

Efficacy of Radiofrequency Neurotomy in Chronic Low Back Pain: A Systematic Review and Meta-Analysis

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Purpose: The objective of the systematic review and meta-analysis is to evaluate the efficacy of radiofrequency neurotomy as a therapeutic lumbar facet joint intervention.

Patients and Methods: Utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist, a systematic review and meta-analysis was performed. A comprehensive literature search of multiple data sources from 1966 to September 2020 including manual searches of bibliography of known review articles was performed. The inclusion criteria were based on the selection of patients with chronic low back pain with diagnosis confirmed based on controlled diagnostic blocks and with the publication of at least 6 months of results of appropriate outcome parameters. Quality assessment of the trials was performed with Cochrane review criteria and interventional pain management techniques-quality appraisal of reliability and risk of bias assessment (IPM-QRB). The level of evidence of effectiveness is classified at five levels ranging from Level I to Level V. The primary outcome measure was a significant reduction in pain, eg, short term (up to 6 months) and long term (more than 6 months). The secondary outcome measure was an improvement in functional status.

Results: A total of 12 randomized controlled trials (RCTs) met the inclusion criteria for evaluating the efficacy of lumbar radiofrequency neurotomy. Radiofrequency neurotomy showed Level II evidence for efficacy for both the short term and long term.

Conclusion: This systematic review of the assessment of the efficacy of radiofrequency neurotomy in managing chronic low back pain was based on the inclusion of 12 RCTs with a diagnostic block and at least 6 months of follow-up results that showed Level II evidence for both short-term and long-term improvement.

Keywords: diagnostic facet joint nerve blocks, facet joint pain, facet joint nerve blocks, randomized trials, radiofrequency neurotomy, systematic review, meta-analysis

Introduction

Chronic axial low back pain, with or without extremity pain is one of the major causes of disability and escalating health care costs.¹⁻⁷ In fact, morbidity and chronic disability now account for nearly half of the US health burden, despite substantial progress and improvement in overall health.^{6,7} In addition, among the 30 leading diseases and injuries contributing to years lives with disability in 2010 in the United States, low back pain ranked number one. Further, Dieleman et al^{1,2} showed an escalating spending pattern of low back and neck pain increasing from \$87.6 billion in 2013 to \$134.5 billion in 2016, with more than 53.5% increase between 2013 and 2016.

Chronic persistent low back pain lasting longer than 1 year is reported in 25% to 60% of the patients.^{3–5} Overall prevalence of low back pain over a period of 1 year time frame ranged from 22% to 65% with an estimated lifetime occurrence of 11% to 84%.^{3,4} Among the multiple modalities utilized in managing facet joint pain, interventional techniques with facet joint interventions have been shown to be critically important with continued ongoing discussions on effectiveness, indications and medical necessity, selection of patients for therapeutic interventions, and finally utilization patterns with extensive literature.^{3,4,8}

In addition, the COVID-19 pandemic and the opioid epidemic have affected all aspects of human life, especially those of chronic pain sufferers.^{3,4,17,22–28} The pandemic has resulted in reduced access with modifications in treatment modalities, with increased psychological stressors, and suffering.^{4,17,22–28} The use of interventional techniques for the treatment of spinal pain increased exponentially until 2009, at which point utilization began to decrease.^{8–12} Among these, facet joint interventions showed an overall 1.9% annual increase from 2009 to 2018 compared to 17% annual increases from 2000 to 2009.^{8,9,11} The analysis of expenditures for facet joint interventions in Medicare population¹¹ also showed an increase in expenditures of 79% from 2009 to 2018 in the form of total costs for facet joint interventions; however, the inflation-adjusted costs with 2018 US dollars showed an overall increase of 53% with an annual increase of 4.9%. Further, lumbar facet joint injection procedures increased by 37% from 2009 to 2018, whereas lumbar radiofrequency neurotomy procedures increased by 169%. Compared to the Medicare population which increased by 30.1% from 2009 to 2018, the total number of patients undergoing facet joint interventions increased by 65.1% with an annual increase rate of 5.7%. In contrast, epidural procedures¹² showed a decrease of inflation-adjusted costs overall 2%, whereas prior to inflation adjustment, total expenditures increased by 14.6% or an annual increase of 1.5%. Further, the number of patient visits and services demonstrated a decline for epidural procedures compared to Medicare growth of population, in contrast to facet joint interventions. In addition, expenditures of epidural interventions showed declines.¹²

Significant debate in reference to effectiveness and efficacy, utilization patterns, and indications and medical necessity of interventional techniques in general and facet joint interventions in particular, including radiofrequency

neurotomy procedures continues among patients, clinicians, researchers, and payors.^{3,4,8–12,18–22,28–37}

Advanced diagnostic techniques like imaging and controlled diagnostic blocks point to multiple structures including facet joints, sacroiliac joints, intervertebral discs, and nerve roots as a possible origin of chronic low back pain.^{3,38–47} The diagnosis of a lumbar facet joint as the cause of chronic pain cannot be accurately established by history, physical, or imaging alone.^{3,38–47} The diagnosis by controlled diagnostic blocks has been shown to be reasonably accurate.^{3,38–40,46,47} However, the prevalence of “pure” lumbar zygapophysial joint pain in patients with chronic low back pain with placebo controlled diagnostic blocks and 100% pain relief as the criterion standard has been shown to be 15%, with acute pain model.⁴⁵ In this manuscript, the authors have excluded any patients who have had longer relief than a few hours. In contrast, with a philosophical paradigm shift from an acute to a chronic pain model, Manchikanti et al⁴⁶ have shown a prevalence rate of 34.1% and false-positive rate of 49.8% in chronic low back pain, utilizing controlled comparative local anesthetic blocks with a criterion standard of 80% pain relief. Currently, intraarticular injections, facet joint nerve blocks, and radiofrequency neurotomy are used for therapeutic management.^{3,39,40} However, the evidence continues to be variable with discordant opinions in systematic reviews.^{3,39,40,48–50}

This systematic review and meta-analysis of randomized controlled trials (RCTs) of radiofrequency neurotomy in managing chronic low back pain is sought to provide updated evidence.

Methods

A systematic review and meta-analysis was performed based on methodological and reporting quality of systematic reviews as described by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).^{51,52}

The objective of this systematic review and meta-analysis, therefore was to assess the efficacy and effectiveness of radiofrequency thermoneurolysis in managing chronic low back pain of facet joint origin.

Studies Included

Randomized controlled trials (RCTs).

Participants Included

Patients with low back pain for at least 3 months’ duration. Studies with inadequate or lack of response to

conservative therapies including non-steroidal anti-inflammatory drugs (NSAIDs), exercise regimens, physical therapy, and other conservative therapies and at least 6 months of follow-up were included. Studies with inclusion of acute causes of low back pain such as trauma, fractures, malignancies were excluded. Patients diagnosed with a single or double diagnostic block were included.

Interventions Included

Radiofrequency neurotomy performed under radiological imaging (fluoroscopy, computed tomography (CT), or magnetic resonance imaging (MRI)) were included while blind and ultrasound-guided interventions were excluded.

Outcome Measures Included

The primary outcome measure was pain relief. The secondary outcome measure was an improvement in functional status. The outcomes of less than 6 months of management were considered short term and 6 months or longer were considered long term.

Literature Search

A comprehensive literature search was conducted to include randomized control trials published from all countries and in all languages. Searches were performed from the following sources without language restrictions.

1. PubMed from 1966 <https://pubmed.ncbi.nlm.nih.gov/>
2. Cochrane Library <https://www.cochranelibrary.com/>
3. Google Scholar <https://scholar.google.com/>
4. US National Guideline Clearinghouse (NGC) <https://www.ahrq.gov/gam/index.html>
5. Clinical Trials <https://www.clinicaltrials.gov/>
6. Previous systematic reviews and cross-references
7. All other sources including non-indexed journals and abstracts

The search period was from 1966 through September 2020.

Search Strategy

The search strategy emphasized chronic low back pain treated with lumbar facet joint interventions. The search terms included: (((((((((((spinal pain, chronic low back pain) OR chronic back pain) OR facet joint pain) OR lumbosacral pain) OR postlaminectomy) OR lumbar surgery syndrome) OR zygapophysial)) AND (((((((facet joint

OR zygapophysial) OR zygapophysial) OR medial branch block OR intraarticular injection OR radiofrequency neurotomy) OR radiofrequency ablation.

Inclusion and Exclusion Criteria

RCTs studying radiofrequency neurotomy with at least 6 months of follow-up were included in this study. No observational studies were included. Only the trials with appropriate diagnosis established by at least one diagnostic block were included. Studies without an appropriate diagnosis, non-randomized studies, non-systematic reviews, case series, and case reports were excluded.

Data Collection and Analysis

Two review authors independently, established search criteria, searched the literature, and extracted data from the selected studies. Disagreements between the two reviewer authors were resolved by a third author.

Methodological Quality Assessment

RCTs were assessed for their quality or risk of bias methodologically with Cochrane review criteria (Table 1)⁵³ and Interventional Pain Management techniques–Quality Appraisal of reliability and Risk of Bias Assessment (IPM-QRB) (Table 2).⁵⁴

Risk of Bias of Individual Studies

Trials that met the inclusion criteria and scored at least 9 of 13 using Cochrane review criteria were considered high quality, while trials scoring 5–8 were considered of moderate quality. Trials that scored less than 5 were considered of low quality and were excluded from the analysis.

Trials meeting the inclusion criteria were also assessed with IPM-QRB criteria.⁵⁴ Studies scoring 32–48 were considered of high quality, those scored 16–31 were of moderate quality and those that scored below 16 were considered of low quality and were excluded from the analysis.

Methodological quality of the trials was assessed by two authors, independently in an unblinded manner. If a discrepancy occurred, a third author was involved to resolve the conflict. When an issue of conflict of interest was raised in reviewing the manuscript (regarding authorship), the involved authors were not allowed to review those manuscripts for quality assessment.

Table 1 Sources of Risk of Bias and Cochrane Review Rating System

Bias Domain	Source of Bias		Possible Answers
Selection	(1) Was the method of randomization adequate?	A random (unpredictable) assignment sequence. Examples of adequate methods are coin toss (for studies with 2 groups), rolling a dice (for studies with 2 or more groups), drawing of balls of different colors, drawing of ballots with the study group labels from a dark bag, computer-generated random sequence, preordered sealed envelopes, sequentially ordered vials, telephone call to a central office, and preordered list of treatment assignments.	Yes/No/Unsure
		Examples of inadequate methods are: alternation, birth date, social insurance/security number, date in which they are invited to participate in the study, and hospital registration number.	
Selection	(2) Was the treatment allocation concealed?	Assignment generated by an independent person not responsible for determining the eligibility of the patients. This person has no information about the persons included in the trial and has no influence on the assignment sequence or on the decision about eligibility of the patient.	Yes/No/Unsure
Performance	(3) Was the patient blinded to the intervention?	Index and control groups are indistinguishable for the patients or if the success of blinding was tested among the patients and it was successful.	Yes/No/Unsure
Performance	(4) Was the care provider blinded to the intervention?	Index and control groups are indistinguishable for the care providers or if the success of blinding was tested among the care providers and it was successful.	Yes/No/Unsure
Detection	(5) Was the outcome assessor blinded to the intervention?	Adequacy of blinding should be assessed for each primary outcome separately. This item should be scored "yes" if the success of blinding was tested among the outcome assessors and it was successful or:	Yes/No/Unsure
		<ul style="list-style-type: none"> For patient-reported outcomes in which the patient is the outcome assessor (eg, pain, disability): the blinding procedure is adequate for outcome assessors if participant blinding is scored "yes" 	
		<ul style="list-style-type: none"> For outcome criteria assessed during scheduled visit and that supposes a contact between participants and outcome assessors (eg, clinical examination): the blinding procedure is adequate if patients are blinded, and the treatment or adverse effects of the treatment cannot be noticed during clinical examination 	
		<ul style="list-style-type: none"> For outcome criteria that do not suppose a contact with participants (eg, radiography, magnetic resonance imaging): the blinding procedure is adequate if the treatment or adverse effects of the treatment cannot be noticed when assessing the main outcome 	
		<ul style="list-style-type: none"> For outcome criteria that are clinical or therapeutic events that will be determined by the interaction between patients and care providers (eg, cointerventions, hospitalization length, treatment failure), in which the care provider is the outcome assessor: the blinding procedure is adequate for outcome assessors if item "4" (caregivers) is scored "yes" 	
<ul style="list-style-type: none"> For outcome criteria that are assessed from data of the medical forms: the blinding procedure is adequate if the treatment or adverse effects of the treatment cannot be noticed on the extracted data 			

(Continued)

Table I (Continued).

