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REVIEW

A Systematic Review and Meta-analysis of the Effectiveness of Radiofrequency Neurotomy in Managing Chronic Neck Pain

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ABSTRACT

Background: Extensive research into potential sources of neck pain and referred pain into the upper extremities and head has shown that the cervical facet joints can be a potential pain source confirmed by precision, diagnostic blocks.

Study Design: Systematic review and meta-analysis utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist, quality assessment of the included studies, conventional and single-arm meta-analysis, and best evidence synthesis.

Objective: The objective of this systematic review and meta-analysis is to evaluate the effectiveness of radiofrequency neurotomy as a therapeutic cervical facet joint intervention in managing chronic neck pain.

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Methods: Available literature was included. Methodologic quality assessment of studies was performed from 1996 to September 2021. The level of evidence of effectiveness was determined.
Results: Based on the qualitative and quantitative analysis with single-arm meta-analysis and Grading of Recommendations, Assessment, Development and Evaluations (GRADE) system of appraisal, with inclusion of one randomized controlled trial (RCT) of 12 patients in the treatment group and eight positive observational studies with inclusion of 589 patients showing positive outcomes with moderate to high clinical applicability, the evidence is level II in managing neck pain with cervical radiofrequency neurotomy. The evidence for managing cervicogenic headache was level III to IV with qualitative analysis and single-arm meta-analysis and GRADE system of appraisal, with the inclusion of 15 patients in the treatment group in a positive RCT and 134 patients in observational studies. An overwhelming majority of the studies produced multiple lesions.
Limitations: There was a paucity of literature and heterogeneity among the available studies.
Conclusion: This systematic review and meta-analysis shows level II evidence with radiofrequency neurotomy on a long-term basis in managing chronic neck pain with level III to IV evidence in managing cervicogenic headaches.

Keywords: Cervical facet or zygapophysial joint pain; Chronic spinal pain; Controlled comparative local anesthetic blocks; Diagnostic accuracy; Facet joint nerve blocks; Radiofrequency neurotomy

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Key Summary Points

Chronic axial neck pain is one of the major causes of disability and healthcare costs, accounting for nearly half of the US health care burden, with neck pain among the top three causes

Cervical facet joints have been shown to be potential sources of neck pain and referred pain into upper extremities and head

The present systematic review identified a total of 5 RCTs and 15 observational studies with 2 RCTs evaluating the role of radiofrequency in managing facet joint pain

The evidence is level II in managing neck pain with cervical radiofrequency neurotomy and level III to IV in managing cervicogenic headache

There continues to be significant paucity of literature and heterogeneity among the available studies

INTRODUCTION

Chronic axial neck pain with or without headache or upper extremity pain is one of the major causes of disability and health care costs. The widely published literature shows that morbidity and chronic disability now account for nearly half of the US health care burden, with neck pain ranking as number three among the 30 leading diseases and injuries [1–6]. In addition, Dieleman et al. [7, 8] showed an estimated spending of $134.5 billion in 2016, with a 53.5% increase from $87.6 billion spent in 2013, in managing low back and neck pain, accounting for the highest amount of various disease categories.

Bogduk and Marsland [9] described facet joints as a source of idiopathic neck pain in 1988. Since then, numerous diagnostic accuracy studies, systematic reviews, and guidelines have been published [3, 10–20]. Multiple discussions have continued to evolve in reference to the diagnosis of facet joint pain and subsequent therapy with either facet joint nerve blocks or radiofrequency neurotomy [3, 21, 22]. The present evidence shows that the prevalence and false positive rates of diagnosis of facet joint pain with controlled comparative local anesthetic blocks utilizing 80% criterion standard ranges from 29% to 60% and 27% to 63%, respectively, with high variability. The discussion centers around the value and validity based on the acute pain model or chronic pain model. The group headed by Bogduk described that any response longer than 2 h for short-acting local anesthetic and 8 h for long-acting local anesthetic was a discordant response and judged it as false positive [10, 11, 14–16, 23]. This theory was tested with lumbar facet joint nerve blocks with 100% pain relief as the criterion standard [23]. The prevalence was shown to be 15% [23]. Manchikanti et al. [10] showed prevalence and false positive rates of 49.3% and 25.6%, respectively, in chronic neck pain using a chronic pain model. They also showed that the duration of relief of at least 80% was 6 days with lidocaine and 12 days with bupivacaine, with a total relief of at least 50% of 31 days and 55 days, respectively. In addition to multiple publications by Manchikanti et al. [10, 18–22, 24], a recent randomized controlled trial (RCT) by van Eerd et al. [25] of the comparative value of local anesthetic blocks with radiofrequency neurotomy in patients with clinically diagnosed cervical facet joint pain showed pain treatment success of 61.1% in both groups, either with local anesthetic alone or with local anesthetic and radiofrequency neurotomy with a single lesion at 3 months, 55.6% in the denervation group and 51.3% in the bupivacaine alone group at 6-month follow-up with no significant difference among the groups, reinforcing long-term relief of local anesthetic injections [24, 26–31].

Among the therapeutic interventions, radiofrequency has been considered as the standard treatment to provide long-term improvement; however, there has been only one RCT and three observational studies

assessed in the previous evaluations [3]. The first systematic review by Geurts et al. [32] identified only one RCT by Lord et al. [33]. A recent systematic review of the literature by Engel et al. [34] published in 2020 evaluated the effectiveness of cervical medial branch thermal radiofrequency neurotomy stratified by selection criteria. They concluded that higher degrees of relief from cervical medial branch thermal radiofrequency neurotomy are more often achieved, to a statistically significant extent, if patients are selected on the basis of the complete relief of index pain following comparative diagnostic blocks and used a randomized trial [33] and multiple nonrandomized studies [33, 35–42]. They utilized selection criteria as complete relief, with placebo-controlled blocks, complete relief with comparative blocks, 75% relief with comparative blocks, or 50% relief with comparative blocks. Thus, they showed that on the basis of a lesser degree of relief, patients are less likely to obtain complete relief. In another review of best practice guidelines, Lee et al. [43] utilized one RCT [33] and multiple clinical studies [33, 36, 38, 39, 41, 42] like Engel et al. [34]. They concluded that the efficacy of radiofrequency neurotomy was directly related to the rigor of the diagnostic blocks performed, as well as the use of proper technique for both diagnostic and neurotomy procedures. They also opined that utilizing multiple passes and two separate approaches may allow for neurotomy in a larger proportion of the medial branch, resulting in improved pain relief with longer duration. in a systematic review in preparation of guidelines, Manchikanti et al. [3] showed level II evidence for short-term and long-term effectiveness utilizing one RCT [33] and three observational studies [35, 36, 41] and provided level II evidence with moderate strength of recommendation when performed after the diagnosis of cervical facet joint pain with controlled comparative local anesthetic blocks utilizing 80% pain relief of criterion standard. However, there are also other issues related to producing multiple lesions at each nerve and needle sizes may be variable, too. These can alter the responses and also the side effect profile.

Table 1 Qualitative modified approach to grading of evidence of therapeutic effectiveness studies Modified from: Manchikanti L et al. A modified approach to grading of evidence. Pain Physician. 2014;17:E319–25 [67]

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

In a recent publication, Manchikanti et al.'s [44] comparative effectiveness study of cervical facet radiofrequency and cervical facet joint nerve blocks in a similar group of population showed that a significant proportion of the radiofrequency-treated patients (29%) obtained inadequate relief (less than minimum of 6 months) and 4% of patients also developed side effects related to irritation, swelling, and increased levels of pain, etc. In fact, this study showed that cervical facet joint nerve blocks may be better than radiofrequency neurotomy

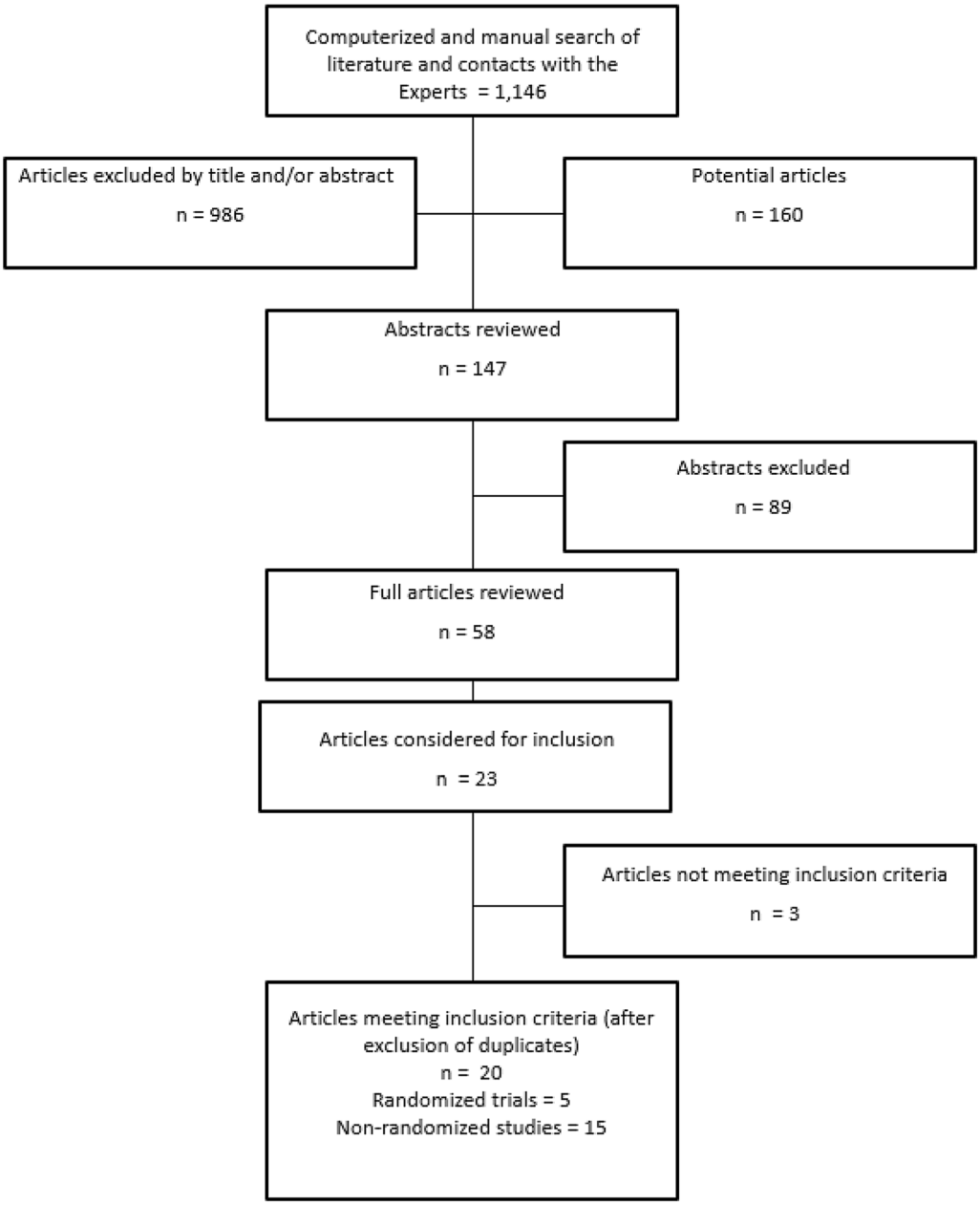

Fig. 1 Flow diagram illustrating the results of literature search conducted to evaluate cervical radiofrequency neurotomy

in reference to the tolerance and providing relief as expected for 3 months and with a cost utility of 1 year of quality-of-life improvement ($4994 vs. $5364).

