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Comprehensive genicular nerve radiofrequency ablation for refractory knee pain using a dual-tined electrode: A technical description and cross-sectional cohort study

Hasan Sen *, Audrey Adler, Amanda N. Cooper, Napatpaphan Kanjanapanang, Jason E. Mascoe, Alexandra E. Fogarty, Allison Glinka Przybysz, Aaron Conger, Zachary L. McCormick

Department of Physical Medicine and Rehabilitation, University of Utah, Salt Lake City, UT, United States

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ABSTRACT

Background: Genicular nerve radiofrequency ablation (GNRFA) is an effective treatment for refractory knee pain. However, refinements of GNRFA protocols are ongoing as new technologies emerge amidst accumulating evidence supporting expanded lesioning strategies.

Objectives: Describe a novel, comprehensive GNRFA protocol utilizing dual-tined electrodes to target six genicular nerves and report clinical outcomes in a cross-sectional cohort. This technique incorporates both bipolar and monopolar ablation for precise, effective lesioning.

Methods: Consecutive patients who underwent GNRFA with the described protocol at a tertiary academic center were contacted for follow-up. Baseline demographic and clinical data were collected from electronic medical records, and outcomes were assessed via standardized telephone survey. The primary outcome was the proportion of participants with ≥50 % numerical rating scale (NRS) pain score reduction. Secondary outcomes included the respective proportions of participants with ≥2-point NRS reduction and Patient Global Impression of Change (PGIC) scores ≥6, reflecting a "much improved" or better status.

Results: Fourteen patients (16 GNRFA procedures) were included. At a mean follow-up of 9.0 ± 1.5 months, 50.0 % (95 %CI:28.0–72.0 %) of participants reported ≥50 % NRS reduction, 62.5 % (95 %CI:38.6–81.5 %) experienced ≥2-point NRS reduction, and 56.3 % (95 %CI:33.2–76.9 %) reported PGIC scores ≥6. No new opioid use, arthroplasties, or procedural complications were reported at follow-up.

Conclusion: Our expanded, 6-nerve GNRFA protocol using dual-tined electrodes provided clinically significant pain relief in most patients with no associated complications. This technique shows promise as a safe, effective treatment option for refractory knee pain due to knee osteoarthritis in patients selected by single genicular nerve blocks requiring ≥50 % pain relief. Larger prospective studies with longer follow-up are needed to confirm these findings.

1. Introduction

Chronic knee pain, particularly in individuals with osteoarthritis (OA), is a prevalent cause of disability worldwide [1,2]. Genicular nerve radiofrequency ablation (GNRFA) is a minimally invasive treatment for alleviating chronic knee pain in patients with knee osteoarthritis [3]. However, the optimal GNRFA technique and target sites for denervation remain uncertain as knowledge of genicular nerve anatomy and its variability continues to evolve [3–9].

The original technique introduced by Choi et al. [10] described anatomical landmarks for targeting three genicular nerves (the superomedial [SMGN], superolateral [SLGN], and inferomedial genicular [IMGN] nerves). While numerous randomized controlled trials [10–19] used this traditional protocol demonstrated the relative safety and effectiveness of GNRFA, other studies failed to outperform sham procedures or comparative therapies when only targeting these three nerves

* Corresponding author. Department of Physical Medicine and Rehabilitation, University of Utah School of Medicine, 590 Wakara Way, Salt Lake City, UT, 84103, United States.

E-mail address: hasan.sen@utah.edu (H. Sen).

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[20–22]. These inconsistent results suggest that clinical success may be dependent on the ablation technique and targeting, technology employed, and operator experience, highlighting the need for refinement of the original approach to optimize patient outcomes.