Bias Domain	Source of Bias		Possible Answers
Attrition	(6) Was the drop-out rate described and acceptable?	The number of participants who were included in the study but did not complete the observation period or were not included in the analysis must be described and reasons given. If the percentage of withdrawals and drop-outs does not exceed 20% for short-term follow-up and 30% for long-term follow-up and does not lead to substantial bias a “yes” is scored (N.B. these percentages are arbitrary, not supported by literature).	Yes/No/Unsure
Attrition	(7) Were all randomized participants analyzed in the group to which they were allocated?	All randomized patients are reported/analyzed in the group they were allocated to by randomization for the most important moments of effect measurement (minus missing values) irrespective of noncompliance and cointerventions.	Yes/No/Unsure
Reporting	(8) Are reports of the study free of suggestion of selective outcome reporting?	All the results from all prespecified outcomes have been adequately reported in the published report of the trial. This information is either obtained by comparing the protocol and the report, or in the absence of the protocol, assessing that the published report includes enough information to make this judgment.	Yes/No/Unsure
Selection	(9) Were the groups similar at baseline regarding the most important prognostic indicators?	Groups have to be similar at baseline regarding demographic factors, duration and severity of complaints, percentage of patients with neurological symptoms, and value of main outcome measure(s).	Yes/No/Unsure
Performance	(10) Were cointerventions avoided or similar?	If there were no cointerventions or they were similar between the index and control groups.	Yes/No/Unsure
Performance	(11) Was the compliance acceptable in all groups?	The reviewer determines if the compliance with the interventions is acceptable, based on the reported intensity, duration, number and frequency of sessions for both the index intervention and control intervention(s). For example, physiotherapy treatment is usually administered for several sessions; therefore it is necessary to assess how many sessions each patient attended. For single-session interventions (eg, surgery), this item is irrelevant.	Yes/No/Unsure
Detection	(12) Was the timing of the outcome assessment similar in all groups?	Timing of outcome assessment should be identical for all intervention groups and for all primary outcome measures.	Yes/No/Unsure
Other	(13) Are other sources of potential bias unlikely?	Other types of biases. For example: <ul style="list-style-type: none"> • When the outcome measures were not valid. There should be evidence from a previous or present scientific study that the primary outcome can be considered valid in the context of the present. • Industry-sponsored trials. The conflict of interest (COI) statement should explicitly state that the researchers have had full possession of the trial process from planning to reporting without funders with potential COI having any possibility to interfere in the process. If, for example, the statistical analyses have been done by a funder with a potential COI, usually “unsure” is scored. 	Yes/No/Unsure

Notes: Adapted and modified from: Furlan AD, Malmivaara A, Chou R, et al; Editorial Board of the Cochrane Back, Neck Group. 2015 Updated method guideline for systematic reviews in the Cochrane Back and Neck Group. *Spine (Phila Pa 1976)*. 2015;40(21):1660–1673. With permission from the American Society of Interventional Pain Physicians.⁵³

Table 2 Item Checklist for Assessment of Randomized Controlled Trials of IPM Techniques Utilizing IPM – QRB

		Scoring
I.	TRIAL DESIGN AND GUIDANCE REPORTING	
1.	CONSORT or SPIRIT Trial designed and reported without any guidance Trial designed and reported utilizing minimum criteria other than CONSORT or SPIRIT criteria or trial was conducted prior to 2005 Trial implies it was based on CONSORT or SPIRIT without clear description with moderately significant criteria for randomized trials or the trial was conducted before 2005 Explicit use of CONSORT or SPIRIT with identification of criteria or trial conducted with high level reporting and criteria or conducted before 2005	0 1 2 3
II.	DESIGN FACTORS	
2.	Type and Design of Trial Poorly designed control group (quasi selection, convenient sampling) Proper active-control or sham procedure with injection of active agent Proper placebo control (no active solutions into active structures)	0 2 3
3.	Setting/Physician General setting with no specialty affiliation and general physician Specialty of anesthesia/PMR/neurology/radiology/ortho, etc. Interventional pain management with interventional pain management physician	0 1 2
4.	Imaging Blind procedures Ultrasound CT Fluoro	0 1 2 3
5.	Sample Size Less than 50 participants in the study without appropriate sample size determination Sample size calculation with less than 25 patients in each group Appropriate sample size calculation with at least 25 patients in each group Appropriate sample size calculation with 50 patients in each group	0 1 2 3
6.	Statistical Methodology None or inappropriate Appropriate	0 1
III.	PATIENT FACTORS	
7.	Inclusiveness of Population	
7a.	For epidural procedures: Poorly identified mixed population Clearly identified mixed population Disorders specific trials (ie, well-defined spinal stenosis and disc herniation, disorder specific, disc herniation or spinal stenosis or post surgery syndrome)	0 1 2
7b.	For facet or sacroiliac joint interventions: No diagnostic blocks Selection with single diagnostic blocks Selection with placebo or dual diagnostic blocks	0 1 2
8.	Duration of Pain <3 months 3–6 months > 6 months	0 1 2

(Continued)

Table 2 (Continued).

		Scoring
9.	Previous Treatments Conservative management including drug therapy, exercise therapy, physical therapy, etc. Were not utilized Were utilized sporadically in some patients Were utilized in all patients	0 1 2
10.	Duration of Follow-up with Appropriate Interventions Less than 3 months or 12 weeks for epidural or facet joint procedures, etc. and 6 months for intradiscal procedures and implantables 3–6 months for epidural or facet joint procedures, etc., or 1 year for intradiscal procedures or implantables 6–17 months for epidurals or facet joint procedures, etc., and 2 years or longer for discal procedures and implantables 18 months or longer for epidurals and facet joint procedures, etc., or 5 years or longer for discal procedures and implantables	0 1 2 3
IV.	OUTCOMES	
11.	Outcomes Assessment Criteria for Significant Improvement No descriptions of outcomes OR <20% change in pain rating or functional status Pain rating with a decrease of 2 or more points or more than 20% reduction OR functional status improvement of more than 20% Pain rating with decrease of ≥ 2 points AND $\geq 20\%$ change or functional status improvement of $\geq 20\%$ Pain rating with a decrease of 3 or more points or more than 50% reduction OR functional status improvement with a 50% or 40% reduction in disability score Significant improvement with pain and function $\geq 50\%$ or 3 points and 40% reduction in disability scores	0 1 2 2 4
12.	Analysis of all Randomized Participants in the Groups Not performed Performed without intent-to-treat analysis without inclusion of all randomized participants All participants included with or without intent-to-treat analysis	0 1 2
13.	Description of Drop-Out Rate No description of dropouts, despite reporting of incomplete data or $\geq 20\%$ withdrawal Less than 20% withdrawal in 1 year in any group Less than 30% withdrawal at 2 years in any group	0 1 2
14.	Similarity of Groups at Baseline for Important Prognostic Indicators Groups dissimilar with significant influence on outcomes with or without appropriate randomization and allocation Groups dissimilar without influence on outcomes despite appropriate randomization and allocation Groups similar with appropriate randomization and allocation	0 1 2
15.	Role of Co-Interventions Co-interventions were provided but were not similar in the majority of participants No co-interventions or similar co-interventions were provided in the majority of the participants	0 1
V.	Randomization	
16.	Method of Randomization Quasi randomized or poorly randomized or not described Adequate randomization (coin toss, drawing of balls of different colors, drawing of ballots) High quality randomization (Computer generated random sequence, pre-ordered sealed envelopes, sequentially ordered vials, telephone call, pre-ordered list of treatment assignments, etc)	0 1 2
VI.	ALLOCATION CONCEALMENT	
17.	Concealed Treatment Allocation Poor concealment of allocation (open enrollment) or inadequate description of concealment Concealment of allocation with borderline or good description of the process with probability of failure of concealment High-quality concealment with strict controls (independent assignment without influence on the assignment sequence)	0 1 2

(Continued)

Table 2 (Continued).

		Scoring
VII.	BLINDING	
18.	Patient Blinding Patients not blinded Patients blinded adequately	0 1
19.	Care Provider Blinding Care provider not blinded Care provider blinded adequately	0 1
20.	Outcome Assessor Blinding Outcome assessor not blinded or was able to identify the groups Performed by a blinded independent assessor with inability to identify the assignment-based provider intervention (ie, subcutaneous injection, intramuscular distant injection, difference in preparation or equipment use, numbness and weakness, etc.)	0 1
VIII.	CONFLICTS OF INTEREST	
21.	Funding and Sponsorship Trial included industry employees Industry employees involved; high levels of funding with remunerations by industry or an organization funded with conflicts Industry or organizational funding with reimbursement of expenses with some involvement Industry or organization funding of expenses without involvement Funding by internal resources only with supporting entity unrelated to industry Governmental funding without conflict such as NIH, NHS, AHRQ	-3 -3 0 1 2 3
22.	Conflicts of Interest None disclosed with potential implied conflict Marginally disclosed with potential conflict Well disclosed with minor conflicts Well disclosed with no conflicts Hidden conflicts with poor disclosure Misleading disclosure with conflicts Major impact related to conflicts	0 1 2 3 -1 -2 -3
TOTAL		48

Notes: Source: Manchikanti L, Hirsch JA, Cohen SP, et al. Assessment of methodologic quality of randomized trials of interventional techniques: Development of an interventional pain management specific instrument. *Pain Physician*. 2014;17(3):E263-E290.⁵⁴

Outcome Measures

An outcome is considered clinically significant if a reduction of 3 points on Visual Analog Scale (VAS) or Numeric Rating Scale (NRS), or at least 50% reduction in pain and improvement in the functional status. A positive study is said to be clinically significant and effective indicating that the primary outcome should be statistically significant at a P -value ≤ 0.05 .

Analysis of Evidence

The evidence was analyzed utilizing qualitative and quantitative evidence synthesis. Quantitative evidence synthesis was performed utilizing conventional meta-analysis and a single-arm meta-analysis.

Qualitative Analysis

The qualitative analysis of the evidence was performed based on best-evidence synthesis, modified and collated using multiple criteria, including the Cochrane Review criteria and United States Preventive Services Task Force (USPSTF) criteria as illustrated in Table 3.⁵⁵ The analysis was conducted using five levels of evidence ranging from strong to opinion- or consensus-based. The results of best evidence as per grading were utilized. At least two of the review authors independently, in a standardized manner, analyzed the evidence. Any disagreements between reviewers were resolved by a third author and consensus was attained. If there were any conflicts of interest (eg, authorship), the reviewers of interest were recused from assessment and analysis.

Table 3 Qualitative Modified Approach to Grading of Evidence of Therapeutic Effectiveness Studies

Level I	Strong	Evidence obtained from multiple relevant high-quality randomized controlled trials
Level II	Moderate	Evidence obtained from at least one relevant high-quality randomized controlled trial or multiple relevant moderate or low-quality randomized controlled trials
Level III	Fair	Evidence obtained from at least one relevant moderate or low-quality randomized trial or Evidence obtained from at least one relevant high-quality non-randomized trial or observational study with multiple moderate or low-quality observational studies
Level IV	Limited	Evidence obtained from multiple moderate or low-quality relevant observational studies
Level V	Consensus based	Opinion or consensus of large group of clinicians and/or scientists

Notes: Modified from: Manchikanti L, Falco FJE, Benyamin RM, Kaye AD, Boswell MV, Hirsch JA. A modified approach to grading of evidence. *Pain Physician*. 2014;17(3):E319-E325.⁵⁵

Meta-Analysis

For dual-arm meta-analysis, Review Manager software (Rev Man 5.3) was used (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark, 2008).

For single-arm meta-analysis, software Comprehensive Meta-analysis version 3.0 was used (Biostat Inc., Englewood, NJ).

For pain and improvement of function data, the studies were reported as the standardized mean differences (SMD) with 95% confidence intervals (CI).

Data were plotted by using forest plots to evaluate treatment effects. Heterogeneity was interpreted through I^2 statistics.

Results

The flow diagram illustrates the search results and the final number of studies that were considered for inclusion (Figure 1).

The full manuscript was reviewed for 89 studies, out of which 15 RCTs⁵⁶⁻⁷⁰ were selected and 12 of them met the inclusion criteria to include in this systematic review. Three trials were excluded.^{57,58,70} Civelek et al⁵⁷ was excluded due to lack of diagnostic blocks prior to providing radiofrequency denervation procedure. Cohen et al⁵⁸ and van Tilburg et al⁷⁰ was excluded due to short-term assessment of 3 months. Of the remaining 12 trials, 7 of them were active control trials,^{56,59,60,62-64,66} and the remaining 5 were placebo or sham control.^{61,65,67-69}

Methodological Quality Assessment

The results of methodological quality assessment of the RCTs meeting the inclusion criteria carried out using

Cochrane review criteria and IPM-QRB criteria are illustrated in Tables 4 and 5.

Utilizing the Cochrane quality assessment and the previously established score ranges in the methods section of this study, 10 trials^{56,59,60,62-65,67-69} scored between 9 and 13, thus meeting our criteria of high-quality studies, while 2 trials^{61,66} scored between 5 and 8, thus said to be studies of moderate quality.

Based on the IPM-QRB criteria for randomized trials, 8 trials^{56,59,60,62-64,68,69} scored between 32 and 48, hence they are of high quality, while 4 trials^{61,65-67} scored between 16 and 31, thus are considered as moderate quality trials. Thus, only 8 trials met the criteria for high-quality with both instruments.^{56,59,60,62-64,68,69} This indicates the importance of IPM specific instruments in methodologic quality assessments.

Study Characteristics

Table 6 shows the study characteristics of all the included randomized trials.