Additionally, the COVID-19 pandemic and the opioid epidemic have affected chronic pain sufferers substantially with both access to treatment and costs [45–52]. Recent analysis of national health care spending in the USA showed an increase of 9.7% to reach $4.1 trillion in 2020, a much faster rate than the 4.3% increase seen in 2019 [51]. The acceleration in 2020 was due to a 36% increase in federal expenditures for health care that occurred

Table 2 Methodological quality assessment of randomized trials of cervical facet joint radiofrequency thermoneurolysis utilizing Cochrane review criteria Source: Furlan AD 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;40:1660–73 [64]

	Lord et al. [33]	van Eerd et al. [25]	Stovner et al. [72]	Haspeslagh et al. [73]	Wallis et al. [71]
Randomization adequate	Y	Y	U	Y	Y
Concealed treatment allocation	Y	Y	U	Y	Y
Patient blinded	Y	Y	Y	N	Y
Care provider blinded	Y	Y	Y	N	Y
Outcome assessor blinded	Y	Y	Y	N	Y
Dropout rate described	Y	Y	Y	Y	Y
All randomized participants analyzed in the group	Y	Y	N	N	Y
Reports of the study free of suggestion of selective outcome reporting	Y	Y	N	N	Y
Groups similar at baseline regarding most important prognostic indicators	Y	Y	N	Y	Y
Co-intervention avoided or similar in all groups	Y	Y	Y	Y	Y
Compliance acceptable in all groups	Y	Y	N	N	Y
Time of outcome assessment in all groups similar	Y	Y	Y	Y	Y
Are other sources of potential bias not likely	Y	Y	N	N	Y
Score	13/13	13/13	6/13	6/13	13/13

Y yes, *N* no, *U* unclear

largely in response to the COVID-19 pandemic. These increases were reported despite health care expenditures for health care unrelated to the COVID-19 pandemic. Further, consolidation of providers into an employment model by health systems, which has increased substantially, has been contributing to increasing health care expenses [52]. Multiple effects due to COVID-19 with increased psychological stress and suffering may also have a significant effect on outcomes. The use of interventional techniques for the treatment of spinal pain increased exponentially until 2009, at which point utilization started decreasing [53–58]. A recent analysis of utilization patterns and fee-for-service (FFS) Medicare population, including the impact of COVID-19, showed declining interventional techniques with overall decrease of interventional techniques at an annual rate of 0.4% per 100,000 Medicare population from 2010 to 2019, with an annual increase of 2.1% for facet joint interventions and sacroiliac joint injections from 2010 to 2019. However, the decrease from 2019 to 2020 due to the COVID-19 pandemic was 18.7% for all interventions compared to 17.5% for facet joint interventions and sacroiliac joint blocks [59].

Table 3 Methodologic quality assessment of randomized trials of cervical facet joint radiofrequency thermoneurolysis utilizing IPM-QRB criteria Source: Manchikanti L et al. Assessment of methodologic quality of randomized trials of interventional techniques: development of an interventional pain management specific instrument. Pain Physician. 2014;17:E263–90 [65]

		Lord et al. [33]	van Eerd et al. [25]	Stovner et al. [72]	Haspeslagh et al. [73]	Wallis et al. [71]
I	Trial design and guidance reporting					
1	Consort or spirit	3	3	3	3	3
II	Design factors					
2	Type and design of trial	3	1	3	3	3
3	Setting/physician	2	2	2	2	2
4	Imaging	3	3	3	3	3
5	Sample size	1	2	0	0	0
6	Statistical methodology	1	1	1	1	1
III	Patient factors					
7	Inclusiveness of population					
	For facet or sacroiliac joint interventions	2	0	0	0	2
8	Duration of pain	2	2	2	2	2
9	Previous treatments	2	2	2	2	2
10	Duration of follow-up with appropriate interventions	2	2	2	2	2
IV	Outcomes					
11	Outcomes assessment criteria for significant improvement	4	0	2	1	4
12	Analysis of all randomized participants in the groups	2	2	0	0	2
13	Description of dropout rate	2	2	0	0	2
14	Similarity of groups at baseline for important prognostic indicators	2	2	0	2	2
15	Role of co-interventions	1	1	0	1	1
V	Randomization					
16	Method of randomization	2	2	1	1	2
VI	Allocation concealment					
17	Concealed treatment allocation	2	2	0	0	2
VII	Blinding					
18	Patient blinding	1	1	1	0	1
19	Care provider blinding	1	1	1	0	1

Table 3 continued

		Lord et al. [33]	van Eerd et al. [25]	Stovner et al. [72]	Haspeslagh et al. [73]	Wallis et al. [71]
20	Outcome assessor blinding	1	1	1	0	1
VIII	Conflicts of interest					
21	Funding and sponsorship	3	3	1	1	3
22	Conflicts of interest	3	3	3	3	3
Total		45	38	28	27	44

Consequently, the debate in reference to effectiveness and efficacy, utilization patterns, and indications and medical necessity of cervical radiofrequency neurotomy procedures continues among patients, clinicians, researchers, and payors [3, 44].

The present systematic review and meta-analysis of RCTs and observational studies of radiofrequency neurotomy in managing chronic neck pain is sought to provide updated evidence.

METHODS

A systematic review and meta-analysis were performed on the basis of methodological and reporting quality of systematic reviews as described by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [60, 61]. Methodology from other reviews was also utilized [62, 63].

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

Ethics Compliance

This article is based on previously conducted studies and does not contain any studies with human participants or animals performed by any of the authors.

Literature Search

A comprehensive literature search was conducted to include RCTs 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 2021.

Search Strategy

The search strategy emphasized chronic neck pain treated with cervical facet joint interventions. The search terms included ((((((spinal pain, chronic low back pain) OR chronic back pain) OR facet joint pain) OR cervical surgery syndrome) OR zygapophysial)) AND ((((facet joint) OR zygapophyseal) OR zygapophysial) OR

Table 4 IPM checklist for assessment of nonrandomized or observational studies of cervical facet joint radiofrequency thermoneurolysis utilizing IPM-QRBNR criteria Source: Manchikanti L et al. Development of an interventional pain management specific instrument for methodologic quality assessment of nonrandomized studies of interventional techniques. Pain Physician 2014;17:E291–317 [66]

		Speldewinde [35]	MacVicar et al. [36]	Sapir & Gorup [41]	van Eerd et al. [70]	Burnham et al. [74]	Smith et al. [75, 76]	Lee et al. [77]	Barnsley [38]	Shin et al. [39]	Park et al. [40]	Lord et al. [42]	Manchikanti et al. [44]	Hamer & Purath [86]	Govind et al. [87]
I	Study design and guidance reporting														
1	Strobe or trend guidance	3	3	3	3	3	3	3	3	1	1	1	3	1	1
II	Design factors														
2	Study design and type	1	1	4	4	4	4	3	3	1	1	1	1	1	1
3	Setting/physician	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4	Imaging	3	3	3	3	3	3	3	3	3	3	3	3	3	3
5	Sample size	1	2	0	0	0	2	0	0	0	0	0	1	0	0
6	Statistical methodology	1	1	1	1	1	2	1	0	0	0	0	1	0	0
III	Patient factors														
7	Inclusiveness of population														
	For facet or sacroiliac joint interventions:	4	4	4	0	4	3	3	4	2	3	4	4	2	4
8	Duration of pain	2	2	2	2	2	2	2	2	2	2	2	2	2	2
9	Previous treatments	2	2	2	2	2	2	2	2	2	2	2	2	2	2
10	Duration of follow-up with appropriate interventions	4	4	4	3	3	1	3	3	3	2	2	2	2	2
IV	Outcomes														
11	Outcomes assessment criteria for significant improvement	4	4	2	4	4	4	2	4	3	3	3	3	3	3
12	Description of dropout rate	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4 continued

		Speldewinde [35]	MacVicar et al. [36]	Sapir & Gorup [41]	van Eerd et al. [70]	Burnham et al. [74]	Smith et al. [75, 76]	Lee et al. [77]	Barnsley [38]	Shin et al. [39]	Park et al. [40]	Lord et al. [42]	Manchikanti et al. [44]	Hamer & Purath [86]	Govind et al. [87]
13	Similarity of groups at baseline for important prognostic indicators	0	0	2	0	0	0	0	0	0	0	0	2	0	0
14	Role of co-interventions	2	2	2	2	2	2	2	2	1	1	1	2	1	1
V	Assignment														
15	Method of assignment of participants	0	0	4	0	0	0	0	0	0	0	0	3	0	0
VI	Conflicts of interest														
16	Funding and sponsorship	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Total		33	34	39	30	34	34	30	32	24	24	25	35	23	25

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. The trials with appropriate diagnosis established by diagnostic blocks or clinical diagnosis were included.

All observational studies of radiofrequency neurotomy with at least 6 months of follow-up were also included meeting the criteria.

Studies without an appropriate diagnosis and case reports were excluded.

Methodological Quality Assessment

RCTs were assessed for their quality or risk of bias methodologically utilizing Cochrane review criteria (Table 1 in the supplementary material) [64], Interventional Pain Management techniques–Quality Appraisal of reliability and Risk of Bias Assessment (IPM-QRB) (Table 2 in the supplementary material) [65], and Interventional Pain Management Techniques–Quality Appraisal of Reliability and Risk of Bias Assessment for Nonrandomized Studies (IPM-QRBNR) was utilized for observational studies, as shown in Table 3 in the supplementary material [66].

Risk of Bias of Individual Studies

Trials that met the inclusion criteria and scored at least 9 of 13 using the Cochrane review criteria [64] 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 [65]. 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.

Table 5 Study characteristics of randomized trials assessing cervical radiofrequency neurotomy in neck pain and headache

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Neck pain							
Lord et al., 1996 [33] Randomized, sham control, double-blind Quality scores: Cochrane = 13/13 IPM-QRB = 45/48	24 patients selected in a specialty cervical spine research unit in Australia suffering with chronic pain of cervical facet joint origin after whiplash injury and have failed conservative management. The diagnosis was confirmed with the use of double-blind, placebo-controlled local anesthetics with complete pain relief	Diagnostic blocks with 100% pain relief criteria Sham: 12 Intervention: 12 After the needle was positioned, both groups received 2 mL of 0.5% bupivacaine infiltrating each target nerve Control group received sham RF neurotomy at temperature of 37 °C Active treatment group received RF neurotomy Needle size: 22-gauge, 10 cm, exposed active tip 4 mm Injectate: 2 mL of 0.5% bupivacaine Conventional RFTN 80 °C, 90 s Number of lesions: 5 to 6 Duration of procedure: 3 h	• VAS • McGill pain questionnaire • 3, 6, and 12-month follow-up Patients were followed until they reported that their pain had returned to 50% of the preoperative level	NA	Sham 8% Active treatment group 58% Positive	Active treatment group 58% Positive	• Short- and long-term effectiveness. Study may be criticized for long duration of the technique with 3 h, with 5–6 lesions and small sample size • Efficacy was shown in patients with motor vehicle injury and chronic whiplash related neck pain • A smaller active tip was utilized with a 4 mm active exposed tip • Chronic degenerative pathology was not studied

Table 5 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
van Eerd et al., 2021 [25] Randomized, active control Quality scores: Cochrane = 13/13 IPM-QRB = 38/48	76 patients with chronic cervical facet joint pain were included on the basis of the diagnosis with clinical criteria No diagnostic blocks were performed	No diagnostic blocks Control group: Bupivacaine alone medial branch blocks Intervention group: RF denervation combined with bupivacaine The control group received sham RF denervation similar to the protocol of denervation with RF generator disconnected, plus bupivacaine injection 0.5 mL, 0.25%, at each nerve Intervention group received RF denervation and bupivacaine injection 0.5 mL, 0.25%, at each nerve Conventional RFTN using 23 V for 90 s Needle size: 5 cm injection needle with a 5 mm exposed tip Number of lesions: a single lesion was produced	The primary outcome at 3 months and 6 months consisted of: • Pain intensity • Self-reported treatment effect • Neck Disability Index • Use of pain medication Duration of effect was determined using telephone interviews Measurements: 6 weeks, 3 months, 6 months 6-month follow-up measure was defined as primary endpoint	Control with bupivacaine 61.1% RF denervation + bupivacaine 61.1% No significant difference	Pain reduction of ≥ 30% as positive outcome Control with bupivacaine alone 51.3% RF denervation + bupivacaine 55.6% No significant difference Positive for bupivacaine alone and RF denervation + bupivacaine	NA	• Positive short-term improvement with criterion of ≥ 30% pain reduction as studied for 6 months with bupivacaine alone or RF denervation + bupivacaine, with no significant difference, specifically at 3 months with 61.1% in both groups, whereas at 6 months 55.6% in denervation group versus 51.3% in local anesthetic alone group with no significant difference • This study shows that local anesthetics are long-acting, at least equivalent to radiofrequency neurotomy in patients with clinically diagnosed facet joint pain with some decline, though statistically not significant at 6 months • The authors also commented that they found a difference in the long-term effect after 6-month follow-up in favor of the RF treatment as one can expect • The median time to the end of the success for patients in the RF group was 42 months, compared with 12 months in the bupivacaine group, which was highly impressive for both groups