Expanded protocols involving five or more neural targets have shown promising outcomes in observational cohort studies with real-world populations [23–27]. In addition to increasing the number of denervation sites, utilizing more recent technologies that create larger lesion volumes, such as multi-tined RFA electrodes, may also improve outcomes by increasing the likelihood of successfully capturing targeted nerves. The use of dual-tined electrodes (Nimbus®), combined with a bipolar RFA technique, allows for expanded coverage of tissue territory when ablating multiple genicular nerves and may enhance the effectiveness of the procedure. Importantly, bipolar lesioning must be performed in a manner that maximizes neural capture to achieve optimal outcomes.

We previously conducted a study in which five or more genicular nerves were targeted with dual-tined electrodes advanced parallel to periosteum. This initial method yielded suboptimal outcomes, with a responder rate of only 33 % for ≥50 % pain relief [28]. As such, we adapted our technique by directing electrodes along a more perpendicular path to the femoral epicondyle periosteum (Fig. 1). As a result of their unique elongated spheroid lesion morphology [29,30], dual-tined electrodes produce greater thermal lesion heights superficial to periosteum as the angle of approach increases towards 90° (perpendicular) [31]. We posited that utilizing a more perpendicular approach to the periosteum of the femoral epicondyle to create bipolar strip lesions may increase the likelihood of capturing the target genicular nerves (SMGN, nerve to vastus medialis [NVM], SLGN, and terminal articular branch of the common fibular nerve [TABCFN]), as they are known to travel superficially to the periosteal surface at certain locations along their known courses (Fig. 2) [4]. We continued to utilize the original, relatively parallel approach for monopolar lesioning of the inferior ablation targets of IMGN and the recurrent fibular nerve [RFN], as these nerves are consistently located close to the tibial periosteal surface [4].

The aim of this study was to (1) provide a technical description of a comprehensive GNRFA protocol using dual-tined electrodes (Nimbus®) to target six genicular nerves (SMGN, NVM, SLGN, TABCFN, IMGN, RFN) and (2) report clinical outcomes for a cohort that underwent this procedure at our institution.

2. Methods

2.1. Data collection

This cross-sectional cohort study was conducted at a single tertiary academic center with local Institutional Review Board approval (IRB 00138414). The electronic medical records of consecutive patients with chronic knee pain who underwent GNRFA using dual-tined electrodes with targeting of 6 genicular nerves between April and December 2024 were reviewed. Inclusion criteria were (1) minimum of 3 months since the GNRFA procedure; (2) response to contact by telephone, email, or paper mail and willingness to complete a standardized outcomes survey related to the GNRFA procedure; and (3) lack of involvement in litigation (including worker's compensation claims) related in any way to the index knee pain.

Baseline data were collected via chart review included the following: (1) age at the time of GNRFA; (2) sex; (3) BMI; (4) smoking status; (5) duration of index knee pain; (6) Kelgren-Lawrence scores specific to each compartment of the knee (medial, lateral, patellofemoral); (7) history of total or partial arthroplasty in index knee; (8) highest recorded numeric rating scale (NRS) pain score within three months before GNRFA; (9) baseline opioid analgesic use for index knee pain specifically; (10) baseline anxiety or depression medication use; (11) percent pain relief with prognostic genicular nerve block; (12) number of GNRFA procedures prior to the index procedure; (13) date of GNRFA; and (14) GNRFA laterality. Patients were contacted via a letter sent on behalf of their treating physician regarding the research project. Patients who agreed to participate in the study completed a post-GNRFA phone call survey which captured current NRS pain score, self-reported improvement by the Patient Global Impression of Change (PGIC), self-reported satisfaction with the procedure, current use of daily opioid analgesics for index knee pain, total or partial TKA surgery since GNRFA, and any adverse events associated with GNRFA.

2.2. Procedures

All procedures were performed by Physical Medicine and Rehabilitation physicians with subspecialty fellowship training in Pain Medicine or Interventional Spine and Musculoskeletal Medicine.

2.2.1. Genicular nerve blocks

Genicular nerve blocks were performed under multiplanar fluoroscopic guidance with use of contrast medium to rule out intravascular uptake, as described previously [27]. Target sites were based on the known anatomic locations of the genicular nerves [9,32]. Prognostic genicular blocks were classified as positive if they were associated with a pain reduction of 50 % or more during movements or activities that typically provoked pain, concordant with the duration of the local anesthetic used.