Analysis of Evidence

Qualitative Analysis

Table 7 shows the effectiveness of radiofrequency neurotomy. The included trials studied a total of 1049 patients, with 461 patients undergoing conventional radiofrequency neurotomy. Among these, in 10 positive trials, the total number of patients included were 717 with 296 undergoing conventional radiofrequency neurotomy. Among the two negative trials,^{61,68} a total of 332 patients were included with 165 undergoing radiofrequency neurotomy. Juch et al⁶¹ with low methodological quality and high risk of bias, included 125 of 251 patients with conventional radiofrequency

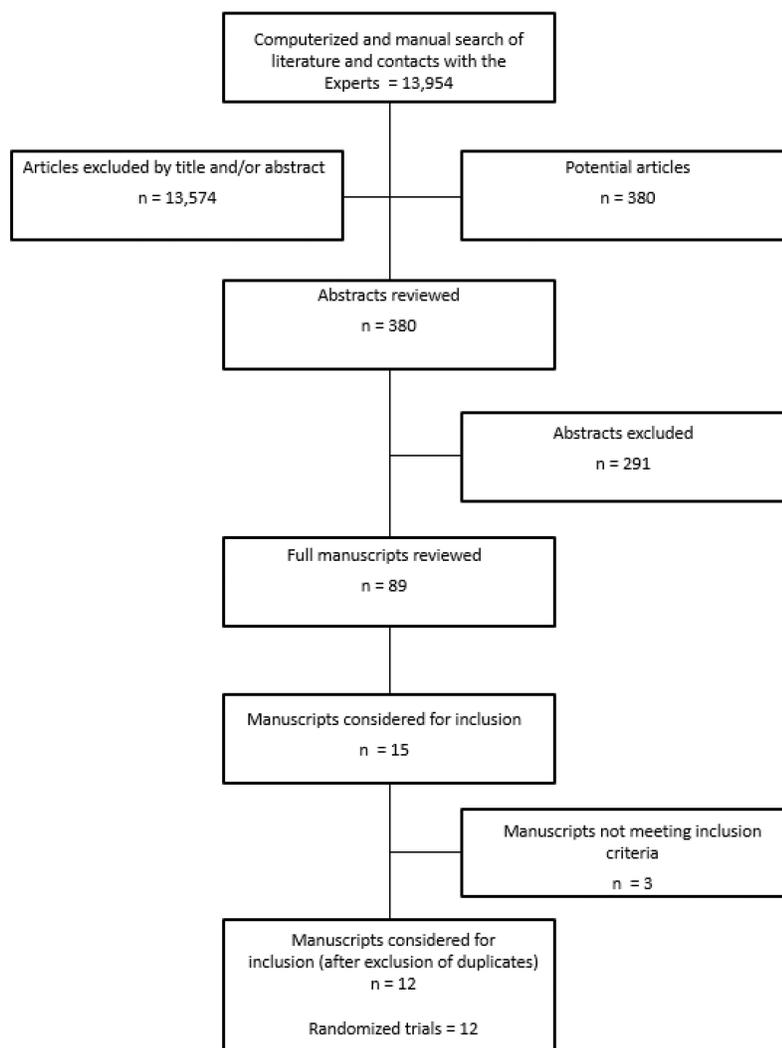


Figure 1 Flow diagram illustrating the results of literature search conducted to evaluate lumbar radiofrequency thermoneurolysis.

neurotomy. Whereas, the second study by van Wijk et al⁶⁸ included 81 patients with 40 patients undergoing conventional radiofrequency. Thus, a total of 165 patients were studied with conventional radiofrequency neurotomy with lack of improvement or considered negative; however, only van Wijk et al⁶⁸ was sham controlled. Consequently, based on 12 studies, a total of 1049 patients were included with 461 undergoing radiofrequency neurotomy, with 296 of 717 showing positive results and 165 of 332 showing negative results. Among positive trials, the number of patients in each study varied from 16 to 45. Among the four sham controlled trials,^{64,65,68,69} one study was negative on both short-term and long-term follow-up,⁶⁸ whereas two studies were positive,^{64,69} both for short and long term and one study was positive for only short-term.⁶⁵

Overall, based on the qualitative analysis, the level of evidence of efficacy is Level II with moderate evidence.

Quantitative Analysis

Quantitative analysis was performed utilizing conventional dual-arm meta-analysis and single-arm meta-analysis. The data from all the RCTs providing appropriate criteria were included with six trials qualifying for dual-arm meta-analysis in one of the categories; whereas, for single-arm meta-analysis 10 RCTs met criteria for inclusion.

Conventional Dual-Arm Meta-Analysis

Of the five placebo or sham controlled studies,^{61,65,67–69} two studies were not included due to lack of availability of

Table 4 Methodological Quality Assessment of Randomized Trials of Lumbar Facet Joint Radiofrequency Thermoneurolysis Utilizing Cochrane Review Criteria⁵³

	Juch et al ⁶¹	Nath et al ⁶⁵	Tekin et al ⁶⁷	van Wijk et al ⁶⁸	van Kleef et al ⁶⁹	Çetin & Yektaş ⁵⁶	Lakemeier et al ⁵⁹
Randomization adequate	Y	Y	Y	Y	Y	Y	Y
Concealed treatment allocation	N	Y	Y	Y	Y	Y	Y
Patient blinded	N	Y	Y	Y	Y	Y	Y
Care provider blinded	N	Y	Y	Y	Y	N	N
Outcome assessor blinded	N	Y	Y	Y	Y	Y	N
Drop-out rate described	N	Y	Y	Y	Y	Y	Y
All randomized participants analyzed in the group	N	Y	Y	Y	Y	Y	Y
Reports of the study free of suggestion of selective outcome reporting	N	Y	Y	Y	Y	Y	Y
Groups similar at baseline regarding most important prognostic indicators	Y	Y	Y	Y	Y	Y	Y
Co-intervention avoided or similar in all groups	Y	Y	Y	Y	Y	Y	Y
Compliance acceptable in all groups	Y	Y	Y	Y	Y	Y	N
Time of outcome assessment in all groups similar	Y	Y	Y	Y	Y	Y	Y
Are other sources of potential bias not likely	Y	Y	U	Y	Y	Y	U
SCORE	6/13	13/13	12/13	13/13	13/13	12/13	9/13
	Dobrogowski et al ⁶⁰	McCormick et al ⁶²	Moon et al ⁶³	Moussa & Khedr ⁶⁴	Song et al ⁶⁶		
Randomization adequate	Y	Y	Y	Y	U		
Concealed treatment allocation	U	Y	Y	Y	U		
Patient blinded	Y	Y	Y	Y	N		
Care provider blinded	Y	N	Y	N	N		
Outcome assessor blinded	U	Y	Y	Y	Y		
Drop-out rate described	Y	Y	Y	Y	N		
All randomized participants analyzed in the group	Y	Y	N	U	U		
Reports of the study free of suggestion of selective outcome reporting	Y	Y	Y	Y	Y		
Groups similar at baseline regarding most important prognostic indicators	Y	Y	Y	Y	Y		
Co-intervention avoided or similar in all groups	Y	Y	Y	Y	N		
Compliance acceptable in all groups	Y	Y	N	U	Y		

(Continued)

Table 4 (Continued).

Time of outcome assessment in all groups similar	Y	Y	N	Y	Y		
Are other sources of potential bias not likely	U	U	U	Y	Y		
SCORE	10/13	11/13	9/13	10/13	6/13		

Abbreviations: Y, yes; N, no; U, unclear.

appropriate data. Van Wijk et al⁶⁸ provided only data at 3-month follow-up, whereas 6- and 12-month follow-up data were not available. van Kleef et al⁶⁹ had data available only at 8-week point time with no data to be included in meta-analysis at 6 and 12 months of follow-up. Consequently, a comparative cumulative analysis of data from three RCTs that compared lumbar radiofrequency neurotomy using conventional radiofrequency ablation (CRFA) with sham procedure as the control group was performed as shown in Figure 2.

Figure 2A shows short-term follow-up (6 months or less) data with inclusion of three trials.^{64,65,67} The cumulative analysis showed that radiofrequency neurotomy with CRFA reduced pain scores by 1.98 (with a 95% confidence interval between -0.5 and 4.47) compared to a sham procedure. However, it was not statistically significant with a *P*-value of 0.12.

For 12-month data, only two studies were available, which included Tekin et al⁶⁷ and Juch et al⁶¹. Out of the five trials,^{61,65,67-69} only two trials^{61,67} were available with data to be included as shown in Figure 2B.

Overall, there were four sham-controlled trials described as placebo-controlled.^{64,65,68,69} Among these, a single study⁶⁸ showed negative results for short- and long-term improvement. One study presented only short-term results with improvement at 6 months (65). Two studies showed short-term and long-term positive results.^{64,69} Thus, three of the four placebo-controlled trials showed positive results for short term and two of the four showed positive results for short and long term.

The results in this analysis were favoring CRFA at 12 months.

Conventional dual-arm analysis was also performed at 6 and 12 months for active control trials. Overall, six studies were included of the seven active-controlled trials available (Figure 3).

The analysis showed the results favoring CRFA at 6 months; however, the results were favoring the active control group at 12 months.

Functional status using Oswestry Disability Index (ODI) scores was reported in only two out of the five trials^{61,67} at 6-month follow-up point as shown in Figure 4. At 12 months, functional status was assessed utilizing ODI in only in two studies.^{61,67}

Outcomes results of sham-controlled trials and active-controlled trials have been described in qualitative analysis.

Single-Arm Meta-Analysis

A single-arm cumulative analysis of the data from 10 RCTs, in which at least one arm of the study patients underwent radiofrequency neurotomy. The cumulative analysis was conducted between the initial and final pain VAS scores at 6 months follow-up in the CRFA arm of the studies.

In the single-arm cumulative analysis as shown in Figure 5A, CRFA reduced pain VAS score by 3.43 (with a 95% confidence interval between 2.66 and 4.19) at the end of 6 months follow-up. It was also statistically significant with a *P*-value of <0.00001.

Similarly, a single-arm cumulative analysis was done at 12 months follow-up, for which only five RCTs had the required data at 12 months (Figure 5B). The single-arm cumulative analysis showed that CRFA reduced pain VAS score by 3.68 (with a 95% confidence interval between 2.34 and 5.02) at the end of the 12-month follow-up. It was also statistically significant at a *P*-value of <0.00001.

Single-arm analysis was also performed on functional status with ODI scores at 6 and 12 months. Only two studies met inclusion criteria, both at 6 and 12 months. As shown in Figure 6, the data showed significant improvement in functional status at 6 and 12 months in CRFA group.

Table 5 Methodologic Quality Assessment of Randomized Trials of Lumbar Facet Joint Radiofrequency Thermoneurolysis Utilizing IPM – QRB Criteria⁵⁴

	Juch et al ⁶¹	Nath et al ⁶⁵	Tekin et al ⁶⁷	van Wijck et al ⁶⁸	van Kleef et al ⁶⁹	Çetin & Yektaş ⁵⁶	Lakemeier et al ⁵⁹	Dobrogowski et al ⁶⁰
I. TRIAL DESIGN AND GUIDANCE REPORTING								
1. CONSORT or SPIRIT	2	3	2	2	2	2	2	2
II. DESIGN FACTORS								
2. Type and Design of Trial	2	2	2	2	2	2	2	3
3. Setting/Physician	2	2	2	2	1	2	1	2
4. Imaging	3	3	3	3	3	3	3	3
5. Sample Size	2	3	2	2	2	2	2	1
6. Statistical Methodology	1	1	1	1	1	1	1	1
III. PATIENT FACTORS								
7. Inclusiveness of Population	2	1	2	2	1	2	1	1
8. Duration of Pain	2	0	2	2	2	2	2	2
9. Previous Treatments	1	0	1	2	2	2	2	2
10. Duration of Follow-up with Appropriate Interventions	1	0	1	1	2	3	2	2
IV. OUTCOMES								
11. Outcomes Assessment Criteria for Significant Improvement	1	0	1	2	2	2	2	2
12. Analysis of all Randomized Participants in the Groups	0	2	0	0	2	2	2	1
13. Description of Drop-Out Rate	0	2	0	2	2	2	2	1
14. Similarity of Groups at Baseline for Important Prognostic Indicators	2	2	2	2	2	2	2	2
15. Role of Co-interventions	1	1	1	1	1	1	1	1
V. RANDOMIZATION								
16. Method of Randomization	2	2	2	2	2	2	2	2
VI. ALLOCATION CONCEALMENT								

(Continued)

Table 5 (Continued).