Table 5 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Headache							
Stovner et al., 2004 [72] Randomized, sham control, double-blind Quality scores: Cochrane = 6/13 IPM-QRB = 28/48	12 patients with a disabling, long-standing, and treatment-resistant, strictly unilateral cervicogenic headache were included. The diagnosis was based on clinical criteria Selection criteria were clinical; however, prior to neurotomy all patients were also given diagnostic cervical medial branch blocks of the facet joints C2–C6 on the symptomatic side along with greater occipital nerve block. However, results of the blockades were not among the inclusion criteria	Number of patients: sham 6 Intervention 6 6 were randomized to receive RF of facet joints C2–C6 ipsilateral to the pain, and 6 were randomized to sham treatment Diagnostic blocks were not part of inclusion criteria Cervical RF medial branch neurotomies were performed from C2 to C6 on the symptomatic side with a posterolateral approach. Prior to neurotomy local anesthetic was injected. At least 3–4 lesions were produced at each level with 1 mm apart Injectate: 0.1 mL of local anesthetic Conventional RF neurotomy at 85 °C, 60 s, 50 mm, 22-gauge cannula, active exposed tip not available Number of lesions: 3–4 Duration of procedure: 90 min	• Pain relief • Range of motion measurements • Days with intense pain • A meaningful clinical response was defined as a reduction of at least 30% of days with significant headache • Major parameters were measured at 3, 12, and 24 months after treatment Of the 12 patients, one patient died, one patient could not attend 1-year follow-up, and one patient did not complete the diary at 24 months Three other patients started a process for getting compensation and one patient had a pending litigation with almost 50% of the patients inappropriately followed	4 of 6 patients in treatment group and 2 of 6 patients in sham group had > 30% improvement Positive treatment group 66% Negative sham group 33%	NA	1 of 12 patients in treatment group show 30% improvement. In sham group it was 0% Negative both groups	• This is an extremely small study with 6 patients in each group. Further, over 50% of had problems. No diagnostic criteria were utilized. Multiple lesions, as many as 4, were made at each level Consequently, the study is shown as negative for RF neurotomy in patients with cervicogenic headache with C2–C6 medial branch neurotomy • As a result of various issues related to the study, the results are not a reflection of RF neurotomy and its role in managing cervicogenic headache

Table 5 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Haspeslagh et al., 2006 [73] Randomized, double-blind, active control Quality scores: Cochrane = 6/13 IPM-QRB = 27/48	30 patients with cervicogenic headache according to the Sjaastad diagnostic criteria, were randomized with 15 patients to RF treatment group with cervical facet joint denervation followed by cervical dorsal root ganglion lesioning when necessary, and 15 patients receiving local anesthetic injections with steroid at the greater occipital nerve, in addition to TENS when necessary The treatment group received local anesthetic injection and RF neurotomy of cervical facet joint nerves and if necessary dorsal root ganglion The control group received occipital nerve blocks followed by application of TENS	Control: 15 Intervention: 15 Conventional RFTN at 67 °C for 60 s Solution: 1 mL of 2% lidocaine Needle size: 22-gauge, 5 cm, 4 mm active exposed tip Control group application of TENS unit at each level Duration of procedure: NA	• VAS • Global perceived effect scores • Quality of life scores • Headache diary Outcomes were assessed at 8, 16, 24, and 48 weeks	RF group 66.7%, success rate Control group 53.3% success rate Positive	NA	RF group 53.3% success rate Control group 46.7% success rate RF positive	• This is an extremely confusing study with a small number of patients. Initially treatment group underwent RF lesioning, then also underwent diagnostic blocks if they did not receive appropriate relief. In addition to the facet joint lesioning they also underwent dorsal root ganglion lesioning • In the control group with occipital nerve blocks and application of TENS unit, patients did rather well with almost equal improvement • Large numbers of patients were withdrawn from the study • Overall, there was no difference between radiofrequency treatment of cervical facet joints and upper dorsal root ganglion compared to greater occipital nerve block, followed by TENS for patients fulling the criteria of cervicogenic headache

Table 5 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Psychological distress							
Wallis et al., 1997 [71] Randomized, double blind, sham control Quality scores: Cochrane = 13/13 IPM-QRB = 44/48	17 patients with a single painful cervical zygapophysial joint were studied in a randomized, double-blind sham-controlled trial of RF Patients were selected with 100% relief with placebo control and comparative local anesthetic blocks. The trial was also conducted under the strict triple-blind conditions 24 patients from Lord et al.'s study [33] were included with 12 patients undergoing the control procedures, 7 of the 24 patients had concurrent pain stemming from joints at segmental levels other than the one for which they were treated. Consequently, they were excluded with 17 patients remaining in the study	Number of patients: 17 Diagnostic blocks with 100% pain relief criteria Patients received RF neurotomy Injectate: 2 mL of 0.5% bupivacaine Conventional RFTN 80 °C, 90 s Sham: 12 Intervention: 12 Needle size: 22-gauge, 10 cm, 4 mm exposed active tip Number of lesions: 5–6 Duration of procedure: 3 h	• VAS • McGill Pain Questionnaire • SCL-90-R psychological questionnaire Follow-up was conducted preoperatively and 3 months postoperatively by medical interview and examination	NA Resolution of psychological distress in patients with pain-free status	NA	NA	• Psychological distress was resolved in all 9 patients who were pain free; whereas it was resolved only in one patient who still had pain, and 7 patients continued to be in distress • Significant differences were found for the obsessive compulsive and global severity index subscale scores, anxiety, and phobic anxiety subscales • Results of this study show total improvement in patients with pain-free status with their psychological distress

IPM-QRB Interventional Pain Management techniques–Quality Appraisal of Reliability and Risk of Bias Assessment, *NA* not applicable, *TENS* transcutaneous electrical nerve stimulation, *RF* radiofrequency, *RFTN* radiofrequency thermoneurolysis, *VAS* visual analog scale

On the basis of IPM-QRBNR criteria [66], studies meeting the inclusion criteria but scoring less than 16 were considered low quality and were excluded, studies scoring from 16 to 31 were considered moderate quality, and studies scoring from 32 to 48 were considered high quality and were included.

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.

Outcome Measures

An outcome is considered clinically significant if a reduction of 2 points on the 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.

The qualitative analysis of the evidence was performed on the basis of 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 1 [67]. 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 and Grading of Recommendations, Assessment, Development and Evaluations (GRADE) system of appraisal for determining the body of evidence [68]. Clinical relevance and pragmatism of all studies were assessed [69]. 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 (e.g., authorship), the reviewers of interest were recused from assessment and analysis.

RESULTS

Literature Search

The flow diagram illustrates the search results and the final number of studies that were considered for inclusion (Fig. 1). The search criteria started with a total of 1146 publications, with 28 studies [25, 33, 35–42, 44, 70–88] with different aspects considered for inclusion. The full articles were reviewed for 23 studies [25, 33, 35–42, 44, 70–78, 86–88]. Among the 23 studies considered for inclusion, two studies were excluded because of lack of availability of the full articles [78, 88]. An additional study [37] was also excluded as it was reporting previously published data. Overall, 20 studies met inclusion criteria [25, 33, 35, 36, 38–42, 44, 70–77, 86, 87], out of which five RCTs [25, 33, 71–73] were selected (Fig. 1). Of the five RCTs, only one of them assessed with a sham control [33] and one was an active-control trial [25] studying efficacy for neck pain, two RCTs evaluated the role of radiofrequency in managing cervicogenic headache [72, 73], and one assessed psychological distress [71]. Among the 15 observational studies [35, 36, 38–42, 44, 70, 74–77, 86, 87], there were eight studies assessing neck pain [35, 36, 38, 39, 41, 70, 74, 77], five studies assessing cervicogenic headache [40, 42, 77, 86, 87], and two studies assessed psychological functioning [75, 76]. Among the RCTs assessing neck pain, only one study [33] utilized diagnostic blocks as the criterion standard for inclusion, whereas the second study was performed on the basis of clinical examination [25]. Among the observational studies, all of them except one study utilized diagnostic blocks prior to the

Table 6 Study characteristics of observational studies assessing cervical radiofrequency neurotomy

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Speldewinde, 2011 [35] Prospective data collection of retrospective series Quality score: IPM-QRBNR = 33/48	151 patients with ≥ 80% relief from dual comparative medial branch blocks were included for cervical RF The article presented finding of a single-author's own internal review of outcomes of cervical RF neurotomy in Australia. The data encompassed from 2001 to 2009. They assessed with the changes in the technique. The patients from 2001 to 2007 and compared them to 2008 to 2010. Technical comparisons were related to the needle size of 22-gauge cannula, with 10 mm active tip, with 90 s lesioning which was later changed to 18-gauge cannula with 60 s lesioning period, both at 80 °C	Diagnostic blocks with 80% pain relief A total of 104 patients were included in the first cohort of 2001 to 2007, whereas in the second cohort from 2007 to 2009, 47 patients were included 22-gauge cannula, with 10 mm tip, in the first phase, and 18-gauge cannula in the second phase 90 s or 60 s Number of lesions: minimum of 3 "contiguous burns" to each target nerve 80 °C for 90 s Second cohort: 18-gauge cannula, 80 °C for 60 s Injectate: NA	• Numeric rating scale • Functional rating index with 4 activities of daily living scale • General health questionnaire • Depression, anxiety, stress scale Duration of pain relief, and overall amount of pain relief A successful outcome was defined as at least 50% reduction of pain for at least 2 months, in the region relevant to the joint or joints treated	NA	Overall success rate was 79% in cohort A, 85% in cohort B, with overall success rate of 76% from 6 to 36 months Average pain relief was 88% and average duration of relief was 12 months Positive	Overall success rate was 79% in cohort A, 85% in cohort B, with overall success rate of 76% from 6 to 36 months Average pain relief was 88% and average duration of relief was 12 months Positive	This is the largest study performed assessing the largest report of outcomes of percutaneous cervical facet joint neurotomy in a community setting. The results are superior compared to other reports, with ≥ 50% relief as the criterion standard

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
MacVicar et al., 2012 [36] Prospective case series Quality score: IPM-QRBNR = 34/48	Selection criteria included complete relief of pain following controlled medial branch blocks 104 patients were included The data was collected from 2 similar practices. The majority of patients had one symptomatic joint and the levels treated most commonly were C2–3 and C5–6	Diagnostic blocks with 100% pain relief Conventional radiofrequency neurotomy, 16-gauge, 10 cm, 5 mm active tip, oblique lesions at 80 °C and sagittal lesions at 85 °C for 90 s for each lesion Number of lesions: 2–4 Time to complete the procedure: 1.5–2 h. 1.5 for third occipital nerve and 2 h for a single facet joint denervation Injectate: not described The majority of patients had one symptomatic joint and most common levels treated were C2–3 and C5–6 joints	Successful outcome was complete relief of pain or at least 80% relief for at least 6 months, with complete restoration of activities of daily living, numeric pain rating scale, 4 activities of daily living, return to work, use of health care services The outcomes were assessed at 1, 3, 6, 9, and 12 months after treatment and 6-month intervals thereafter at each of the practices	66% success rate Positive	66% success rate Positive	66% success rate Positive	• Positive study • This is a study of cervical medial branch radiofrequency neurotomy from 2 separate practices with strict inclusion criteria and strict outcomes criteria • These criteria may not be applicable in the USA and the study is not randomized controlled and there was no comparative group • They utilized a 16-gauge cannula, which is too large, with 10 cm active tip, yet they produced a minimum of 3 lesions

