of long-term occupational surveillance data. Few studies evaluate durability beyond two years, monitor recurrent workplace injury, or assess sustained employment outcomes after intervention. Evidence on cost-effectiveness from employer, insurer, and public health perspectives is also sparse, despite the essential role of economic feasibility for broad implementation. Additionally, psychosocial and ergonomic contributors to chronic occupational pain are often underrepresented in intervention studies. Most trials evaluate procedures in isolation rather than as part of integrated multidisciplinary return-to-work models. This creates a gap in understanding how interventional procedures interact with workplace modifications, behavioral rehabilitation, and occupational health policies.

Finally, many studies have relatively small sample sizes, industry sponsorship, or moderate risk of bias, reducing confidence in generalizability. There is also limited inclusion of female workers, aging workers, and workers with multiple comorbidities, despite these populations representing a growing segment of the workforce.

5.2 Future Directions

Future research should prioritize standardized and occupation-focused study designs. Consensus guidelines are needed for biologic preparation methods, image-guided procedural techniques, and neuromodulation protocols to improve reproducibility and facilitate evidence synthesis.

Large multicenter pragmatic trials conducted within real-world occupational settings are essential. These studies should routinely include work-related endpoints such as time to return to work, sustained work participation, productivity restoration, opioid reduction, and long-term disability prevention. Integration of wearable monitoring systems and digital occupational health platforms may also allow continuous tracking of recovery and workplace function.

Emerging technologies offer additional opportunities for advancement. Artificial intelligence-assisted imaging, robotic-guided interventions, wearable neuromodulation devices, and regenerative biologics with personalized dosing strategies may improve precision and long-term outcomes. Research evaluating these technologies in occupational populations will be important for determining clinical and practical value.

Future investigations should also emphasize multidisciplinary integration. Combining interventional pain procedures with ergonomic redesign, physiotherapy, psychological support, vocational rehabilitation, and employer-based accommodations may provide more durable outcomes than isolated procedural care. Comparative studies evaluating integrated occupational rehabilitation pathways are therefore needed.

Economic evaluation must become a routine component of future studies. Cost-effectiveness analyses from employer, workers' compensation, and public healthcare perspectives will help determine scalability and equitable implementation. In addition, workforce registries and longitudinal surveillance systems should be developed to monitor long-term safety, repeat interventions, recurrent injury, and sustained employment outcomes.

Finally, future research should focus on equitable access to advanced pain technologies. Studies involving low-resource healthcare systems, small-scale industries, and informal workers are necessary to ensure that innovation in occupational pain management does not widen existing disparities in workplace health care.

VI. CONCLUSION

New interventional pain treatments give occupational medicine real options beyond standard care. Image-guided precision interventions are already accurate and easy to scale. Neuromodulation offers lasting, opioid-sparing relief and the best evidence for helping people return to work in tough cases. Repair-based therapies look promising but need more standardization. The main takeaway is that readiness for real-world use and the ability to scale up, not just newness, should guide adoption. These treatments work best when combined with return-to-work planning and ergonomic changes. To reach their full potential, we need work-focused studies, consistent protocols, and economic data from real workplace settings.

Tables

Table 1. Eligibility criteria (PICOS framework).

Element	Inclusion	Exclusion
Population	Working-age adults (≥18 y) with musculoskeletal or chronic pain of occupational relevance	Pediatric populations; conditions with no occupational relevance

Intervention	Regenerative (e.g., PRP/orthobiologics); neuromodulation (SCS, PNS); image-guided precision interventions (US-guided injection, RFA)	Purely pharmacological or surgical comparators studied in isolation
Comparator	Conventional care, sham, or standard (landmark-guided) procedure	None extractable
Outcomes	Pain, function, return-to-work / work capacity, durability, adverse events, cost	No clinical or work-relevant outcome reported
Study design	RCTs, prospective cohorts, high-quality systematic reviews/meta-analyses	Animal/in vitro/preclinical; narrative reviews; abstracts without data

Table 2. Summary of evidence streams, occupational relevance, and translational readiness.

Technology stream	Representative evidence	Key occupational outcome signal	Translational readiness/scalability
Regenerative – platelet-rich plasma	O'Dowd (2022); Peerbooms et al. (2010); Berrigan et al. (2024); Moraes et al. (2014); de Vos et al. (2014)	Improved pain/function in chronic tendinopathy (e.g., lateral epicondylitis); evidence heterogeneous	Procedurally simple and low-infrastructure, but limited by non-standardized protocols and sparse work-outcome data
Neuromodulation – SCS and PNS	Moens et al. (2019). Kumar et al. (2007); Al-Kaisy et al. (2014); Gilmore et al. (2020)	Higher odds of return-to-work; sustained pain relief and opioid reduction in refractory cases	Mature for selected patients; capital/expertise-intensive (best as referral pathway); removable PNS lowers threshold
Image-guided precision – US guidance and RFA	Shen et al. (2024); Oo et al. (2024); Lyman et al. (2022)	Greater injection accuracy and patient-reported benefit; durable relief (CRFA to 24 months)	Highly scalable; portable, radiation-free, point-of-care; day-case ablation fits occupational pathways

Declarations

Funding
No external funding was received for this study.

Conflicts of Interest
The author declares no conflicts of interest.

Author Contributions
Supreet Khare conceived the study, designed the review methodology, performed the literature review, analyzed the evidence, interpreted the findings, and wrote and approved the final manuscript.

Ethics Approval
Not applicable. This study is a systematic review of previously published literature.

Consent to Participate
Not applicable.

Consent for Publication

Not applicable.

Data Availability

All data analyzed during this study are included within the published literature cited in this review.

Use of Generative Artificial Intelligence

Generative artificial intelligence tools were used to assist with language refinement, manuscript organization, and editorial improvements. All literature selection, interpretation of evidence, scientific conclusions, and final manuscript content were reviewed, verified, and approved by the author, who accepts full responsibility for the integrity and accuracy of the work.

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