17.	Concealed Treatment Allocation	0	0	0	0	2	2	2	2	2	2	2
VII. BLINDING												
18.	Patient Blinding	0	0	0	0	1	1	1	1	1	1	1
19.	Care Provider Blinding	0	0	0	0	1	0	1	1	0	0	0
20.	Outcome Assessor Blinding	0	0	0	0	1	0	1	1	0	0	1
VIII. CONFLICTS OF INTEREST												
21.	Funding and Sponsorship	2	2	2	2	2	2	2	2	2	2	2
22.	Conflicts of Interest	0	2	0	0	3	3	0	0	3	3	3
TOTAL		26	28	26	38	37	37	39	37	37	37	37
McCormick et al ⁶²												
Moon et al ⁶³												
Moussa & Khedr ⁶⁴												
Song et al ⁶⁶												
I. TRIAL DESIGN AND GUIDANCE REPORTING												
1.	CONSORT or SPIRIT					2				2		2
II. DESIGN FACTORS												
2.	Type and Design of Trial					3				2		2
3.	Setting/Physician					2				2		1
4.	Imaging					3				3		3
5.	Sample Size					1				2		0
6.	Statistical Methodology					1				1		1
III. PATIENT FACTORS												
7.	Inclusiveness of Population					1				2		2
8.	Duration of Pain					2				2		1
9.	Previous Treatments					2				2		2
10.	Duration of Follow-up with Appropriate Interventions					2				1		3
IV. OUTCOMES												

11.	Outcomes Assessment Criteria for Significant Improvement	2	2	2	2	2
12.	Analysis of all Randomized Participants in the Groups	1	0	1	1	0
13.	Description of Drop Out Rate	1	2	2	2	0
14.	Similarity of Groups at Baseline for Important Prognostic Indicators	2	2	2	2	2
15.	Role of Co-Interventions	1	1	1	1	1
V.	RANDOMIZATION					
16.	Method of Randomization	2	2	2	2	0
VI.	ALLOCATION CONCEALMENT					
17.	Concealed Treatment Allocation	2	2	2	2	0
VII.	BLINDING					
18.	Patient Blinding	1	1	1	1	0
19.	Care Provider Blinding	0	1	1	0	0
20.	Outcome Assessor Blinding	1	1	1	1	1
VIII.	CONFLICTS OF INTEREST					
21.	Funding and Sponsorship	2	2	3	3	3
22.	Conflicts of Interest	3	3	3	3	3
TOTAL		37	41	41	41	29

Table 6 Study Characteristics of Randomized Controlled Trials Assessing Lumbar Radiofrequency Neurotomy

Study Study Characteristic Methodological Quality Scoring	Number of Patients & Selection Criteria	Control	Interventions	Outcome Measures	Time of Measurement	Results	Strengths	Weaknesses	Conclusions
Juch et al, ⁶¹ 2017 MINT randomized, non- blinded, pragmatic clinical trial Quality Scores: Cochrane = 6/13 IPM-QRB = 26/48	A total of 251 patients were randomized into facet trial with 126 patients in the control group receiving exercise program as randomized. 125 patients were randomized to intervention group.	Patients randomized to control group received exercise program as randomized.	Patients in the intervention group, radiofrequency ablation after testing positive with at least 50% relief with a single block of facet joint nerves with pain reduction within 30 to 90 minutes after the block. Radiofrequency neurotomy was performed with a conventional radiofrequency ablation procedure with a 22 gauge electrode. Co-interventions except standardized exercise program were not allowed for 3 months. Over-the- counter analgesics were allowed.	NRS, global perceived recovery, Oswestry Disability Index, EuroQol 5D Health Questionnaire, Rand-36, West Haven-Yale Multidimensional Pain Inventory	3, 6, 9, 12 months	There was no significant difference between radiofrequency ablation group compared to exercise program group in the control.	A large randomized clinical trial	There are numerous weaknesses in this trial. Inappropriate selection criteria with 50% relief for a few hours which is not recommended by any guidelines. Not a blinded procedure. The electrode was too thin with exposed tip may or may not be over the nerve utilizing a perpendicular placement of the electrode. Outcome measures were inappropriate. This study received extensive correspondence and negative comments all over for its defective design and performance.	A poorly designed and performed trial showing negative results.

<p>Nath et al.⁶⁵ 2008 Randomized, double-blind, sham control trial Quality Scores: Cochrane = 13/13 IPM-QRB = 28/48</p>	<p>40 patients with chronic low back pain for at least 2 years with 80% relief of low back pain after controlled medial branch blocks. The patients were randomized into an active and a control group.</p>	<p>Sham control with placement of the needles with injection of local anesthetic without radiofrequency neurotomy.</p>	<p>The 20 patients in the active group received conventional lumbar facet joint radiofrequency neurolysis at 85°C for 60 seconds. The 20 patients in the control group received sham treatment without radiofrequency neurolysis of the lumbar facet joints.</p>	<p>NRS, global functional improvement, reduced opioid intake, employment status.</p>	<p>6 months</p>	<p>Significant reduction not only in back, and leg pain; functional improvement; opioid reduction; and employment status in the active group compared to the control group.</p>	<p>Randomized, double-blind trial after the diagnosis of facet joint pain with triple diagnostic blocks</p>	<p>Short-term follow-up with small number of patients</p>	<p>Efficacy of radiofrequency neurotomy was shown compared to local anesthetic injection and sham lesioning.</p>
<p>Tekin et al.⁶⁷ 2007 Randomized, active and sham, double-blind controlled trial Quality Scores: Cochrane = 12/13 IPM-QRB = 26/48</p>	<p>60 patients with chronic low back pain randomized into 3 groups with 20 patients in each group. Single diagnostic block of facet joint nerves with 0.3 mL of lidocaine 2% with 50% or greater relief.</p>	<p>Sham control with local anesthetic injection</p>	<p>Either pulsed radiofrequency (42°C for 4 minutes) or conventional radiofrequency neurotomy (80°C for 90 seconds) in 20 patients in each group.</p>	<p>VAS and ODI</p>	<p>3, 6, and 12 months</p>	<p>VAS and ODI scores decreased in all groups from 3 procedural levels. Decrease in pain scores was maintained in the conventional radiofrequency group at 6 months and one year. However, in pulsed radiofrequency group, the improvement was significant only at 6 months, but not one year.</p>	<p>Randomized, double-blind, controlled trial comparing control, pulsed radiofrequency, and conventional radiofrequency neurotomy. Authors also utilized a parallel needle placement approach</p>	<p>Small sample size with a single block and 50% relief as inclusion criteria. Authors did not report significant improvement percentages.</p>	<p>Efficacy with conventional radiofrequency neurotomy up to one year, whereas efficacy with local anesthetic block with sham control radiofrequency neurotomy and pulsed radiofrequency neurotomy at 6 months only.</p>

(Continued)

Table 6 (Continued).

Study Study Characteristic Methodological Quality Scoring	Number of Patients & Selection Criteria	Control	Interventions	Outcome Measures	Time of Measurement	Results	Strengths	Weaknesses	Conclusions
van Wijk et al. ⁶⁸ 2005 Randomized, double-blind, sham control trial Quality Scores: Cochrane = 13/13 IPM-QRB = 38/48	81 patients with chronic low back pain were evaluated with radiofrequency neurotomy with 41 patients in the control group with at least 50% relief for 30 minutes with a single block with intraarticular injection of 0.5 mL lidocaine 2%.	Sham lesion procedure after local anesthetic injection	40 patients received conventional radiofrequency lesioning at 80°C for 60 seconds and 41 patients received sham lesioning.	Pain relief, physical activities, analgesic intake, GPE, Short-form- 36, quality of life measures	3 months	GPE improved after radiofrequency facet joint denervation. The Visual Analog Scale in both groups improved. The combined outcome measures showed no difference between radiofrequency facet joint denervation (27.5% vs 29.3% success rate).	Double-blind, sham control, randomized trial	Poor selection with a single diagnostic block of 50% pain reduction even though 17.5% of the patients were tested positive. Further, authors described that the needle was positioned parallel; however, the radiographic figures illustrate the needle was being positioned perpendicularly rather than parallel to the nerve.	Lack of efficacy with methodologic deficiencies and a short-term follow- up.
Van Kleef et al. ⁶⁹ 1999 Randomized, double-blind, sham control trial Quality Scores: Cochrane = 13/13 IPM-QRB = 37/48	31 patients with a history of at least one year of chronic low back pain randomly assigned to one of 2 treatment groups. Single diagnostic block with 50% relief.	Sham control of radiofrequency after local anesthetic injection in 16 patients	The 15 patients in the conventional radiofrequency treatment group received an 80° C radiofrequency lesion for 60 seconds.	VAS, pain scores, GPE, ODI	3, 6, and 12 months	After 3, 6, and 12 months, the number of successes in the lesion and sham groups was 9 of 15 (60%) and 4 of 16 (25%), 7 of 15 (47%) and 3 of 16 (19%), and 7 of 15 (47%) and 2 of 16 (13%) respectively. There was a statistically significant difference.	Double-blind, randomized, sham controlled trial	A single block with a small sample with inclusion criteria of 50% pain relief to enter the study. The study has been criticized that electrodes were placed at an angle to the target nerve, instead of parallel.	Efficacy shown in a small sample with a single diagnostic block

Çetin & Yektaş, ⁵⁶ 2018 Randomized, double-blind, active-controlled trial Quality Scores: Cochrane = 12/13 IPM-QRB = 39/48	118 patients were randomized to Group 1 to receive pulsed radiofrequency and Group 2 with 45 patients receiving conventional radiofrequency.	Pulsed radiofrequency was performed at 42° for 30 minutes. Bupivacaine was injected prior to the procedure and following the procedure, 2 mg of methylprednisolone was injected through RF needle at each level in both groups.	Conventional radiofrequency ablation was performed at 80° for 90 seconds. Bupivacaine was injected prior to the procedure and following the procedure, 2 mg of methylprednisolone was injected through RF needle at each level in both groups.	VAS, Odom criteria	1, 3, 6 months, 1 year, 2 years	Conventional radiofrequency ablation provided significantly better relief at 6 months, one year, and 2 years.	Randomized, double-blind control trial	Active control trials	This trial shows excellent outcomes with conventional radiofrequency neurotomy over a period of 2 years.
Lakemeier et al, ⁵⁹ 2013 Randomized, double-blind, active controlled trial Quality Scores: Cochrane = 9/13 IPM-QRB = 37/48	56 patients were randomized into 2 groups with 29 patients receiving intraarticular steroid injections and 27 patients receiving radiofrequency denervation after the diagnosis was made with intraarticular injection of local anesthetic with a single block with pain reduction of at least 50%.	Intraarticular injection of local anesthetic and steroid	Radiofrequency neurotomy for 90 seconds at 80°C	Roland-Morris questionnaire, VAS, ODI, analgesic intake	6 months	Pain relief and functional improvement were observed in both groups. There were no significant differences between the 2 groups for pain relief and functional status improvement.	Lack of placebo group. Relatively short-term follow-up.	Randomized, double-blind trial with single diagnostic block with intraarticular injection	Both groups showed improvement. Effectiveness at 6 months in both groups with intraarticular injection or radiofrequency neurotomy.
Dobrogowski et al, ⁶⁰ 2005 Randomized, active control trial Quality Scores: Cochrane = 10/13 IPM-QRB = 37/48	45 consecutive patients with chronic low back pain judged to be positive with significant relief with 2 controlled diagnostic blocks	Injection of saline in patients after conventional radiofrequency (85° for 60 seconds) neurotomy to evaluate postoperative pain	Conventional radiofrequency neurotomy at 85°C for 60 seconds, followed by injection of either methylprednisolone or pentoxifylline	VAS, minimum of 50% reduction of pain intensity, patient satisfaction score	One, 3, 6, and 12 months	≥ 50% reduction of pain intensity was observed in 66% of the patients 12 months later. There was no difference in the long-term outcomes.	Randomized, active control trial	Very small study with highly defined inclusion criteria evaluating effectiveness of radiofrequency neurotomy and postoperative pain.	Radiofrequency neurotomy effective with or without steroid injection after neurolysis.

(Continued)

Table 6 (Continued).

Study Study Characteristic Methodological Quality Scoring	Number of Patients & Selection Criteria	Control	Interventions	Outcome Measures	Time of Measurement	Results	Strengths	Weaknesses	Conclusions
McCormick et al. ⁶² 2019 Randomized, single blinded, controlled trial. Quality Scores: Cochrane = 11/13 IPM-QRB = 37/48	43 patients were randomized to two groups. 21 received cooled radiofrequency ablation while 22 received traditional radiofrequency ablation of medial branch nerve. Patients who had at least 75% pain relief on a diagnostic block were included in study.	Received traditional percutaneous radiofrequency ablation of medial branch nerve.	Received cooled percutaneous radiofrequency ablation of medial branch nerve.	Primary outcome: $\geq 50\%$ NRS reduction at 6 months. Secondary outcomes: NRS, ODI and patient global impression of change.	6 months	A $\geq 50\%$ decrease in NRS was observed in 52% (95% CI 31% to 74%) and 44% (95% CI 22% to 69%) in the cooled RFA and traditional RFA respectively with no significant difference between the groups ($p=0.75$).	Randomized, single blinded.	Relatively small sample size, up to 7% participants outcomes were not reported. Followed only for 6 months. Not a double blinded study.	Study showed both cooled radiofrequency ablation and traditional radiofrequency ablation had over 50% success rates in reducing pain and improving function at 6 months. However, there was no significant difference between the groups.

<p>Moon et al.⁶³ 2013 Randomized, active control, comparative analysis Quality Scores: Cochrane = 9/13 IPM-QRB = 41/48</p>	<p>82 patients were included with low back pain with 41 patients in each group either with a parallel placement of the needle or perpendicular placement of the needle. Concordant pain relief of >50% after a comparative local anesthetic block.</p>	<p>An active control trial with needle placement with perpendicular approach.</p>	<p>41 patients in each group were treated with radiofrequency (80°C for 90 seconds) after appropriate diagnosis of facet joint pain with dual diagnostic blocks with 50% relief as the criterion standard. The needle was positioned either utilizing a discal or perpendicular approach or utilizing a tunnel vision approach with parallel placement of the needle.</p>	<p>NRS, ODI</p>	<p>One month and 6 months</p>	<p>Patients in both groups showed a statistically significant reduction in NRS and Oswestry Disability Index scores from baseline to that of the scores at one and 6 months (all $P < 0.0001$, Bonferroni corrected).</p>	<p>Randomized, double-blind, controlled trial. The major strength is that authors have proven that parallel approach may not be the best as has been described. Diagnosis of facet joint pain by dual blocks.</p>	<p>Active controlled trial without placebo group. Short-term follow-up.</p>	<p>Positive results in an active controlled trial in a relatively short-term follow-up of 6 months, with positioning of the needle either with distal approach (perpendicular placement or tunnel vision) with parallel placement of the needle with some superiority with perpendicular approach. This trial abates any criticism of needle positioning one way or the other and the traditional needle positioning appears to be superior to parallel needle placement.</p>
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(Continued)

Table 6 (Continued).