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Sapir and Gorup, 2001 [41] Prospective Quality score: IPM-QRBNR = 39/48	A prospective evaluation comparing litigant and nonlitigant patients. In this evaluation, 50 patients with cervical whiplash, who remained symptomatic after 20 weeks of conservative management, were included. Of these, 30 patients were litigants and 18 were nonlitigants. Four patients did not complete the study giving 92% retention rate. Data was collected from 46 patients for final analysis	Litigants: 30 Nonlitigants: 18 All patients underwent dual diagnostic cervical medial branch blocks with ≥ 80% relief Conventional RF at 80 °C for 90 s Number of lesions: 2 Needle size: 22-gauge, 10 cm with 4 mm active tip	• VAS • Self-reported improvement, immediately after and 1 year after radiofrequency neurotomy Both groups improved with treatment	NA	NA	≥ 50% relief Litigants 46% Nonlitigants 73% Positive in nonlitigant 73%	• Even though this is a prospective study, they compared litigant and nonlitigant patients after whiplash injury • 73% of nonlitigants and 46% of litigants reported ≥ 50% relief • Overall, this is a positive study performed in the USA in patients with whiplash
van Eerd et al., 2014 [70] Retrospective explorative study Quality score: IPM-QRBNR = 30/48	65 patients were included of the 130 consecutive patients with axial neck pain in Netherlands in a cervical medial branch radiofrequency treatment with a single posterolateral approach in an exploratory study. The inclusion criteria were clinical assessment with no diagnostic blockade	No diagnostic blocks Conventional radiofrequency at 80 °C for 60 s Needle size: 5 cm Injectate: 0.5 mL of 1% lidocaine Number of lesions: 1	• Pain relief • Patient Global Impression of Change Outcomes: Successful group • Very much improved • Much improved 2 months, 1 year, 2 years, & 3 years	NA	NA	36.9% of 65 or 72.7% of successful group at 2 months 24 patients were successful 1 year after the intervention 24 of 65 patients (36.92%) Overall success rate 36.9% Negative	• This is a pilot study utilizing a single lesion technique with a posterolateral approach. Overall, results appear to be negative. However, the selection criteria were not based on the diagnostic blocks • After 2 months, 51% of these patients experienced pain reduction defined as 'very much improved" or 'much improved' on the PGIC scale • The important aspect of this study is avoidance of multiple RF lesions • On the basis of this study, the authors also performed a randomized, double-blind, active-controlled trial [25]

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Burnham et al., 2020 [74] Cross-sectional, cohort, retrospective study Quality score: IPM-QRBNR = 34/48	50 patients were included with review of medical records of 87 consecutive patients. Authors compared effectiveness of cervical medial branch radiofrequency ablation for chronic facet joint syndrome in patients selected by a practical medial branch block paradigm. They divided the patients into 2 groups with diagnostic block response of 80–99% compared to 100% pain relief and symptom improvement	Diagnostic blocks Group I: 80–99% relief Group II 100% relief Conventional radiofrequency neurotomy: 40 patients or 80% Cooled radiofrequency neurotomy: 10 patients or 20% Conventional radiofrequency neurotomy 80 °C for 90 s Cannula size: 18-gauge with 10 mm active tip Cooled radiofrequency: 18-gauge probe with 2–4 mm active tip Injectate: 2 mL of 2–4% lidocaine was injected Cooled radiofrequency was performed for 150 s at 60 °C Number of lesions: Conventional: 2 Cooled radiofrequency: 1	• NRS • Patient Global Impression of Change The primary outcomes were the proportion of patients reporting ≥ 50% reduction of index pain. Outcomes were monitored at 6 and 12 months and 2 years	NA	NA	54% positive outcome with ≥ 50% pain relief Positive	• Positive study • Patients were selected by a medial branch block paradigm with 80–99% pain relief, or 100% pain relief. There was no difference between 2 regimens • The authors used an 18-gauge needle with 10 mm active tip for conventional radiofrequency and 17-gauge needle for cooled radiofrequency with a single lesion for cooled radiofrequency and 2 lesions for conventional radiofrequency neurotomy • Overall, the improvement was only borderline and also adds to the evidence that there may not be any significant difference between 80% improvement or 100% improvement

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Shin et al., 2006 [39] Retrospective Quality score: IPM-QRBNR = 24/48	A total of 28 patients were studied with chronic neck pain with or without referred pain for more than 3 months. Patient selection criteria included diagnostic blocks, followed by radiofrequency neurotomy	Dual diagnostic blocks with 50% pain relief Cannula size: 21-gauge RF cannula, 10 cm with 5 mm active tip 80 °C for 90 s Injectate: 1 mL of 2% lidocaine before the lesioning. 1 mL of 0.5% bupivacaine mixed with 8 mg per mL of triamcinolone injected after the lesioning Number of lesions: 2–4 Diagnostic blocks performed	Pain relief	NA	68% 19 of 28 patients Positive	54% 15 of 28 patients Positive	• Positive study • In this small study, 28 patients were included with a 12-month follow-up • Diagnostic criteria utilized was 50%. 68% reported successful outcome according to outcome criteria after 6 months of follow-up and 8 (42%) of 19 patients reported complete pain relief of pain • Patients showed recurrence of pain between 6 and 12 months, reducing the success rate at 12 months to 54%
Barnsley et al., 2005 [38] Retrospective Quality score: IPM-QRBNR = 32/48	35 consecutive patients were assessed with outcomes of percutaneous radiofrequency neurotomy with 47 procedures	Patients were selected on the basis of the controlled comparative local anesthetic blocks with 80% relief Conventional radiofrequency: 80 °C for 90 s Solutions: NA Radionics electrode Electrode introduced twice with 4–6 lesions	Primary outcome: Duration of relief Secondary outcomes: Postoperative pain and adverse effects	NA	74% of patients complete relief Positive	NA	• In this study, percutaneous radiofrequency neurotomy for chronic neck pain was assessed in a series of consecutive patients utilizing radionics electrode cannula. 2–3 lesions were performed with each passage • Majority of lesions were performed 2–3 in 23 of 35 patients • 80% of the patients reported significant improvement at 36-week follow-up • Overall, this is a positive study, well performed, similar to an RCT with an independent assessor

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Manchikanti et al., 2022 [44] Retrospective case control study Quality score: IPM-QRBNR = 35/48	163 patients with cervical radiofrequency neurotomy and 132 patients with cervical medial branch blocks were compared, including cost utility. Patients underwent either medial branch blocks if required after 3 months, or radiofrequency neurotomy after 6 months. Radiofrequency neurotomy was performed with a 20-gauge 10 cm cannula with 10 mm active tip	Patients were selected with 80% positive response to controlled diagnostic blocks Needle size: 20-gauge needle with 10 mm active tip 80 °C for 60 s Injection of 1 mL mixture of 2% lidocaine and 0.5% bupivacaine Medial branch blocks with 22-gauge, 2.5″ or 3.0″ needle with injection of 1.5 mL of bupivacaine at each level Number of lesions: 1	Pain relief Primary outcome: Proportion of patients with ≥ 50% pain relief	100% success rate in both groups Positive	69% success rate in the radiofrequency group compared to 94% in the medial branch group Positive	64% success rate in the radiofrequency group compared to 81% in the medial branch group Positive	• This is the first study of this nature showing positive results in a comparative evaluation of outcomes and cost utility with therapeutic medial branch blocks with radiofrequency neurotomy. This encompassed a clinical setting with repeat blocks as repeat procedures as needed with an average of 2 procedures • This assessment also showed cost utility of QALY of $4994 for cervical medial branch blocks compared to $5364 for cervical radiofrequency neurotomy • A significant proportion of patients (29%,) had inadequate relief of less than 6 months and 4% of the patients had significant side effects in the radiofrequency group • There was significant improvement described in both groups from baseline to 12 months with pain relief and proportion of patients with ≥ 50% pain relief • Overall, average pain relief for each procedure for medial branch blocks was 13–14 weeks, compared for radiofrequency neurotomy, of 20–25 weeks • Significant relief was noted in a high proportion of patients in both groups with 99% in medial branch block group and 93% in the radiofrequency neurotomy group • Cost utility analysis also showed average cost for QALY of $4994 for medial branch blocks compared to $5364 for cervical radiofrequency neurotomy • The results also showed that 6 patients, or 4%, experienced side effects, whereas 47 patients, or 29%, reported inadequate pain relief

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Lord et al., 1995 [42] Retrospective Quality score: IPM-QRBNR = 25/48	The authors conducted an audit of 19 patients. The duration of complete pain relief was the principal outcome measure. Among these, 10 patients were treated for headache with third occipital neurotomy and 10 patients underwent lower cervical medial branch neurotomy. All the patients underwent comparative controlled local anesthetic blocks prior to the enrollment	Comparative controlled diagnostic blocks with complete relief Needle size: 22-gauge, 10 cm with 4 mm exposed tip 10 cm length, exposed tip 6 mm for third occipital nerve 80 °C for 90 s Injectate solution: 1 mL of 0.5% bupivacaine Number of lesions: 4–6 40% occipital neurotomy 70% zygapophysial joint neurotomy	The duration of complete pain relief Follow-up 6 and 12 months	Negative: occipital neurotomy Positive: cervical zygapophysial joint neurotomy	Negative: occipital neurotomy Positive: zygapophysial joint neurotomy	Occipital 40% Cervical 70% Negative: occipital neurotomy Positive: cervical zygapophysial joint neurotomy	• This was a pilot study prior to conducting RCT • The authors changed the technical aspects during the procedure, which improved the outcomes in later studies. Side effects included cutaneous numbness lasting for 1–3 weeks • Ataxia was regular side effect of third occipital neurotomy • Most patients suffered this effect lasting 2–3 days
Park et al., 2011 [40] Retrospective Quality score: IPM-QRBNR = 24/48	11 patients with neck pain and headache were included. The authors assessed the effect of radiofrequency neurotomy for lower cervical medial branches on cervicogenic headache	Candidates for radiofrequency neurotomy were selected on the basis of the results of response to comparative local anesthetic blocks with lidocaine and bupivacaine, showing at least 90% pain relief and the duration of the relief concordant with local anesthetic pharmacologic action SMK-C 10 cannula with a 4 mm exposed tip 90 °C for 60 s Number of lesions: 1	VAS Primary outcome: more than 50% improvement for at least 6 months	NA	63.6% success rate at 6 months Positive	NA	This is a positive but small study showing radiofrequency neurotomy of lower cervical medial branches in effect provides significant pain relief lasting at least for 6 months

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Smith et al., 2015, 2014 [75, 76] Prospective Quality score: IPM-QRBNR = 34/48	In this prospective observational study, 53 consecutive individuals with chronic whiplash-associated disorder were included. They assessed modulation of cervical facet joint nociception and reduction of psychological features in individuals with chronic whiplash symptoms following radiofrequency neurotomy	Patients with at least 50% relief with dual diagnostic blocks were included Injectate: NA Lesioning: 80 °C for 75 s Number of lesions: 1–3	VAS, Neck Disability Index (NDI), psychological distress measured using: The General Health Questionnaire 28 Posttraumatic Stress Diagnostic Scale The Pain Catastrophizing Scale Quantitative Sensory Test: Nociceptive Flexion Reflex Thermal pain thresholds Pressure pain thresholds Brachial plexus provocation test Movement measures Range of motion Cranio-cervical flexion test	• Pain • Disability • Psychological distress • Pain catastrophizing significantly decreased Positive	NA	NA	• Overall, this is a positive study showing the effects of cervical radiofrequency neurotomy • These studies focus on modulation of facet joint nociception and changes in psychological features in individuals with chronic whiplash symptoms showing significant improvement in pain, disability, and psychological distress. However, there was no significant change in posttraumatic stress symptoms severity • Reducing pain with cervical radiofrequency neurotomy was associated with significant improvement in psychological distress and pain catastrophizing, but not posttraumatic stress symptoms • They also showed that upon return of the pain after radiofrequency neurotomy, levels of disability increased and were similar to prior to radiofrequency neurotomy • There were other features which deteriorated including quantitative sensory testing measures and range of motion