Study Characteristic Methodological Quality Scoring	Number of Patients & Selection Criteria	Control	Interventions	Outcome Measures	Time of Measurement	Results	Strengths	Weaknesses	Conclusions
Moussa and Khedi, ⁶⁴ 2016 Randomized, double-blind, active-controlled trial Quality Scores: Cochrane = 10/13 IPM-QRB = 41/48	120 patients were randomized to three groups of 40 each. First group received percutaneous radiofrequency coagulation of the facet joint capsule, second group underwent percutaneous denervation of the medical dorsal branch and the third wash sham group. Patients with chronic low back pain for over one year duration despite of at least three months of conservative management and who achieved near complete pain reduction after two diagnostic blocks.	Sham lesion procedure after local anesthetic injection	One group received percutaneous radiofrequency coagulation of facet joint capsule and the second group underwent percutaneous denervation of the medial dorsal branch.	Several outcome measures were measured VAS, ODI, and GPE. However the primary outcome was determined by a predefined multidimensional COM at one year follow-up.	3, 6, 12, 24, and 36 months.	Success measured by COM at 1 year in the radiofrequency coagulation of joint capsule, denervation of medial dorsal branch and sham groups were 67.5%, 57.5% and 10% respectively which was statistically significant ($p=0.038$).	Randomized double blinded. All the interventional procedures were done by one neurosurgeon reducing potential operator-dependent confounding patients diagnosed with facet joint pain by dual blocks.	Relatively small sample size, average 8, 13 and 20% patients lost to follow up at 1, 2 and 3 years respectively.	Study showed that both radiofrequency coagulation of facet joint capsule and medial branch nerve significantly improved pain in chronic low back pain patients at one year compared to the sham group. However, these benefits were seen at 2 and 3 years follow-up for group in which the facet joint capsule was targeted but diminished in the group in which medial branch nerve was targeted.

<p>Song et al.⁶⁶ 2019 Randomized, single-blind (investigator), active-controlled trial Quality Scores: Cochrane = 6/13 IPM-QRB = 29/48</p>	<p>40 patients were randomized to two groups of 20 each. One group received Radiofrequency neurotomy while the other group underwent endoscopic neurotomy. Patients who had at least 3 months of chronic low back pain and showed at least 80% pain relief following a single diagnostic block.</p>	<p>The control group underwent endoscopic neurotomy of lumbar medial branch nerve.</p>	<p>The intervention group underwent fluoroscopy assisted radiofrequency neurotomy of lumbar medial branch nerve.</p>	<p>VAS and ODI scores were measured.</p>	<p>3 weeks, 6 months, 1 and 2 years.</p>	<p>Radiofrequency group showed significant effectiveness at 3 weeks, 6 months, and 1 year but not significantly effective at 2 years. Endoscopy group showed significantly effective at even at 2 years but the efficacy declined. There was no significant difference between the groups at 3 weeks after the procedure however, at 6 months and longer the endoscopy group showed significantly better outcomes.</p>	<p>Randomized, investigator blinded study.</p>	<p>Very small sample size, single blinded (investigator only), single center, and patients medication and physiotherapy were not taken into account. Single diagnostic block was used for diagnosis.</p>	<p>Both radiofrequency neurotomy and endoscopic neurotomy of the medial branch nerve were effective but endoscopic neurotomy has better and longer lasting outcomes.</p>
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Abbreviations: VAS, Visual Analog Scale; ODI, Oswestry Disability Index; RF, radiofrequency; NRS, Numeric rating scale; GPE, global perceived effect; COM1, combined outcome measure; IPM-QRB, interventional pain management techniques- quality appraisal of reliability and risk of bias assessment.

Table 7 Effectiveness of Lumbar Radiofrequency in Facet Joint Pain

Study	Patients	Interventions	Pain Relief and Function			Results			Comments
			3 Mos.	6 Mos.	12 Mos.	Short-Term ≤ 6 Mos.	> 6 Mos.	Long-Term ≥ 1 Year	
Juch et al, ⁶¹ 2017 MINT randomized, non-blinded, pragmatic clinical trial Quality Scores: Cochrane = 6/13 IPMI-QRB = 26/48	A total of 251 patients were randomized into facet trial with 126 patients in the control group receiving exercise program as randomized. 125 patients were randomized to intervention group.	Patients in the intervention group, radiofrequency ablation after testing positive with at least 50% relief with a single block of facet joint nerves with pain reduction within 30 to 90 minutes after the block. Radiofrequency neurotomy was performed with a conventional radiofrequency ablation procedure with a 22 gauge electrode.	NSD	NSD	NSD	N	N	N	Lack of effectiveness
Nath et al, ⁶⁵ 2008 RA, DB, Sham control Quality Scores: Cochrane = 13/13 IPMI-QRB = 28/48	40	Radiofrequency = 20 Sham = 20	NA	Significant proportion of patients in interventional group	NA	P for radiofrequency N for sham or active	P for radiofrequency N for sham or active	NA	Effective for short-term and long-term
Tekin et al, ⁶⁷ 2007 RA, AC and sham, DB Quality Scores: Cochrane = 12/13 IPMI-QRB = 26/48	60	CRF = 20 PRF = 20 Control = 20	NA	SI with CRF	SI with CRF	NA	P for radiofrequency N for sham	P for radiofrequency N for sham	Effective for long-term improvement
van Wijk et al, ⁶⁸ 2005 RA, DB, Sham control Quality Scores: Cochrane = 13/13 IPMI-QRB = 38/48	81	Radiofrequency = 40 Sham = 41	27.5% vs 29.3%	27.5% vs 29.3%	27.5% vs 29.3%	N	N	N	Lack of effectiveness with short- and long-term

Dobrogowski et al, ⁶⁰ 2005 RA, AC Quality Scores: Cochrane = 10/13 IPM-QRB = 37/48	45	CRF	NA	60%	NA	NA	NA	P	NA	Short-term effectiveness
van Kleef et al, ⁶⁹ 1999 RA, DB, sham control Quality Scores: Cochrane = 13/13 IPM-QRB = 37/48	31	Radiofrequency = 15 Sham = 16	60% vs 25%	47% vs 19%	47% vs 13%	P for radiofrequency N for sham or active	P for radiofrequency N for sham	P for radiofrequency N for sham	P for radiofrequency N for sham	Effectiveness with short- and long-term
Moon et al, ⁶³ 2013 Prospective, RA, comparative study Quality Scores: Cochrane = 9/13 IPM-QRB = 41/48	Total = 82 Tunnel vision approach group – 41 patients included and 34 patients analyzed.	Radiofrequency neurotomy distal approach	SI in both groups	SI in both groups	NA	P	P	P	NA	Short-term effectiveness
Lakemeier et al, ⁵⁹ 2013 RA, DB Quality Scores: Cochrane = 9/13 IPM-QRB = 37/48	Total = 56 Steroid group = 29 patients Radiofrequency group = 27 patients	Intraarticular lumbar facet joint steroid injections compared to lumbar facet joint radiofrequency denervation	NA	SI in both groups	NA	P	P	P	NA	Short-term effectiveness
Çetin & Yektaş, ⁵⁶ 2018 Randomized, double-blind, controlled trial Quality Scores: Cochrane = 12/13 IPM-QRB = 39/48	118 patients were randomized to Group 1 to receive pulsed radiofrequency and Group 2 with 45 patients receiving conventional radiofrequency.	Pulsed radiofrequency vs conventional radiofrequency	SI	SI	SI	P	P	P	P	Positive trial for CRF for short and long-term effectiveness

(Continued)

Table 7 (Continued).

Study Study Characteristic Methodological Quality Scoring	Patients	Interventions	Pain Relief and Function			Results			Comments
			3 Mos.	6 Mos.	12 Mos.	Short-Term ≤ 6 Mos.	Long-Term		
							> 6 Mos.	≥ 1 Year	
McCormick et al, ⁶² 2019 Randomized, single-blind, comparative study Quality score: Cochrane = 11/13 IPM-QRB = 37/48	43	MBN cooled RFA = 21 MBN traditional RFA = 22	NA	SI in both groups	NA	NA	P	NA	Both effective for short term. No significant difference between the groups
Moussa & Khedr, ⁶⁴ 2016 Randomized, double blind, controlled trial, sham control Quality score: Cochrane = 10/13 IPM-QRB = 41/48	120	Radio frequency coagulation of facet joint capsule = 40 Radio frequency denervation of medial dorsal branch =40 Sham = 40	SI in all three groups	SI in two groups except sham group	SI in two groups except sham group		P	P	Both intervention groups effective for short term and long term
Song et al, ⁶⁶ 2019 Randomized, unblinded, comparative study Quality score: Cochrane = 6/13 IPM-QRB = 29/48	40	Radiofrequency neurotomy = 20 Endoscopic neurotomy = 20 of lumbar medial branch	SI in both the groups	SI in both the groups	SI in both the groups		P	P	Both groups effective for up to one year. The radiofrequency group lost effectiveness at 2 years

Abbreviations: RA, randomized; DB, double-blind; AC, active control; ST, steroid; LA, local anesthetic; SAL, saline; SI, significant improvement; NSD, no significant difference; NE, not effective; CRFA, radiofrequency Ablation; P, positive; N, negative; NA, not applicable; MBN, medial branch nerve; IPM-QRB, interventional pain management techniques- quality appraisal of reliability and risk of bias assessment.

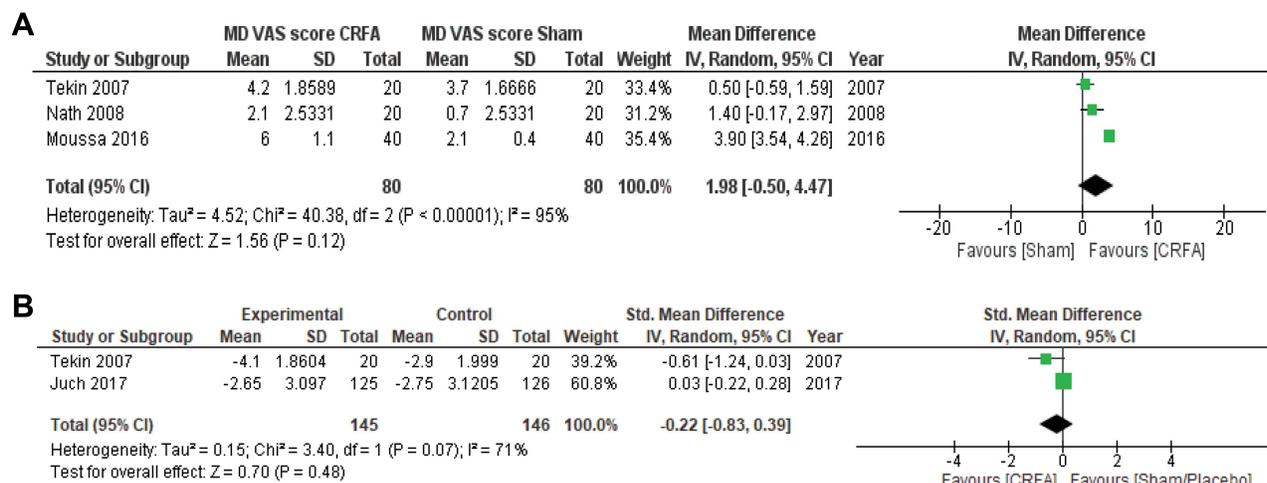


Figure 2 (A) Conventional dual-arm meta-analysis of pain relief of radiofrequency neurotomy vs sham control group at 6-month follow-up. **(B)** Conventional dual-arm meta-analysis of pain relief of radiofrequency neurotomy vs sham control group at 12-month follow-up.