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Lee et al., 2007 [77] Observational study Quality score: IPM-QRBNR = 30/48	In this evaluation, the authors included 30 patients They excluded patients needing multilevel cervical blocks and those involved in litigation or compensational programs. There were 16 men and 14 women undergoing RF neurotomy on medial branches of posterior primary ramus at C3 and C4 nerves	Diagnostic cervical medial branch blocks at C3/C4 with at least 50% pain relief with controlled comparative local anesthetic blocks were included 80 °C at 90 s Injectate: 0.5 mL 1% lidocaine Needle: SMK-C 10 cannula, 22-gauge length, 10 cm with 5 mm exposed tip Number of lesions: 1	VAS, number of headaches per week, amount of analgesic intake Successful outcome was pain relief of 75% Outcomes were monitored at 1, 6, and 12 months	NA	77% success rate with 75% pain relief Positive	73% success rate with 75% pain relief Positive	• This is a positive small study with a total of 30 patients similar to Park et al. [40]. The lesioning was performed at C3 and C4; however, only a single lesion was performed • They excluded patients with multiple level involvement • This is a positive study meeting clinical criteria for utilization with significant improvement with a single lesion • Mild side effects were reported with soreness of the posterior neck lasting for less than a week
Hamer and Puruth, 2014 [86] Retrospective observational study Quality score: IPM-QRBNR = 23/48	40 patients with refractory cervicogenic headache and/or occipital neuralgia were included Number of patients: 35	Selection criteria were based on clinical assessment and 50% improvement with diagnostic blocks Needle size: 10 cm or 5 cm Active tip: 10 mm or 5 mm Injectate: 1 mL of lidocaine with 1 mL of betamethasone 6 mg Duration: 80 °C for 90 s Numbers of lesions: 2–3	Pain relief	NA	70% Positive	NA	In this study, results are acceptable with 70% of the patients reporting appropriate pain relief for at least 5 months, which resembles clinical settings. However, the authors have produced multiple lesions

Table 6 continued

Study Study characteristic Methodological quality scoring	Number of patients & selection criteria	Interventions	Outcome measures	Results of pain relief and function			Comments/conclusions
				3 months	6 months	1 year	
Govind et al., 2003 [87] Prospective observational study Quality score: IPM-QRBNR = 25/48	49 patients were included Diagnosis was made on the basis of complete pain relief to diagnostic blocks	Patient selection was complete pain relief following double-blind controlled local anesthetic blocks of occipital nerves Ray electrode exposed tip: NA Injectate: 1–2 mL of 0.5% bupivacaine Number of lesions: 4–6 Exposure time and temperature: NA The puncture sites were pierced with #11 scalpel blade. Multiple electrodes were passed along producing multiple lesions with prolonged duration to perform the procedures	Pain relief	NA	88% Positive	NA	This study was published by the same authors who warned against radiofrequency neurotomy for occipital headache. However, in this study, they have improved the technique substantially achieving excellent outcomes The disadvantages include complete pain relief with local anesthetic blockade

IPM-QRBNR Interventional Pain Management Techniques–Quality Appraisal of Reliability and Risk of Bias Assessment for Nonrandomized Studies, *NA* not applicable, *QALY* quality-adjusted life-year, *RCT* randomized controlled trial, *VAS* visual analog scale, *PGIC* Patient Global Impression Change

Table 7 Qualitative analysis of effectiveness of conventional cervical radiofrequency in managing neck pain

Study Study characteristics Methodological quality scoring	Percent of pain relief of diagnostic blocks and criteria	Patients	Intervention: needles				Pain relief and function				Results	Clinical application	GRADE criteria
			Size	Exposed tip	# of lesions	Exposure time	100% relief		> 50% relief				
							6 months	1 year	6 months	1 year			
Lord et al. [33] Randomized, sham control, double-blind Cochrane = 13/13 IPM-QRB = 45/48	100%	Total: 24 12 each group	22-gauge, 10 cm	4 mm	5–6	80 °C, 90 s	58%	58%	–	–	P	Moderate	–
MacVicar et al. [36] Prospective case series IPM-QRBNR = 34/48	100%	104	16-gauge, 10 cm	5 mm	2–4	80 °C oblique 85 °C sagittal 90 s	66%	66%	–	–	P	Moderate	–
Lord et al., 1995 [42] Retrospective Quality score: IPM-QRBNR = 25/48	100%	19 9 headache 10 neck/ cervical	22- or 16-gauge, 10 cm	4 mm or 6 mm	4–6	80 °C 90 s	–	–	–	Occipital 40% Cervical 70%	N P	Moderate Moderate	–
Barnsley et al., 2005 [38] Retrospective Quality score: IPM-QRBNR = 32/48	100%	35	16-gauge, 10 cm	6 mm	4–6	80 °C 90 s	74%	–	–	–	P	Moderate	–

Table 7 continued

Study Study characteristics Methodological quality scoring	Percent of pain relief of diagnostic blocks and criteria	Patients	Intervention: needles				Pain relief and function				Results	Clinical application	GRADE criteria
			Size	Exposed tip	# of lesions	Exposure time	100% relief		> 50% relief				
							6 months	1 year	6 months	1 year			
Burnham et al., 2020 [74] Cross-sectional, cohort, retrospective study Quality score: IPM-QRBNR = 34/48	100% and 80%	40 Conventional RF 80% 10 Cooled RF 20% Group I: 80%-99% Group II: 100%	18-gauge	Conventional RF: 10 mm Cooled RF: 2–4 mm	2	Conventional RF: 80 °C 90 s Cooled radiofrequency: 60° 150 s	–	–	–	54%	P	Moderate	–
Speldewinde, 2011 [35] Prospective data collection of retrospective series Quality score: IPM-QRBNR = 33/4	80%	151	22- or 18-gauge	10 mm	Minimum 3	80 °C 90 s	76%	76%	–	–	P	Moderate	–
Sapir & Gorup, 2001 [41] Prospective Quality score: IPM-QRBNR = 39/48	80%	48 Litigants: 30 Nonlitigants: 18	22-gauge 10 cm	4 mm	2	80 °C 90 s	–	–	–	Litigants 46% Nonlitigants 73%	N P	Moderate	–
Manchikanti et al., 2022 [44] Retrospective case control study Quality score: IPM-QRBNR = 35/48	80%	163	20-gauge 10 cm	10 mm	1	80 °C 60 s		69%		64%	P	High	–

Table 7 continued

Study Study characteristics Methodological quality scoring	Percent of pain relief of diagnostic blocks and criteria	Patients	Intervention: needles				Pain relief and function				Results	Clinical application	GRADE criteria
			Size	Exposed tip	# of lesions	Exposure time	100% relief		> 50% relief				
							6 months	1 year	6 months	1 year			
Shin et al., 2006 [39] Retrospective Quality score: IPM-QRBNR = 24/48	50%	28	21-gauge 10 cm	5 mm	2–4	80 °C 90 s	42%		68%		P	Moderate	–
van Eerd et al., 2021 [25] Randomized, active control Quality scores: Cochrane = 13/13 IPM-QRB = 38/48	50%	76 Control group: 38 Intervention group: 38	5 cm	5 mm	1	23 V 90 s	NA	NA	NA	NA	N	Low	Decreased
van Eerd et al., 2014 [70] Retrospective explorative study Quality score: IPM-QRBNR = 30/48	None	130	5 cm	NA	1	80 °C 60 s				37%	N	Low	–

P positive

Table 8 Qualitative analysis of effectiveness of conventional cervical radiofrequency in managing headaches

Study Study characteristics Methodological quality scoring	Percent of pain relief with diagnostic blocks and criteria	Patients	Intervention: needles				Pain relief and function				Results	Clinical application	GRADE criteria
			Size	Exposed tip	# of lesions	Exposure time	100% relief		> 50% relief				
							6 months	1 year	6 months	1 year			
Lord et al., 1995 [42] Retrospective Quality score: IPM-QRBNR = 25/48	100%	19 9 headache 10 neck/cervical	22- or 16-gauge, 10 cm	4 mm or 6 mm	4–6	80 °C 90 s	–	–	–	Occipital 40% Cervical 70%	N P	Moderate Moderate	–
Govind et al., 2003 [87] Prospective observational study Quality score: IPM-QRBNR = 25/48	100%	49	Ray electrode	NA	4–6	–	–	88%	–	–	P	Low/moderate	–
Park et al., 2011 [40] Retrospective Quality score: IPM-QRBNR = 24/48	80%	11	SMK-C 10 cannula	4 mm	1	90 °C 60 s	–	–	64%	–	P	High	–

Table 8 continued

Study Study characteristics Methodological quality scoring	Percent of pain relief with diagnostic blocks and criteria	Patients	Intervention: needles				Pain relief and function				Results	Clinical application	GRADE criteria
			Size	Exposed tip	# of lesions	Exposure time	100% relief		> 50% relief				
							6 months	1 year	6 months	1 year			
Lee et al., 2007 [77] Observational study Quality score: IPM-QRBNR = 30/48	50%	30	22 gauge 10 cm	5 mm	1	80 °C 90 s	–	–	77%	73%	P	High	–
Hamer & Puruth, 2014 [86] Retrospective observational study Quality score: IPM-QRBNR = 23/48	50%	35	10 cm or 5 cm	10 mm or 5 mm	2–3	80 °C for 90 s	35%		70%		P	Low	–
Stovner et al., 2004 [72] Randomized, sham control, double-blind Quality scores: Cochrane = 6/13 IPM-QRB = 28/48	None	12 total Sham = 6 Intervention = 6	22-gauge, 5 cm	NA	3–4	85 °C for 60 s	0	0	0	0	N	Absent	–

Table 8 continued

Study characteristics Methodological quality scoring	Percent of pain relief with diagnostic blocks and criteria	Patients	Intervention: needles				Pain relief and function				Results	Clinical application	GRADE criteria
			Size	Exposed tip	# of lesions	Exposure time	100% relief		> 50% relief				
							6 months	1 year	6 months	1 year			
Haspeslagh et al., 2006 [73] Randomized, double-blind, active control Quality scores: Cochrane = 6/13 IPM-QRB = 27/48	None	30 total Control = 15 Intervention = 15	22-gauge, 5 cm	4 mm	1	67 °C for 60 s	–	–	–	53%	P	Low	–

P positive, *N* negative

enrollment; however, van Eerd et al. [70], similar to the RCT [25], based the inclusion on clinical criteria. Only four studies in five publications [39, 75–77, 86] utilized 50% pain relief with dual blocks, whereas the remaining studies utilized 80% or greater pain relief for the inclusion criteria; six studies [33, 36, 42, 71, 74, 87] included 100% relief as the inclusion criteria. Among the four RCTs, a single lesion was applied in only one study, whereas all others utilized multiple lesions ranging from two to six. Among the observational studies, two studies [44, 70] utilized a single lesion, whereas all others utilized multiple lesions of more than two and up to six. Needle cannula sizes varied from 22 to 18 gauge and the exposed tip varied from 4 to 10 mm. Where data is available, all studies utilized a local anesthetic prior to lesioning, whereas one study reported utilizing bupivacaine injection after lesioning. Procedure time description was provided in only a few studies; these included 90 min for three level radiofrequencies [72], and 3 h for a single lesion [33, 71].

Methodological Quality Assessment

The methodological quality assessment of the RCTs meeting the inclusion criteria was carried out using Cochrane review criteria and IPM-QRB, and observational studies utilizing IMP-QRBNR criteria and the results are illustrated in Tables 2, 3, and 4.

According to the Cochrane quality assessment and the previously established score ranges in the "Methods" section of this study, three trials [25, 33, 71] scored between 9 and 13, thus meeting our criteria of high-quality studies, while two trials [72, 73] scored between 5 and 8, thus said to be studies of moderate quality.

On the basis of the IPM-QRB criteria for randomized trials, five trials [25, 33, 71–73] scored between 32 and 48, hence they are of high quality. Thus, only three trials met the criteria for high quality with both instruments [25, 33, 71]. This indicates the importance of IPM specific instruments in methodologic quality assessments.