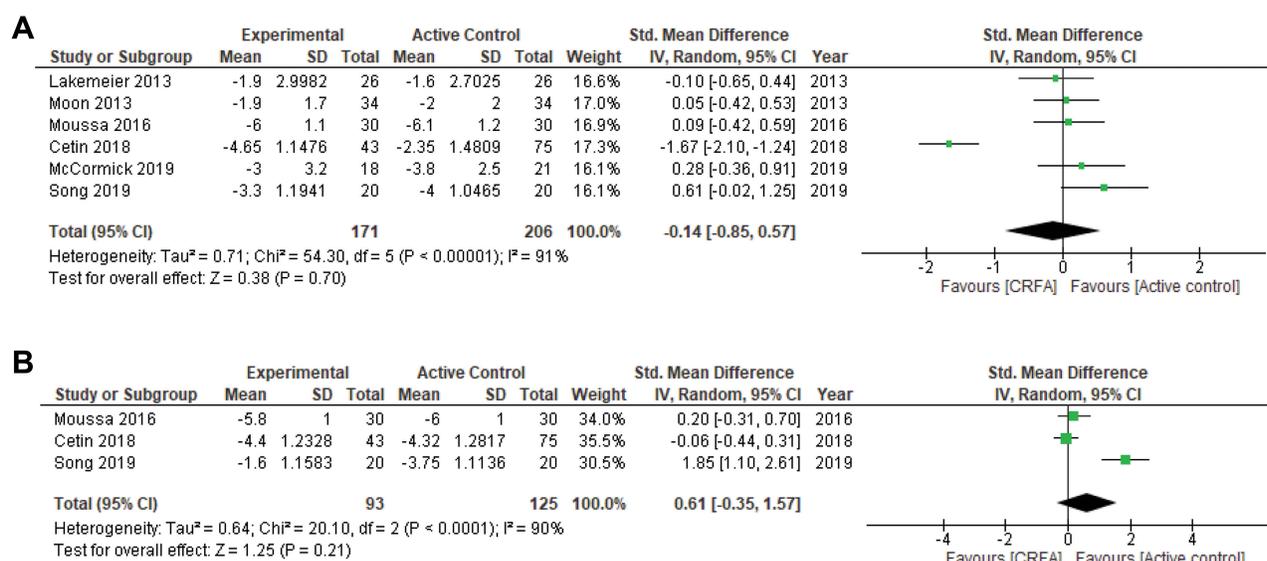


Figure 3 (A) Conventional dual-arm meta-analysis of pain relief of radiofrequency neurotomy of active control trials at 6-month follow-up. **(B)** Conventional dual-arm meta-analysis of pain relief of radiofrequency neurotomy of active control trials at 12-month follow-up.

The evidence of efficacy based on dual-arm and single-arm meta-analysis of CRFA with placebo controlled and active controlled trials, is Level II evidence (moderate), in improving pain and function for short-term and long-term follow-up.

Discussion

This systematic review and meta-analysis of randomized trials of efficacy of lumbar facet joint radiofrequency neurotomy procedures in managing chronic low back pain revealed Level II evidence for short-term effectiveness of 6 months or less and for long-term

effectiveness of 6 months or longer. Out of the 12 trials^{56,59-69} included in this analysis, 6 trials^{56,64-67,69} demonstrated short- and long-term effectiveness, 4 trials^{59,60,62,63} revealed short-term effectiveness only, whereas 2 trials^{61,68} showed lack of effectiveness. The evidence analysis for efficacy was based on five sham-controlled trials,^{64,65,67-69} with one trial assessing short-term outcomes (65) and four trials assessing long-term outcomes.^{64,67-69} Among these, five sham-controlled trials, three of them showed positive long-term outcomes,^{64,67,69} whereas one trial showed only short-term positive outcomes.⁶⁵ However, one trial⁶⁸ showed

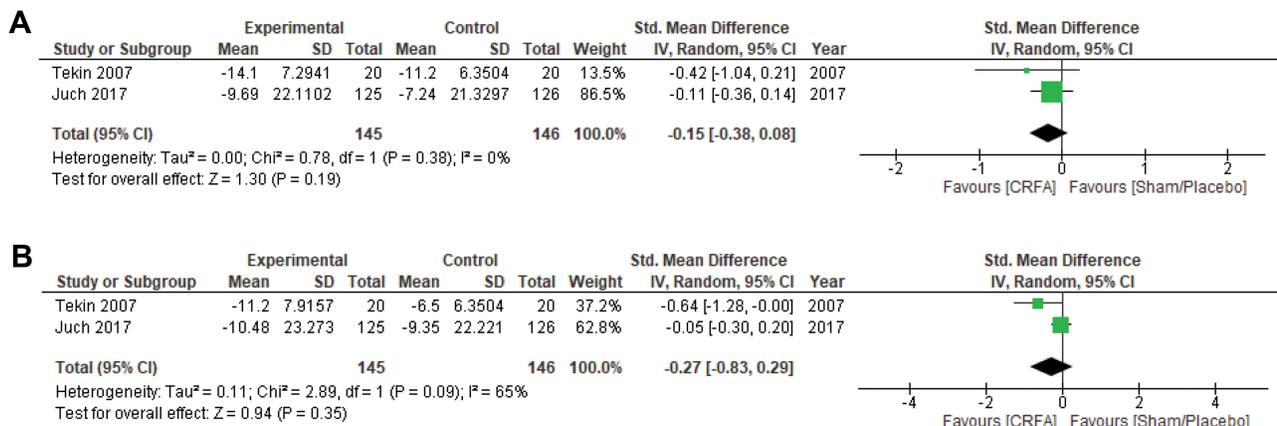


Figure 4 (A) Conventional dual-arm meta-analysis of functional status (ODI) of radiofrequency neurotomy vs sham control group at 6-month follow-up. **(B)** Conventional dual-arm meta-analysis of functional status (ODI) of radiofrequency neurotomy vs sham control group at 12-month follow-up.

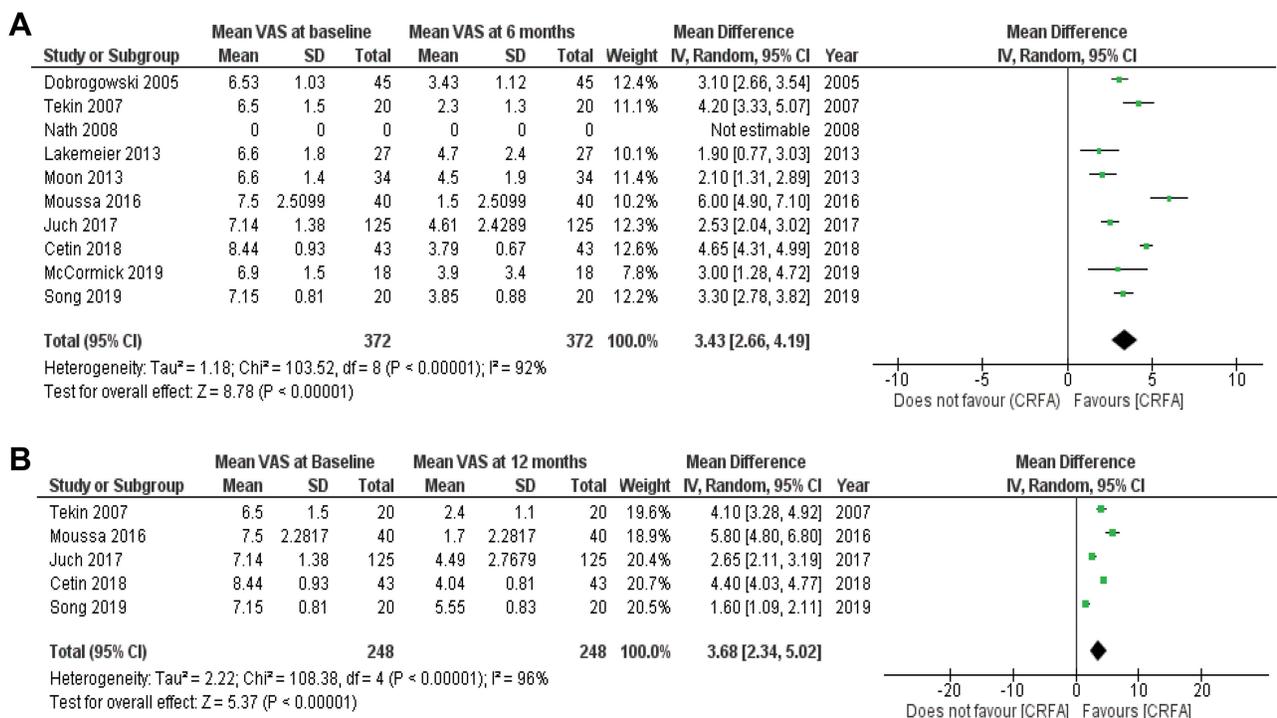


Figure 5 (A) Single arm meta-analysis of pain relief of radiofrequency neurotomy at baseline vs at 6-month follow-up of active-controlled trials. **(B)** Single arm meta-analysis of pain relief of radiofrequency neurotomy at baseline vs at 12-month follow-up of active control trials.

negative results for both short term and long term. Consequently, among the five studies, three showed long-term improvement and four showed short-term improvement. These results were strengthened by active-controlled trials with single-arm meta-analysis. However, among the studies which showed negative results, Juch et al⁶¹ included 251 patients with 126 patients in the control group. Even though the study

had a variety of limitations,^{71–78} it is considered as one of the important studies in the literature. A second high-quality trial also showed lack of significant improvement with radiofrequency neurotomy.⁶⁸ Thus, even though results are seen and positive results were demonstrated in 10 trials, the total number of patients undergoing conventional radiofrequency neurotomy were 296 of 717. In contrast, among the two negative

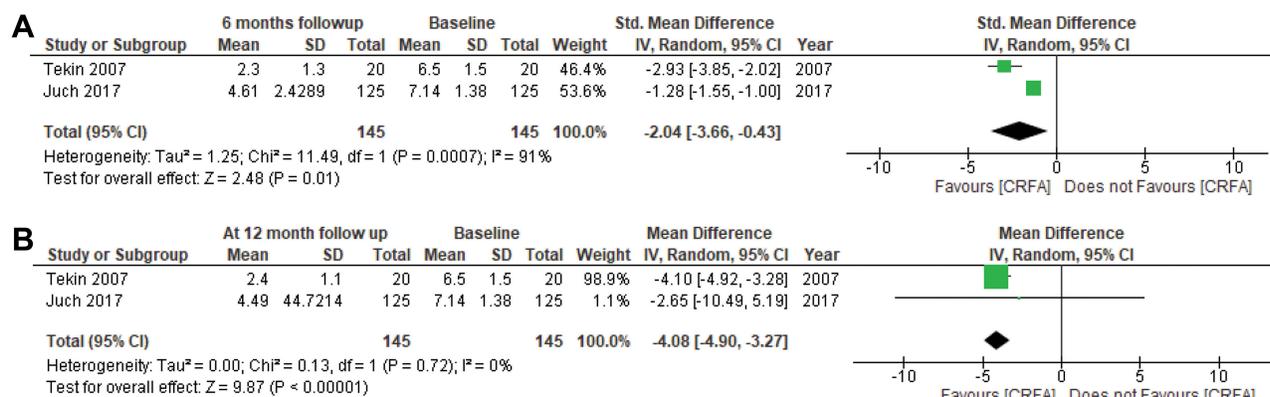


Figure 6 (A) Single-arm meta-analysis of functional status (ODI) of radiofrequency neurotomy at 6-month follow-up in sham control trials. **(B)** Single-arm meta-analysis of functional status (ODI) of radiofrequency neurotomy at 12 month follow-up in sham control trials.

trials,^{61,68} 162 of 332 patients underwent radiofrequency neurotomy. The negative studies were larger than any of the positive studies in inclusion of the number of patients included in the study. Consequently, the evidence is Level II with positive results among 10 of the 12 trials and 2 negative trials.

The results of the present analysis are similar but nonetheless different from other previously published systematic reviews and guidelines. The guidelines for facet joint interventions³ showed Level II evidence for radiofrequency neurotomy in the lumbar spine with inclusion of a total of 11 trials, with 2 of them showing lack of effectiveness. However, two of the studies included in the guidelines were not included in this systematic review. There are additional studies which were not included in the systematic review/guidelines³ and included in the present review. In the systematic review and guidelines (3), the authors utilized 11 trials with the same 2 trials showing negative results and 9 trials showing positive results, The guidelines included both active-control and sham-control trials similar to the present manuscript. Overall, the results agree with this publication. The results of two additional systematic reviews by the same authors^{39,40} were also similar to the present study.

There are other systematic reviews which provide discordant opinions. Maas et al⁵⁰ showed lack of effectiveness. Schneider et al⁴⁹ showed effectiveness in patients with 100% pain relief and utilizing a parallel needle placement with relief in approximately 57% of the patients. Lee et al,⁴⁸ in a meta-analysis, concluded that conventional radiofrequency denervation resulted in a significant

reduction in low back pain with positive results when compared with sham procedures over a period of 1 year. The analysis was performed in 231 patients from multiple studies undergoing denervation procedures. Leggett et al⁷⁹ in an older systematic review analyzed six sham controlled RCTs performed between 1994 and 2008. They found high variability in selection criteria and outcomes with inconclusive effectiveness. In contrast, Poetscher et al⁸⁰ also evaluated nine RCTs comparing the effect of radiofrequency treatment with other forms of treatment and with placebo and found that radiofrequency denervation was more effective than placebo and steroid injection. However, they concluded that evidence should be interpreted with caution.

In this review, 40% of the trials (5 of 12) compared CRFA to sham procedures. The majority of the trials (7 of 12) compared them to other interventions or a different mode of radiofrequency ablation. Lakemeier et al⁵⁹ compared CRFA with intraarticular facet joint steroid injections, but only studied short-term effectiveness. This trial showed a positive result for both conventional radiofrequency and intraarticular steroid injections in short term. Two trials^{56,67} compared conventional radiofrequency to pulsed radiofrequency ablation. In both the studies, conventional radiofrequency demonstrated positive results, while pulsed radiofrequency ablation showed limited effectiveness. One trial⁶⁶ compared CRFA to endoscopic neurotomy. In this trial, both the groups showed positive results in short term and long term according to our established criteria. However, the effectiveness of endoscopic neurotomy lasted for over 2 years while it did not in the CRFA group. Overall, CRFA appears to be effective in

both the short term and long term as an intervention in chronic low back pain of facet joint origin.

From the meta-analysis, though there was no statistical difference of pain VAS score between CRFA and sham procedure at 6 months follow-up, there was a trend towards CRFA being more effective than a sham procedure. These results might in part be related to the small sample sizes of the RCTs, with a cumulative sample size of just 160 patients with 80 in each arm. Thus, more studies with larger patient sample sizes should be conducted to establish the effectiveness of lumbar radiofrequency neurotomy. However, in single-arm analysis, the radiofrequency neurotomy using CRFA showed a statistically significant reduction in the pain VAS scores both at 6 months and 12 months follow-up compared to the baseline.

As with any systematic review and meta-analysis, the validity of this analysis is only as reliable as the validity of the primary studies. Although there were multiple studies in this meta-analysis the patient sample size was low in most of the primary studies.

Multiple issues have been highlighted in reference to the systematic reviews, specifically in interventional pain management.^{3,4,21,81-84} Significant controversy related to placebo and multiple issues related to meta-analysis of active control trials have been discussed. Manchikanti et al⁸¹ have shown sodium chloride solution injected into the epidural space is not a placebo. Similarly, they have shown epidural lidocaine is also not a placebo.²⁶ In this assessment, local anesthetic was utilized during sham control. This can provide relief, which can be significant.³ Consequently, in a dual-arm meta-analysis, it is difficult to assess the role of effectiveness of conventional radiofrequency neurotomy when local anesthetic was utilized prior to sham neurolysis, as well as when an active control was utilized. This affects all placebo and sham control trials, as well as active control trials. None of the previous reviews have performed a single-arm analysis. It has been shown that is crucial to perform a single-arm analysis in multiple studies as expected in this systematic review and meta-analysis.^{3,4,26,27,81-84} Qualitative analysis demonstrated positive results with Level II evidence. Quantitative analysis also showed Level II evidence with dual-arm analysis. However, single-arm analysis meta-analysis showed clear superiority of conventional radiofrequency neurotomy compared to local anesthetic injection or other treatments including pulsed

radiofrequency. Though not appreciated well, single-arm analysis is crucial in elucidating the effectiveness of both groups, whether it is local anesthetic converted into placebo or local anesthetic administered prior to sham procedure. Consequently, differences in conclusions may be the product of methodological differences between investigators.^{3,4,26,81-93}

Conclusion

This systematic review provides evidence variable from Level II for short-term and long-term effectiveness of radiofrequency neurotomy, diagnosed with controlled diagnostic blocks. Overall, the evidence was adjusted to Level II based on the negative studies with large sample sizes.

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Author Contributions

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References

- Dieleman JL, Baral R, Birger M, et al. US spending on personal health care and public health, 1996–2013. *JAMA*. 2016;316(24):2627–2646. doi:10.1001/jama.2016.16885
- Dieleman JL, Cao J, Chapin A, et al. US health care spending by payer and health condition, 1996–2016. *JAMA*. 2020;323(9):863–884. doi:10.1001/jama.2020.0734
- Manchikanti L, Kaye AD, Soin A, et al. Comprehensive evidence-based guidelines for facet joint interventions in the management of chronic spinal pain: American Society of Interventional Pain Physicians (ASIPP) guidelines. *Pain Physician*. 2020;23(3S):S1–S127. doi:10.36076/ppj.2020/23/S1
- Manchikanti L, Knezevic NN, Navani A, et al. Epidural interventions in the management of chronic spinal pain: American Society of Interventional Pain Physicians (ASIPP) comprehensive evidence-based guidelines. *Pain Physician*. 2021;24(S1):S27–S208.
- Manchikanti L, Centeno CJ, Atluri S, et al. Bone marrow concentrate (BMC) therapy in musculoskeletal disorders: evidence-based policy position statement of American Society of Interventional Pain Physicians (ASIPP). *Pain Physician*. 2020;23(2):E85–E131.
- U.S. Burden of Disease Collaborators. The state of US health, 1990–2010: burden of diseases, injuries, and risk factors. *JAMA*. 2013;310(6):591–608. doi:10.1001/jama.2013.13805
- Hoy DG, Bain C, Williams G, et al. A systematic review of the global prevalence of low back pain. *Arthritis Rheum*. 2012;64(6):2028–2037. doi:10.1002/art.34347
- Manchikanti L, Sanapati MR, Pampati V, Boswell MV, Kaye AD, Hirsch JA. Update on reversal and decline of growth of utilization of interventional techniques in managing chronic pain in the Medicare population from 2000 to 2018. *Pain Physician*. 2019;22(6):521–536. doi:10.36076/ppj/2019.22.521
- Manchikanti L, Soin A, Mann DP, et al. Utilization patterns of facet joint interventions in managing spinal pain: a retrospective cohort study in the US fee-for-service medicare population. *Curr Pain Headache Rep*. 2019;23(10):73. doi:10.1007/s11916-019-0816-7
- Manchikanti L, Soin A, Mann DP, Bakshi S, Pampati V, Hirsch JA. Comparative analysis of utilization of epidural procedures in managing chronic pain in the medicare population: pre and post affordable care act. *Spine (Phila Pa 1976)*. 2019;44(3):220–232. doi:10.1097/BRS.0000000000002785
- Manchikanti L, Pampati V, Soin A, et al. Trends of expenditures and utilization of facet joint interventions in fee-for-service (FFS) medicare population from 2009–2018. *Pain Physician*. 2020;23(3S):S129–S147. doi:10.36076/ppj.2020/23/S129
- Manchikanti L, Pampati V, Soin A, Sanapati MR, Kaye AD, Hirsch JA. Declining utilization and inflation-adjusted expenditures for epidural procedures in chronic spinal pain in the medicare population. *Pain Physician*. 2021;24(1):1–15.
- Wagemakers SH, van der Velden JM, Gerlich AS, et al. A systematic review of devices and techniques that objectively measure patients' pain. *Pain Physician*. 2019;22(1):1–13.
- La Touche R, Grande-Alonso M, Arnes-Prieto P, Paris-Alemay A. How does self-efficacy influence pain perception, postural stability and range of motion in individuals with chronic low back pain? *Pain Physician*. 2019;22(1):E1–E13. doi:10.36076/ppj/2019.22.E1
- Coulter ID, Crawford C, Vernon H, et al. Manipulation and mobilization for treating chronic nonspecific neck pain: a systematic review and meta-analysis for an appropriateness panel. *Pain Physician*. 2019;22(2):E55–E70. doi:10.36076/ppj/2019.22.E55
- Bansal D, Asrar MM, Ghai B, Pushpendra D. Prevalence and impact of low back pain in a community-based population in Northern India. *Pain Physician*. 2020;23(4):E389–E398. doi:10.36076/ppj.2020/23/E389
- Manchikanti L, Vanaparthi R, Atluri S, Sachdeva H, Kaye AD, Hirsch JA. COVID-19 and the opioid epidemic: two public health emergencies that intersect with chronic pain. *Pain Ther*. 2021;10:269–286. doi:10.1007/s40122-021-00243-2
- U.S. Department of Health and Human Services, Office of Inspector General. Medicare improperly paid physicians for more than five spinal facet-joint injection sessions during a rolling 12-month period (A-09-20-03003); 2020. Available from: <https://oig.hhs.gov/oas/reports/region9/92003003.asp>. Accessed March 24, 2021.
- U.S. Department of Health and Human Services, Office of Inspector General. Noridian healthcare solutions, LLC, made improper medicare payments of \$4 million to physicians in jurisdiction E for spinal facet-joint injections (A-09-20-03010); 2021. Available from: <https://oig.hhs.gov/oas/reports/region9/92003010.asp>. Accessed March 4, 2021.
- Medical Policy, CGS Administrators LLC. Multi-jurisdictional contractor advisory committee (CAC) meeting. Facet joint and medial nerve branch procedures; 2020.
- National Government Services, Inc. Local coverage determination (LCD). Facet joint interventions for pain management (L35936); 2021.
- Manchikanti L, Singh V, Kaye AD, Hirsch JA. Lessons for better pain management in the future: learning from the past. *Pain Ther*. 2020;9(2):373–391. doi:10.1007/s40122-020-00170-8
- Shah S, Diwan S, Soin A, et al. Evidence-based risk mitigation and stratification during COVID-19 for return to interventional pain practice: American Society of Interventional Pain Physicians (ASIPP) guidelines. *Pain Physician*. 2020;23(4S):S161–S182. doi:10.36076/ppj.2020/23/S161
- Gharibo C, Sharma A, Soin A, et al. Triaging interventional pain procedures during COVID-19 or related elective surgery restrictions: evidence-informed guidance from the American Society of Interventional Pain Physicians (ASIPP). *Pain Physician*. 2020;23(4S):S183–204. doi:10.36076/ppj.2020/23/S183
- Wahezi SE, Duarte RA, Yerra S, et al. Telemedicine during COVID-19 and beyond: a practical guide and best practices multidisciplinary approach for the orthopedic and neurologic pain physical examination. *Pain Physician*. 2020;23(4S):S205–S238.
- Knezevic NN, Manchikanti L, Urits I, et al. Lack of superiority of epidural injections with lidocaine with steroids compared to without steroids in spinal pain: a systematic review and meta-analysis. *Pain Physician*. 2020;23(4S):S239–S270.
- Manchikanti L, Kosanovic R, Vanaparthi R, et al. Steroid distancing in interventional pain management during COVID-19 and beyond: safe, effective and practical approach. *Pain Physician*. 2020;23(4S):S319–S350. doi:10.36076/ppj.2020/23/S319
- Soin A, Vuppala S, Surfield G, et al. Ohio response to COVID-19 and its impact on interventional pain management practices. *Pain Physician*. 2020;23(4S):S439–S448. doi:10.36076/ppj.2020/23/S439
- Singh JR, Miccio VF Jr, Modi DJ, Sein MT. The impact of local steroid administration on the incidence of neuritis following lumbar facet radiofrequency neurotomy. *Pain Physician*. 2019;22(1):69–74. doi:10.36076/ppj/2019.22.69
- Bharti N, Sujith J, Singla N, Panda NB, Bala I. radiofrequency thermoablation of the gasserian ganglion versus the peripheral branches of the trigeminal nerve for treatment of trigeminal neuralgia: a randomized, control trial. *Pain Physician*. 2019;22(2):147–154. doi:10.36076/ppj/2019.22.147
- LaGrew J, Baldyuey P, Vasilopoulos T, Kumar S. Incidence of cervicogenic headache following lower cervical radiofrequency neurotomy. *Pain Physician*. 2019;22(2):E127–E132.
- Pearson ACS, Dexter F. Observational study of the distribution and diversity of interventional pain procedures among hospitals in the State of Iowa. *Pain Physician*. 2019;22(3):E157–E170.
- Wang R, Ma C, Han Y, Tan M, Lu L. Effectiveness of denervation therapy on pain and joint function for patients with refractory knee osteoarthritis: a systematic review and meta-analysis. *Pain Physician*. 2019;22(4):341–352.