On the basis of the IPM-QRBNR criteria for observational studies, five studies [35, 36, 41, 75, 76] scored between 32 and 48, hence they are of high quality, while 10 studies [38–40, 42, 44, 70, 74, 77, 86, 87] scored between 16 and 31, thus are considered as moderate quality.

Study Characteristics of RCTs and Observational Studies

Among the total of five RCTs available, there were two RCTs in the neck pain category [25, 33], two trials for the treatment of headache [72, 73], whereas one trial [71] evaluated psychological distress from the partial data derived from the neck effectiveness study [33].

Table 5 shows the study characteristics of all the included randomized trials assessing cervical radiofrequency neurotomy in neck pain and headache.

The study characteristics of observational studies meeting inclusion criteria are described in Table 6. There were a total of 15 observational studies included in the analysis [35, 36, 38–42, 44, 70, 74–77, 86, 87] with eight studies assessing neck pain [35, 36, 38, 39, 41, 70, 74, 77], five studies assessing cervicogenic headache [40, 42, 77, 86, 87], and two studies assessing psychological functioning [75, 76].

Analysis of Evidence

Table 5 shows the study characteristics of all the studies meeting inclusion criteria for RCTs, whereas Table 6 shows study characteristics of observational studies assessing cervical radiofrequency neurotomy. The analysis of evidence was based on qualitative and quantitative analysis.

Qualitative Analysis

As shown in Tables 7 and 8, qualitative analysis was determined on the basis of multiple factors including the application of diagnostic blocks, number of patients, number of lesions, successful outcomes, clinical utility, and pragmatism. In addition, GRADE criteria were also applied with downgrading or no change or upgrading of the study quality.

Overall, 11 studies were included in the qualitative analysis of treatment of chronic neck pain with radiofrequency neurotomy. Of these, five studies utilized 100% pain relief as the criterion standard for inclusion with inclusion of 201 patients. In all studies [33, 36, 38, 42] except one [74], 4–6 lesions were performed. The results showed complete pain relief variable from 58% to 74% of the patients in three studies [33, 36, 38], whereas 70% was reported in one study with similar 4–6 lesions with at least 50% relief in 70% of the patients

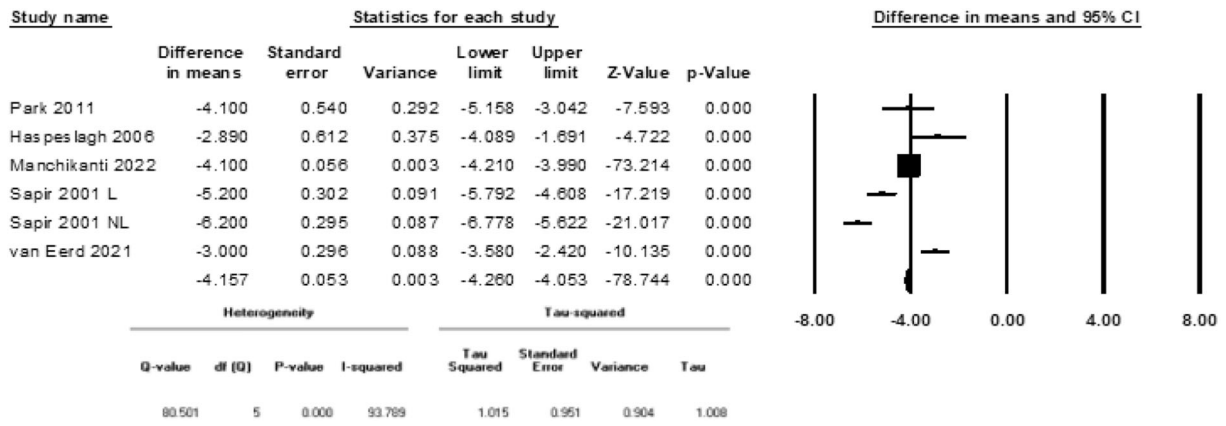

Fig. 2 Single-arm meta-analysis for pain relief at 6-month follow-up: RFA

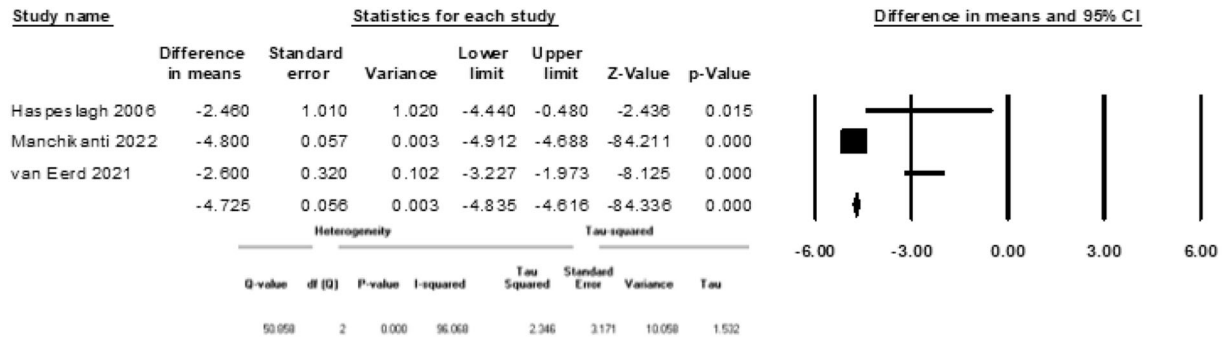

Fig. 3 Single-arm meta-analysis for pain relief at 6-month follow-up: control

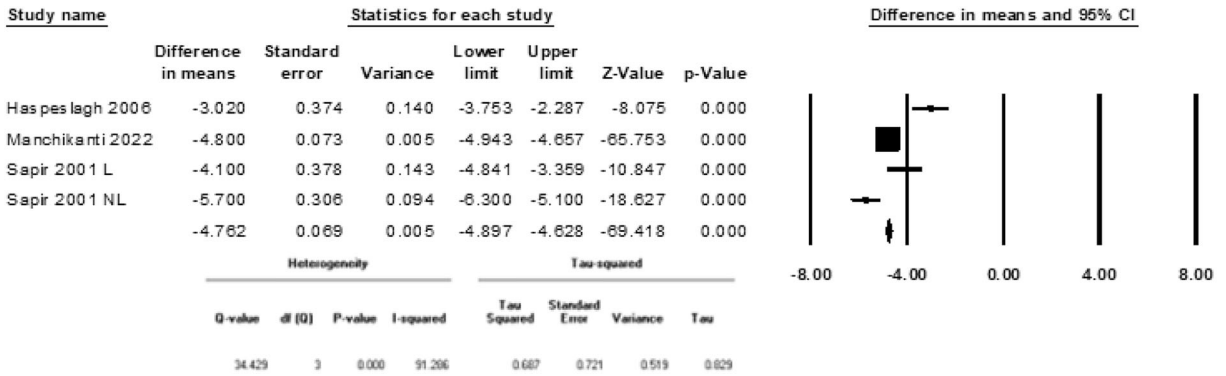

Fig. 4 Single-arm meta-analysis for pain relief at 12-month follow-up: RFA

with one study with twi lesions [74] reporting in 54% of the patients. Clinical utility of these studies was judged as moderate for four studies [33, 36, 38, 42] and high for one study [74]. There was no change in the GRADE criteria.

Three studies utilized at least 80% pain relief as inclusion criterion [35, 41, 44] with controlled diagnostic blocks with inclusion of 361 patients with three lesions produced in one study [35] reporting 39% complete relief and 79% at least 50% relief at 1 year; a minimum of two lesions were produced in one prospective assessment [41] involving 30 litigant patients and 30 nonlitigant patients with improvement in 46% of the former and in 73% of the latter. The study was judged to be positive in nonlitigant patients. Another clinical study [44] comparing radiofrequency neurotomy with cervical medial branch blocks utilizing one lesion reported at least 50% relief in 69% of the patients at 6-month follow-up and 64% at 1-year follow-up with repeat radiofrequency performed as needed. Clinical utility was moderate in two studies [35, 41] and high in one study [44]. There was no change in GRADE criteria.

There was only one study [39] utilizing 50% pain relief as the criterion standard producing four lesions; it reported 100% pain relief in 42% of the patients at 6-month follow-up and in 68% at least 50% pain relief at 6-month follow-up. This was shown to be a positive study with moderate clinical utility with no change in GRADE criteria.

Two studies [25, 65], which included an RCT [25], studied without diagnostic blocks based on clinical criteria. The RCT utilized 30% improvement as the pain relief criterion. Both studies were shown to be negative with low clinical applicability based on selection criteria

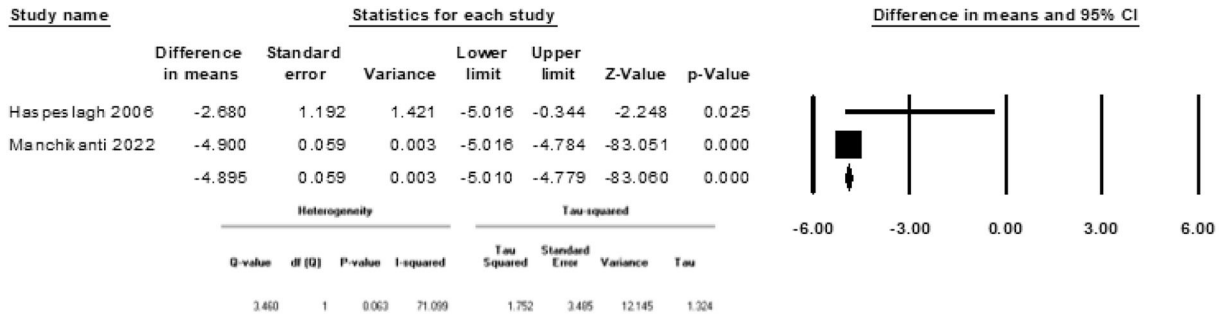

Fig. 5 Single-arm meta-analysis for pain relief at 12-month follow-up: control

with no change in GRADE criteria for the observational study [70] and reduction of GRADE criteria for the RCT [25].

Table 8 shows qualitative analysis for headache. Seven studies met the inclusion criteria [40, 42, 72, 73, 77, 86, 87]. Of these, only two studies [42, 87] utilized complete pain relief as the criterion standard producing multiple lesions with positive results in both studies. In one study [42] utilizing complete pain relief as the criterion standard for diagnosis, nine patients were included with headache producing 4–6 lesions; however, they reported at least 50% pain relief in only 40%. Consequently, this study was shown as negative with absent clinical applicability with reduced grading for headache. The second study [87] evaluated 49 patients with complete pain relief utilizing 4–6 lesions and reported excellent results with 88% of the patients reporting complete pain relief at 6-month follow-up shown to be positive results with moderate clinical applicability due to required 100% pain relief and 4–6 lesions, which is a long duration of procedure. There was no change in the GRADE criteria.

Only one study [40] utilized at least 80% pain relief as the criterion standard and studied 11 patients with a single lesion reporting at least 50% pain relief in 68% at 6 months; this study was shown to be positive with high clinical applicability with no change in scoring based on GRADE criteria.

Two other studies [77, 86] studied 30 patients and 49 patients utilizing 50% pain relief as the criterion standard reporting at least 50% relief in 77% of the patients at 1 year [77] and 70% of the patients at 6 months in the second study [86]. Ironically, the study utilizing a single lesion produced better results [77] compared to 2–3 lesions produced in the second study [86]. Consequently, the study by Lee et al. [77] shows high clinical applicability with no change in GRADE criteria.

Finally, two studies [72, 73] based their treatments on clinical criteria with a small number of patients with 6 plus 15 producing 3–4 lesions in one study [72] and only one lesion in the second study [73]. The study with 3–4 lesions was shown to be negative with absent clinical applicability with reduction in grading criteria. The second study, however, showed with a single lesion at least 50% improvement in 53%of patients, once again with low clinical applicability based on reduced criteria on GRADE. Consequently, it appears from the qualitative analysis that strict inclusion criteria of 100% pain relief with controlled diagnostic blocks and producing multiple lesions are superior to other selection criteria in managing neck pain with moderate to low clinical applicability due to the rigorous criteria, making this approach difficult to apply in the USA, because of the long duration of the procedure, which may not be feasible in the USA.