34. Kapural L, Lee N, Neal K, Burchell M. Long-term retrospective assessment of clinical efficacy of radiofrequency ablation of the knee using a cooled radiofrequency system. *Pain Physician*. 2019;22(5):489–494. doi:10.36076/ppj.2019.22.489
35. Friedrich J, Itano EM, Lynn RR. Management of cardiac implantable electrical devices in patients undergoing radiofrequency ablation for spine pain: physician survey and review of guidelines. *Pain Physician*. 2020;23(4):E335–E342. doi:10.36076/ppj.2020/23/E335
36. Orhurhu V, Khan F, Quispe RC, et al. Use of radiofrequency ablation for the management of facial pain: a systematic review. *Pain Physician*. 2020;23(6):E559–E580.
37. Abarca TL, Dexter F, Epstein RH, Pearson ACS. Hospitals' web site lists of their interventional pain procedures inadequately reflect the diversity of their actual pain medicine practices. *Pain Physician*. 2020;23(6):E723–E730.
38. Boswell MV, Manchikanti L, Kaye AD, et al. A best-evidence systematic appraisal of the diagnostic accuracy and utility of facet (Zygapophysial) joint injections in chronic spinal pain. *Pain Physician*. 2015;18(4):E497–E533. doi:10.36076/ppj.2015/18/E497
39. Manchikanti L, Hirsch JA, Falco FJ, Boswell MV. Management of lumbar zygapophysial (facet) joint pain. *World J Orthop*. 2016;7(5):315–337. doi:10.5312/wjo.v7.i5.315
40. Manchikanti L, Kaye AD, Boswell MV, et al. A systematic review and best evidence synthesis of effectiveness of therapeutic facet joint interventions in managing chronic spinal pain. *Pain Physician*. 2015;18(4):E535–E582. doi:10.36076/ppj.2015/18/E535
41. Kuslich SD, Ulstrom CL, Michael CJ. The tissue origin of low back pain and sciatica: a report of pain response to tissue stimulation during operations on the lumbar spine using local anesthesia. *Orthop Clin North Am*. 1991;22(2):181–187. doi:10.1016/S0030-5898(20)31644-8
42. Schwarzer AC, Aprill CN, Derby R, Fortin J, Kine G, Bogduk N. Clinical features of patients with pain stemming from the lumbar zygapophysial joints. Is the lumbar facet syndrome a clinical entity? *Pain (Phila Pa 1976)*. 1994;19(10):1132–1137. doi:10.1097/00007632-199405001-00006
43. Manchikanti L, Singh V, Pampati V, et al. Evaluation of the relative contributions of various structures in chronic low back pain. *Pain Physician*. 2001;4(4):308–316. doi:10.36076/ppj.2001/4/308
44. DePalma MJ, Ketchum JM, Saullo T. What is the source of chronic low back pain and does age play a role? *Pain Med*. 2011;12(2):224–233. doi:10.1111/j.1526-4637.2010.01045.x
45. MacVicar J, MacVicar AM, Bogduk N. The prevalence of “Pure” lumbar zygapophysial joint pain in patients with chronic low back pain. *Pain Med*. 2021;22(1):41–48. doi:10.1093/pm/pnaa383
46. Manchikanti L, Kosanovic R, Pampati V, et al. Low back pain and diagnostic lumbar facet joint nerve blocks: assessment of prevalence, false-positive rates, and a philosophical paradigm shift from an acute to a chronic pain model. *Pain Physician*. 2020;23(5):519–530. doi:10.36076/ppj.2020/23/519
47. Manchikanti L, Kosanovic R, Cash KA, et al. Assessment of prevalence of cervical facet joint pain with diagnostic cervical medial branch blocks: analysis based on chronic pain model. *Pain Physician*. 2020;23(6):531–540.
48. Lee CH, Chung CK, Kim CH. The efficacy of conventional radiofrequency denervation in patients with chronic low back pain originating from the facet joints: a meta-analysis of randomized controlled trials. *Spine J*. 2017;17(11):1770–1780. doi:10.1016/j.spinee.2017.05.006
49. Schneider BJ, Doan L, Maes MK, et al. Systematic review of the effectiveness of lumbar medial branch thermal radiofrequency neurotomy, stratified for diagnostic methods and procedural technique. *Pain Med*. 2020;21(6):1122–1141. doi:10.1093/pm/pnz349
50. Maas ET, Ostelo RW, Niemisto L, et al. Radiofrequency denervation for chronic low back pain. *Cochrane Database Syst Rev*. 2015;10:CD008572.
51. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. <http://prisma-statement.org/>. Accessed February 17, 2021. doi:10.1136/bmj.n71
52. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Ann Intern Med*. 2009;151(4):W65–W94. doi:10.7326/0003-4819-151-4-200908180-00136
53. Furlan AD, Malmivaara A, Chou R, et al; Editorial Board of the Cochrane Back, Neck Group. 2015 updated method guideline for systematic reviews in the Cochrane back and neck group. *Spine (Phila Pa 1976)*. 2015;40(21):1660–1673. doi:10.1097/BRS.0000000000001061.
54. Manchikanti L, Hirsch JA, Cohen SP, et al. Assessment of methodologic quality of randomized trials of interventional techniques: development of an interventional pain management specific instrument. *Pain Physician*. 2014;17(3):E263–E290. doi:10.36076/ppj.2014/17/E263
55. Manchikanti L, Falco FJE, Benyamin RM, Kaye AD, Boswell MV, Hirsch JA. A modified approach to grading of evidence. *Pain Physician*. 2014;17(3):E319–E325. doi:10.36076/ppj.2014/17/E319
56. Çetin A, Yektaş A. Evaluation of the short- and long-term effectiveness of pulsed radiofrequency and conventional radiofrequency performed for medial branch block in patients with lumbar facet joint pain. *Pain Res Manag*. 2018;43(2):76–80.
57. Civelek E, Cansever T, Kabatas S, et al. Comparison of effectiveness of facet joint injection and radiofrequency denervation in chronic low back pain. *Turk Neurosurg*. 2012;22(2):200–206.
58. Cohen SP, Williams KA, Kurihara C, et al. Multicenter, randomized, comparative cost-effectiveness study comparing 0, 1, and 2 diagnostic medial branch (facet joint nerve) block treatment paradigms before lumbar facet radiofrequency denervation. *Anesthesiology*. 2010;113(2):395–405. doi:10.1097/ALN.0b013e3181e33ae5
59. Lakemeier S, Lind M, Schultz W, et al. A comparison of intraarticular lumbar facet joint steroid injections and lumbar facet joint radiofrequency denervation in the treatment of low back pain: a randomized, controlled, double-blind trial. *Anesth Analg*. 2013;117(1):228–235. doi:10.1213/ANE.0b013e3182910c4d
60. Dobrogowski J, Wrzosek A, Wordliczek J. Radiofrequency denervation with or without addition of pentoxifylline or methylprednisolone for chronic lumbar zygapophysial joint pain. *Pharmacol Rep*. 2005;57(4):475–480.
61. Juch JNS, Maas ET, Ostelo RWJG, et al. Effect of radiofrequency denervation on pain intensity among patients with chronic low back pain: the mint randomized clinical trials. *JAMA*. 2017;318(1):68–81.
62. McCormick ZL, Choi H, Reddy R, et al. Randomized prospective trial of cooled versus traditional radiofrequency ablation of the medial branch nerves for the treatment of lumbar facet joint pain. *Reg Anesth Pain Med*. 2019;44(3):389–397. doi:10.1136/rapm-2018-000035
63. Moon JY, Lee PB, Kim YC, Choi SP, Sim WS. An alternative distal approach for the lumbar medial branch radiofrequency denervation: a prospective randomized comparative study. *Anesth Analg*. 2013;116(5):1133–1140. doi:10.1213/ANE.0b013e31828b35fe
64. Moussa WMM, Khedr W. Percutaneous radiofrequency facet capsule denervation as an alternative target in lumbar facet syndrome. *Clin Neurol Neurosurg*. 2016;150:96–104. doi:10.1016/j.clineuro.2016.09.004
65. Nath S, Nath CA, Pettersson K. Percutaneous lumbar zygapophysial (facet) joint neurotomy using radiofrequency current, in the management of chronic low back pain: a randomized double-blind trial. *Spine (Phila Pa 1976)*. 2008;33(12):1291–1297; discussion 1298. doi:10.1097/BRS.0b013e31817329f0
66. Song K, Li Z, Shuang F, et al. Comparison of the effectiveness of radiofrequency neurotomy and endoscopic neurotomy of lumbar medial branch for facetogenic chronic low back pain: a randomized controlled trial. *World Neurosurg*. 2019;126:e109–e115. doi:10.1016/j.wneu.2019.01.251

67. Tekin I, Mirzai H, Ok G, Erbuyun K, Vatanserver D. A comparison of conventional and pulsed radiofrequency denervation in the treatment of chronic facet joint pain. *Clin J Pain*. 2007;23(6):524–529. doi:10.1097/AJP.0b013e318074c99c
68. van Wijk RMAW, Geurts JWM, Wynne HJ, et al. Radiofrequency denervation of lumbar facet joints in the treatment of chronic low back pain: a randomized, double-blind, sham lesion-controlled trial. *Clin J Pain*. 2005;21(4):335–344. doi:10.1097/01.ajp.0000120792.69705.e9
69. van Kleef M, Barendse GA, Kessels A, Voets HM, Weber WE, de Lange S. Randomized trial of radiofrequency lumbar facet denervation for chronic low back pain. *Spine (Phila Pa 1976)*. 1999;24(18):1937–1942. doi:10.1097/00007632-199909150-00013
70. van Tilburg CWJ, Stronks DL, Groeneweg JG, Huygen FJPM. Randomised sham-controlled double-blind multicentre clinical trial to ascertain the effect of percutaneous radiofrequency treatment for lumbar facet joint pain. *Bone Joint J*. 2016;98-B(11):1526–1533. doi:10.1302/0301-620X.98B11.BJJ-2016-0379.R2
71. Vorobeychik Y, Stojanovic MP, McCormick ZL. Radiofrequency denervation for chronic low back pain. *JAMA*. 2017;318(22):2254–2255. doi:10.1001/jama.2017.16386
72. Rimmalapudi V, Buchalter J, Calodney A. Radiofrequency denervation for chronic low back pain. *JAMA*. 2017;318(22):2255–2256. doi:10.1001/jama.2017.16378
73. Kao MC, Leong MS, Mackey S. Radiofrequency denervation for chronic low back pain. *JAMA*. 2017;318(22):2256. doi:10.1001/jama.2017.16382
74. Kapural L, Provenzano D, Narouze S, et al. Effect of radiofrequency denervation on pain intensity among patients with chronic low back pain: the Mint randomized clinical trials. *JAMA*. 2017;318(1):68–81. doi:10.1001/jama.2017.7918
75. van Kuijk SMJ, Van Zundert J, Hans G, et al. Flawed study design and incorrect presentation of data negatively impact potentially useful interventional treatments for patients with low back pain: a critical review of JAMA's MinT Study. *Pain Pract*. 2018;18(3):292–295. doi:10.1111/papr.12673
76. Argyriou AA, Anastopoulou GG, Bruna J. Inconclusive evidence to support the use of minimally-invasive radiofrequency denervation against chronic low back pain. *Ann Transl Med*. 2018;6(7):127. doi:10.21037/atm.2018.01.23
77. Provenzano DA, Buvanendran A, de León-casasola O, Narouze S, Cohen SP. Interpreting the MINT randomized clinical trials: let us stick to the facts. *Reg Anesth Pain Med*. 2020;45(1):84–86. doi:10.1136/rapm-2019-100905
78. Provenzano DA, Buvanendran A, de León-casasola OA, Narouze S, Cohen SP. Interpreting the MINT randomized trials evaluating radiofrequency ablation for lumbar facet and sacroiliac joint pain: a call from ASRA for better education, study design, and performance. *Reg Anesth Pain Med*. 2018;43(1):68–71. doi:10.1097/AAP.0000000000000699
79. Leggett LE, Soril LJ, Lorenzetti DL, et al. Radiofrequency ablation for chronic low back pain: a systematic review of randomized controlled trials. *Pain Res Manag*. 2014;19(5):e146–153. doi:10.1155/2014/834369
80. Poetscher AW, Gentil AF, Lenza M, Ferretti M. Radiofrequency denervation for facet joint low back pain: a systematic review. *Spine (Phila Pa 1976)*. 2014;39(14):E842–E849. doi:10.1097/BRS.0000000000000337
81. Manchikanti L, Knezevic NN, Sanapati J, Kaye AD, Sanapati MR, Hirsch JA. Is epidural injection of sodium chloride solution a true placebo or an active control agent? A systematic review and meta-analysis. *Pain Physician*. 2021;24(1):41–59.
82. Manchikanti L, Knezevic NN, Sanapati MR, Boswell MV, Kaye AD, Hirsch JA. Effectiveness of percutaneous adhesiolysis in managing chronic central lumbar spinal stenosis: a systematic review and meta-analysis. *Pain Physician*. 2019;22(6):E523–E550. doi:10.36076/ppj/2019.22.E523
83. Manchikanti L, Knezevic NN, Sanapati SP, Sanapati MR, Kaye AD, Hirsch JA. Is percutaneous adhesiolysis effective in managing chronic low back and lower extremity pain in post-surgery syndrome: a systematic review and meta-analysis. *Curr Pain Headache Rep*. 2020;24(6):30. doi:10.1007/s11916-020-00862-y
84. Manchikanti L, Soin A, Boswell MV, Kaye AD, Sanapati M, Hirsch JA. Effectiveness of percutaneous adhesiolysis in post lumbar surgery syndrome: a systematic analysis of findings of systematic reviews. *Pain Physician*. 2019;22(4):307–322. doi:10.36076/ppj/2019.22.307
85. Cappola AR, FitzGerald GA. Confluence, not conflict of interest: name change necessary. *JAMA*. 2015;314(17):1791–1792. doi:10.1001/jama.2015.12020
86. Prusova K, Churcher L, Tyler A, Lokugamage U. Royal college of obstetricians and gynaecologists guidelines: how evidence-based are they? *J Obstet Gynaecol*. 2014;34(8):706–711. doi:10.3109/01443615.2014.920794
87. Clark J, Nijs J, Yeowell G, Goodwin PC. What are the predictors of altered central pain modulation in chronic musculoskeletal pain populations? A systematic review. *Pain Physician*. 2017;20(6):487–500. doi:10.36076/ppj.2017.20.5.487
88. Schwartz D. Evidence-based medicine is NOT the holy grail (Share) – new improved. Available from: <https://www.linkedin.com/pulse/evidence-based-medicine-holy-grail-david-schwartz>. Accessed May 11, 2021.
89. Kaye AD, Manchikanti L, Novitch MB, et al. Responsible, safe, and effective use of antithrombotics and anticoagulants in patients undergoing interventional techniques: American Society of Interventional Pain Physicians (ASIPP) guidelines. *Pain Physician*. 2019;22(1S):S75–S128. doi:10.36076/ppj/2019.22.s75
90. Navani A, Manchikanti L, Albers SL, et al. Responsible, safe, and effective use of biologics in the management of low back pain: American Society of Interventional Pain Physicians (ASIPP) guidelines. *Pain Physician*. 2019;22(1S):S1–S74. doi:10.36076/ppj/2019.22.s1
91. Howick J. The evidence-based medicine renaissance: holy grail or poisoned chalice? *BMC Blog Network*. 2014. Available from: <https://blogs.biomedcentral.com/on-medicine/2014/07/03/the-evidence-based-medicine-renaissance-holy-grail-or-poisoned-chalice/>.
92. Rysavy M. Evidence-based medicine: a science of uncertainty and an art of probability. *Virtual Mentor*. 2013;15(1):4–8.
93. Hickey S, Roberts H. Evidence based medicine: neither good evidence nor good medicine. *Orthomol Med News Service*; 2011. Available from <http://orthomolecular.org/resources/omns/v07n15.shtml>