Among the five studies included with complete pain relief [33, 36, 38, 42, 74], only three of them achieved superior results [33, 36, 38] with complete pain relief, whereas the other two [42, 74], despite 2 or 4–6 lesions, achieved criteria similar to the 80% pain relief groups with 54% and 70% of patients at 1-year follow-up.

Comparatively, there were three studies [35, 41, 44] utilizing 80% pain relief with the controlled diagnostic blocks as the criterion standard utilizing a large proportion of patients. A total of 362 patients utilized either one [44], two [41], or three [35] lesions. However, the pain relief judged by the at least 50% criterion was higher in the three-lesion group with 79%, and two-lesion group, with 73% compared to one-lesion study with 64%. Consequently, clinical utility has been judged as moderate for the first two studies with multiple lesions [35, 41] and high with a single lesion [44], which is the common practice without compromising the outcomes.

There was only one study utilizing at least 50% pain relief as the inclusion criterion with inclusion of 28 patients producing four lesions, and it showed at least 50% relief in 68% of the patients similar to other categories with moderate clinical utility based on four lesions produced.

Thus, overall, on the basis of one RCT [33] with 12 patients in the treatment group and eight positive observational studies [35, 36, 38, 39, 41, 42, 44, 74] with inclusion of 589 patients, the outcomes were positive with moderate to high clinical applicability. Two studies [25, 70] with inclusion of 106 patients showed negative results, one of them being an RCT with low clinical applicability and downgrading as per GRADE criteria. Thus, the evidence is level II with a moderate recommendation for cervical radiofrequency neurotomy in managing neck pain.

The evidence based on qualitative analysis in managing cervicogenic or occipital headache is inferior to managing neck pain with one RCT, with inclusion of six patients in the treatment group, showing negative results [72] and lack of clinical utility; the second RCT [73], with inclusion of 15 patients in the treatment group, showing only borderline outcomes with low clinical utility; and five observational studies [40, 42, 77, 86, 87], with inclusion of 134 patients, showing positive results with moderate to low clinical utility with multiple lesions in every study except one [73], the evidence being level III to IV, yielding a borderline recommendation.

Quantitative Analysis

We sought to perform a quantitative analysis utilizing conventional dual-arm meta-analysis and single-arm meta-analysis. However, there were only two RCTs evaluating radiofrequency in the neck [25, 33] and two evaluating headache [72, 73]. The methodologic quality was highly variable among the two trials [25, 33] performed in the cervical spine. Similarly, methodologic quality and variations were significant in the headache group with a small number of patients included in two RCTs [72, 73] in the headache trials. Consequently, dual-arm analysis was not performed.

A single-arm meta-analysis was performed for all observational studies in managing neck pain and headache separately.

Single-Arm Meta-analysis

Figure 2 shows the results of a single-arm analysis utilizing the radiofrequency ablation groups. Five studies [25, 40, 41, 66, 73] were used to assess pain scores after 6 months using pain scores in patients who underwent radiofrequency neurotomy. As shown in Fig. 2, the pooled mean difference of pain score from baseline to 6 months of follow-up was decreased by 4.157 points (95% CI − 4 .260 to − 4.053, $P < 0.001$).

Figure 3 shows the results of a single-arm analysis utilizing the control treatment groups. Three studies [25, 66, 73] were used to assess pain scores after 6 months using pain scores in patients who underwent the control treatment. As shown in Fig. 3, the pooled mean difference of pain scores from baseline to 6 months of follow-up was decreased by 4.725 points (95% CI − 4.835 to − 4.616, $P < 0.001$).

Figure 4 shows the results of a single-arm analysis utilizing the radiofrequency ablation groups. Three studies [41, 66, 73] were used to assess pain score after 12 months using pain scores in patients who underwent radiofrequency neurotomy. As shown in Fig. 4, the pooled mean difference of pain score from baseline to 12 months of follow-up was

decreased by 4.762 points (95% CI − 4.897 to − 4.628, $P < 0.001$).

Figure 5 shows the results of a single-arm analysis utilizing the control treatment groups. Two studies [66, 73] were used to assess pain scores after 12 months using pain scores in patients who underwent the control treatment. As shown in Fig. 5, the pooled mean difference of pain scores from baseline to 12 months of follow-up was decreased by 4.895 points (95% CI − 5.010 to − 4.779, $P < 0.001$).

Thus, quantitative analysis with single-arm meta-analysis showed positive results at 6 months and 12 months both in treatment and control groups. The differences were rather significant from baseline to follow-up at 6 months and 12 months with 4.2 points decrease in the treatment group, and 4.7 points decrease in the control group at 6-month follow-up, and 4.8 and 4.9 points in the treatment and control groups at 12-month follow-up. The results are similar to qualitative analysis with level II evidence with moderate recommendation for cervical radiofrequency neurotomy in managing neck pain and level III to IV, and thus a borderline recommendation of radiofrequency neurotomy in managing headache with only one study meeting eligibility criteria to be included in single-arm analysis.

DISCUSSION

This systematic review of RCTs and observational studies and meta-analysis of observational studies of the effectiveness of cervical radiofrequency neurotomy in managing chronic neck pain showed level II evidence for long-term effectiveness of 6 months or longer. However, the evidence for neck pain and headaches utilizing radiofrequency neurotomy is level III–IV with only a borderline recommendation.

For qualitative analysis in managing neck pain, one RCT [33] with 12 patients in the treatment group and eight positive observational studies [35, 36, 38, 39, 41, 42, 44, 74] with inclusion of 589 patients showed positive outcomes with moderate to high clinical applicability. However, two studies [25, 70] with the inclusion of 106 patients showed negative results, one of them being an RCT with low clinical applicability and the study was downgraded by application of GRADE criteria.

For quantitative analysis, while conventional meta-analysis was not feasible, single-arm analysis showed positive results in all the included studies [25, 40, 41, 66, 73] in the treatment group, as well as control groups with significant decreases in pain patterns from baseline to the follow-up period of 4.2 and 4.8 points at 6- and 12-month follow-up, respectively, in the treatment group, and 4.7 and 4.9 points in the control group at 6 and 12-month follow-up, respectively. These relief patterns were achieved in the majority of the cases with repeat procedures in multiple studies. Overall success rate ranged from 42% to 74% at 6 months and 58% to 76% at 1 year. These results are based on studies utilizing high levels of diagnostic criteria and many studies producing multiple lesions, often with large needles.

For managing cervicogenic headache these results are poor. We included one RCT [72] with only six patients with negative results and the second RCT [73] with inclusion of 15 patients showing only borderline outcomes with low clinical utility. Further, there were five observational studies [40, 42, 77, 86, 87], with the inclusion of 134 patients, that showed positive results with moderate to low clinical utility with multiple lesions in three studies [42, 86, 87] and a single lesion in two studies [40, 77], the evidence level is level III to IV, with borderline recommendation. Of note, none of the studies met criteria for conventional meta-analysis and only one study met inclusion criteria for single-arm analysis [73].

The results of the present analysis are similar in some aspects, but significantly different in other aspects from other previously published systematic reviews and guidelines.

The guidelines for facet joint interventions [3] showed level II evidence with moderate strength of recommendations with inclusion of one RCT with positive results, and two observational studies with long-term improvement in managing neck pain. Engel et al.'s [34] systematic review of the literature with inclusion of RCTs and observational studies showed

variable results based on selection criteria, including triple placebo-controlled medial branch blocks, dual comparative medial branch blocks, single medial branch blocks, intraarticular blocks, and physical examination findings or symptoms alone. Further, the data showed a greater degree of pain relief more often in patients selected by triple placebo controlled medial branch blocks or dual comparative medial branch blocks, producing 100% relief of the index pain. However, the degree of pain relief was similar when triple or dual comparative blocks were used. It is also of importance to note that Engel et al. [34] stratified the outcomes, showing in patients with placebo controlled or comparative blocks with 100% pain relief a success rate of 52% in the placebo-controlled blocks group with inclusion of 64 patients (94% CI 40–64) with 100% pain relief. Similarly to the placebo-controlled blocks, comparative dual blocks with inclusion of 125 patients showed a success rate of 61% (95% CI 52–70%). In contrast, with 75% relief with comparative blocks the pooled results with inclusion of 234 patients showed a success rate of 31% (95% CI 25–37%) with complete relief; however, there was a 44% success rate with 80% relief (95% CI 37–51%), and a 59% success rate with greater than 50% relief (95% CI 52–66%). Only one study with only six patients studied comparative blocks with a success rate of 50% with greater than 50% relief, whereas with complete relief it was only 17%. It is of importance to note that Engel et al. [34] showed complete relief at the highest level of 61% and 70% at 95% CI at the upper end. However, they have not provided data on 50% success rate. Further, multiple lesions were performed, many of them with several passes, which essentially takes several hours to treat one patient.

Hurley et al. [31] in consensus practice guidelines on interventions for cervical facet joint pain concluded that cervical medial branch radiofrequency ablation may provide benefit to well-selected individuals, with medial branch blocks being more predictive than intraarticular injections. They also added that the most stringent selection criteria are likely to improve denervation outcomes, but at the expense of false negatives with an overall lower success rate.

Overall, the results show that radiofrequency neurotomy is effective in 54–76% with multiple passes providing multiple lesions taking several hours to perform a single lesion, whereas cervical facet joint nerve blocks with easy performance except that the relief is half that of radiofrequency neurotomy in duration with success rate ranging from 85% to 92% at 12-month follow-up, showing level II evidence with moderate strength of recommendation by the American Society of Interventional Pain Physicians (ASIPP) guidelines utilizing one RCT [30] and three observational studies [89–91].

Multiple guidelines and systematic reviews basically considered most of the studies included in the present systematic review and meta-analysis. Consequently, it is crucial to review the clinical characteristics of included randomized and observational studies.

Among the RCTs, van Eerd et al. [25] was the only trial assessing the efficacy and long-term effect of radiofrequency denervation in patients with clinically diagnosed cervical facet joint pain. They compared radiofrequency denervation plus an injection of bupivacaine with the injection of bupivacaine alone, with a sham radiofrequency neurotomy treatment in 76 patients. In this study, a single lesion was produced with a 5 cm needle with a 5 mm active tip. The results were positive in the intervention group showing 55.6% with greater than 30% pain decrease versus 51.3% in the control group with no significant difference. The Neck Disability Index was 15 ± 8.7% in the intervention group compared with 16.5 ± 7.2% in the local anesthetic group. However, the median time to end of the treatment success for patients in the radiofrequency group was 42 months compared to 12 months in the bupivacaine group with significant difference. This study illustrates the importance of local anesthetic alone blockade with significant improvement noted at 3 months, 6 months, and up to 1 year. This was described extensively by Manchikanti et al. [29, 30] in multiple studies with an average relief of 14–16 weeks. However, this study [25] is limited with assessment of 30% pain decrease

instead of 50% or higher decrease in pain and improvement in function.

Lord et al. [33] performed the first RCT utilizing a sham control of percutaneous radiofrequency neurotomy producing multiple lesions in patients with chronic zygapophysial joint pain developing after whiplash injury. They studied 12 patients in each group ($n = 24$) with identification of the source of pain with the use of a double-blind, placebo-controlled, local anesthesia with 100% relief as the criterion standard. The results showed that the median time that elapsed before pain returned to at least 50% of the preoperative level was 263 days in the active treatment group and 8 days in the control group ($p = 0.04$). They also showed that at 27 weeks, seven patients (58%) in the active treatment group were free of pain. The technical details included use of a 10 cm, 22-gauge electrode with a 4 mm exposed tip introduced in two planes and producing 5–6 lesions to accommodate possible variation in the course of the nerve. The duration of the procedure has been described as 3 h per patient [71]. They also reported that six patients (50%) in the control group and 3 (25%) in the active treatment group had a return of their accustomed pain in the period immediately after the procedure. While major advantages of this trial include meticulous selection of the patients and meticulous technique, at the same time, multiple disadvantages include the small sample, even though justified by sample size calculations, long duration for operation time of 3 h per patient, and 5–6 lesions at each level, which is not a clinically reliable practice.

Stovner et al. [72] assessed radiofrequency denervation of facet joints at C2–C6 in cervicogenic headache in a randomized, double-blind, sham-controlled study, with randomization of six patients into each group. The treatment group received radiofrequency neurotomy with 3–4 lesions with a 50 mm, 22-gauge needle. They injected 1 mL of local anesthetic, then produced 3–4 lesions. Overall, two patients showed greater than 50% improvement in each group at 3 months. Multiple drawbacks in this study include the lack of inclusion criteria for diagnostic blocks, extremely small sample size, and producing 3–4 lesions.

Haspeslagh et al. [73] also evaluated the effectiveness of cervical radiofrequency lesioning in an RCT. The authors included 30 patients with cervicogenic headache according to the Sjaastad diagnostic criteria. They randomized 30 patients into two equal groups receiving either radiofrequency treatments with cervical facet joint denervation followed by cervical dorsal root ganglion lesions when necessary or injection of local anesthetic with steroid of the greater occipital nerve, followed by transcutaneous electrical nerve stimulation (TENS) when necessary. Group 1 with radiofrequency neurotomy and cervical dorsal root ganglion neurotomy preceded by local anesthetic injection showed improvement with reduction of the mean VAS of at least 2 points and/or global perceived effect of + 2 or + 3 with a success rate of 66.7% at 16 weeks, while the success rate was 53.3% in the local anesthetic and TENS group. Utilizing the same criteria, at 1-year follow-up, the authors found the improvement was 53.3% in group 1 and 46.7% in group 2. A large number of patients were withdrawn, or data was not available. Consequently, this was judged to be a negative trial.

Wallis et al. [71] evaluated the role of pain relief and radiofrequency neurotomy in the resolution of psychological distress of patients with whiplash, 3 months after the procedure. The study sample was derived from Lord et al.'s [33] radiofrequency study. Of the 24 patients in that study, they used 17 patients with a single painful cervical zygapophysial joint. All patients with complete pain relief exhibited resolution of their preoperative psychological distress, whereas all but one of the patients without pain relief remained unrelieved and continued to suffer from psychological distress.

Among the observational studies meeting inclusion criteria, Speldewinde [35] evaluated 151 patients undergoing cervical radiofrequency neurotomy. This is a single-author, single-practice data collection. The selection criterion was at least 80% pain relief following the controlled, comparative local anesthetic blocks. Outcome assessment was appropriate. Speldewinde assigned patients from 2001 to 2007 as cohort A and 2007 to 2009 as cohort B. There were 104 patients in cohort A and 47 in

cohort B, with a total of 151 patients. The basis for the cohort was that a 22-gauge, 10 cm active tip was used during the earlier periods and that was then changed to an 18-gauge cannula. The conventional radiofrequency neurotomy was provided at 80 °C for 90 s in the early cohort with 18-gauge cannula at 80 °C for 60 s in the second cohort. Speldewinde also produced a minimum of three contiguous burns to each target nerve. Overall, Speldewinde reported significant improvement of greater than 50% in 76% of the patients with 79% of patients in cohort A and 85% of the patients in cohort B with the large needle and shortened radiofrequency neurotomy time. Successful patients were reported to have relief for more than 18 months, with an average duration of 27.5 months and a range of 18–68 months. The author also assessed psychological and functional status improvement which was significantly improved in patients with successful pain relief.

MacVicar et al. [36] studied a total of 104 patients selected from two separate practices. Inclusion criteria were based on complete relief of pain following controlled diagnostic medial branch blocks. They included strict outcome measures with successful outcome defined as complete pain relief of pain or at least 80% relief for at least 6 months, with complete restoration of activities of daily living, with no need for any further health care and return to work. They utilized a 16-gauge cannula with 10 cm active tip and produced at least three lesions at 80 °C and 85 °C for 90 s with the time to complete the operation of 2 h for a single facet joint and 1.5 h to complete the treatment of the third occipital nerve. Sixty-six percent of subjects met the treatment objective at 6 months. The authors have not reported any complications.

Sapir and Gorup [41] evaluated radiofrequency medial branch neurotomy in litigant and nonlitigant patients with cervical whiplash. The inclusion criteria were based on at least 80% pain relief following diagnostic medial branch blocks. Overall, 50 patients met the inclusion criteria, and 46 patients completed the study. A total of 32 litigants and 18 nonlitigants were included. The overall reductions in cervical whiplash symptoms and VAS pain scores were significant, both immediately after the treatment and after 1-year follow-up. The improvement was better after 1 year post treatment with NRS scores with nonlitigants vs. litigants of 2.5 vs. 3.6. The authors postulated that the difference between litigants and nonlitigants in the degree of symptomatology is response to treatment; however, it did not reach significance. Thirteen of the 32 litigant patients settled their case after the treatments. However, they also had pain recur 1 year after the treatment. Overall, 21 patients reported recurrence of pain within 1 year. Time to recurrence defined as 50% return of pain was 8 ± 2 months.

Among other observational studies, Shin et al. [39] studied 28 patients with conventional radiofrequency neurotomy reporting improvement in 68% of patients. Barnsley [38] assessed the role of percutaneous radiofrequency neurotomy for chronic neck pain with evaluation of outcomes in a series of consecutive patients. The results showed 36 of 45 assessable procedures (80%) achieved significant pain relief with 36 weeks of mean relief; 74% of the patients achieved 100% pain relief. Only one serious adverse event with local infection was reported.

In a recent comparative effectiveness study [44] clinical outcomes and cost utility of therapeutic medial branch blocks with radiofrequency neurotomy in managing chronic neck pain of facet joint origin were published. In this study with the main outcome being NRS, significant improvement was defined as at least 50% improvement in pain relief. In this study, 132 patients receiving cervical medial branch blocks and 163 patients with cervical radiofrequency neurotomy were included. One hundred and seven patients in the cervical medial branch group and 105 patients in the radiofrequency group completed 1-year follow-up.

The maximum number of procedures in the medial branch blocks was four per year, whereas that in the radiofrequency neurotomy group was two per year administered at 3 or 6 months, if medically needed with adequate relief of 3 or 6 months with each procedure. The results showed significant improvement reported in100%, 94%, and 81% of the patients in the medial branch blocks group compared to 100%,

69%, and 64% in the radiofrequency neurotomy group at 3, 6, and 12-month follow-up, respectively, with significant differences noted at 6 and 12 months. They also performed cost utility analysis showing an average cost per quality-adjusted life-year (QALY) of $4994 for cervical medial branch blocks compared to $5364 for cervical radiofrequency neurotomy. Interestingly, in this study, 6 of 132 patients (or 5%) in the cervical medial branch group and 53 of 163 (or 33%) of the patients in the cervical radiofrequency neurotomy group were converted to other treatments, either because of side effects (6 patients or 4%) or inadequate relief (47 patients or 29%).

Among the remaining studies meeting the inclusion criteria, four of them studied headache [40, 77, 86, 87] whereas one study included patients with headache as well as neck pain [42]. Two studies from the same group of authors involving the same data focused on modulation of facet joint nociception and reduction of psychological features in individuals with chronic whiplash syndrome in a prospective assessment [75, 76].

Facet joint interventions showed an overall 2.9% annual increase from 2010 to 2019 compared to annual increases of 14.2% from 2000 to 2010, with 19.3% COVID-19 pandemic-related decline from 2019 to 2020. In addition, the analysis of expenditures for facet joint interventions in the Medicare population [58] also showed an increase in expenditures of 79% from 2009 to 2018 in the form of total cost for facet joint interventions. Inflation-adjusted costs with 2018 US dollars, however, showed an overall increase of 53% instead of 79% with an annual increase of 4.9%. Further, cervical facet joint injection procedures increased by 2% annually from 2010 to 2019, whereas cervical radiofrequency neurotomy procedures increased by 8.9%. In comparison, lumbosacral facet joint blocks increased at an annual rate of 0.8% from 2010 to 2019, whereas radiofrequency neurotomy procedures during the same period increased 7.4%. During the COVID-19 pandemic overall facet joint interventions decreased 19.3%, with cervical/thoracic facet joint blocks decreasing 20.2%, lumbar/sacral facet joint blocks decreasing 20.7%, with cervical/thoracic facet neurolysis decreasing 14.1%, and lumbosacral facet neurolysis procedures decreasing 7.3% [59]. In contrast, epidural procedures showed an overall decrease of inflation-adjusted costs of 2%, whereas prior to inflation adjustment, total expenditures increased by 14.6%, an annual increase of 1.5% [54]. Spinal cord stimulation procedures also increased in utilization and costs; however, utilization of percutaneous adhesiolysis procedures and vertebral augmentation procedures have declined significantly [55, 57]. In addition, recent evaluations assessing the impact of the COVID-19 pandemic showed a 18.7% reduction in overall interventional techniques from 2019 to 2020 [59].

With changes in policies in the USA and emerging guidelines, it is conceivable that radiofrequency neurotomy will increase much faster while intraarticular injections and medial branch blocks will continue to decline [92, 93]. As with very few systematic reviews available on this cervical radiofrequency neurotomy procedure and multiple other systematic reviews and meta-analysis, the value and validity of this publication is only as reliable as the validity of the primary studies included. As described earlier, the majority of the studies in this systematic review and meta-analysis are observational studies with a single high-quality RCT [33] with a small number of patients (12 in sham, 12 in intervention), the remaining were observational studies. Consequently, numerous issues have been highlighted in reference to systematic reviews in interventional pain management. These have been discussed in guidelines and multiple other systematic reviews extensively [3, 5, 26–28, 31, 32, 34, 94–103]. Significant discussions continue with descriptions of placebo and inappropriately converted placebo analysis of active control trials. Manchikanti et al. [98] have shown sodium chloride solution injected into the epidural space is not a placebo. Similarly, it has been widely publicized that epidural injection of local anesthetic is an active agent with only short-term differences in improvement with local anesthetic alone compared to local anesthetic with steroids [26–28]. Ironically, in contrast to numerous descriptions, the manuscripts included in this analysis

showed similar improvement with local anesthetic injection compared to radiofrequency neurotomy, however, requiring early repeat injections similar to a short-acting compared to a long-acting drug or any other technique. It is also crucial that real-world evidence be applied in analysis of the evidence with higher clinical relevancy. The majority of the trials and studies included in this analysis showed only moderate clinical relevance due to extensive lesioning and time-consuming techniques. Dal-Ré et al. [69] discussed the issues related to real-world evidence focusing on pragmatic RCTs in contrast to explanatory RCTs, which are used to test hypotheses on whether the intervention causes an outcome of interest in ideal circumstances; pragmatic RCTs aim to provide information on the relative merits of real-world clinical alternatives in routine care. A critical aim of an explanatory RCT is to ensure internal validity (prevention of bias), in contrast to a pragmatic RCT which focuses on maximizing external validity (generalizability of the results to many real-world settings), preserving internal validity as much as possible. Dal-Ré et al. also noted that a genuinely pragmatic RCT should fulfill at least two fundamental features, including conduct of the study resembling usual clinical practice and the results being applicable clinically to multiple other settings.

It is crucial in interventional pain management to identify real-world trials with high clinical applicability. This is the first systematic review comparing cervical radiofrequency in assessing cervical radiofrequency neurotomy utilizing a single-arm meta-analysis. Single-arm meta-analysis essentially showed significant improvement with conventional radiofrequency neurotomy. Even though not well appreciated, single-arm analysis should be made a crucial part of meta-analysis in elucidating the effectiveness of both groups and real-world RCTs.

CONCLUSION

This systematic review provided level II evidence for the short-term and long-term effectiveness of radiofrequency neurotomy in managing neck pain with a diagnosis of facet joint pain with dual control diagnostic blocks with at least 80% criterion standard for diagnosis. However, the evidence is level III–IV for radiofrequency neurotomy in managing headaches. Further, the literature is extremely scant in assessing efficacy or effectiveness of radiofrequency neurotomy in the cervical spine with extremely small sample sizes.

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