2.2.2. Radiofrequency ablation

Patients were positioned supine on a standard fluoroscopy table, with the knee bolstered and flexed at approximately 30°. The knee was exposed, cleaned, and draped in a sterile manner. Moderate sedation with midazolam and fentanyl was used on an as-needed basis at the

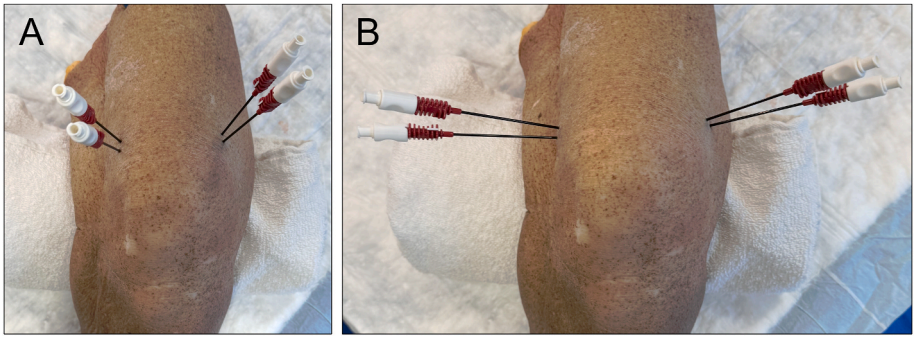

Fig. 1. Images of a cadaveric right knee specimen demonstrating GNRFA targeting the SMGN, NVM, SLGN, and TABCFN using bipolar techniques with dual-tined electrodes advanced towards the periosteal surface of the femoral shaft to epicondyle junction with a relatively **(A)** parallel versus **(B)** perpendicular angle of approach. GNRFA = genicular nerve radiofrequency ablation; NVM = nerve to vastus medialis; SLGN = superior lateral genicular nerve; SMGN = superior medial genicular nerve; TABCFN = terminal articular branch of the common fibular nerve.

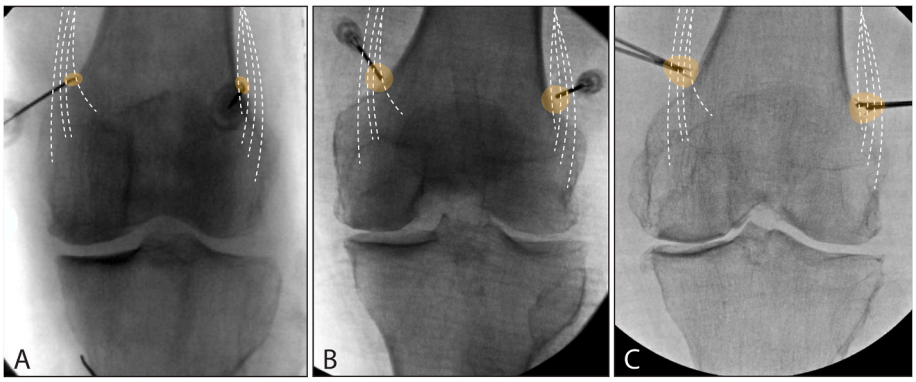

Fig. 2. Fluoroscopic anterior-posterior (AP) views of electrode positions for **(A)** monopolar lesioning targeting the SMGN and SLGN using 22-gauge conventional RF electrodes with 10-mm active tips, according to the original GNRFA protocol introduced by Choi et al. [10], **(B)** bipolar lesioning targeting the SMGN, NVM, SLGN, and TABCFN using dual-tined electrodes advanced along a relatively parallel trajectory towards the periosteal surface of the femoral shaft to epicondyle junction, and **(C)** bipolar lesioning targeting the SMGN, NVM, SLGN, and TABCFN using dual-tined electrodes advanced perpendicularly towards the periosteal surface of the femoral shaft to epicondyle junction. Schematic representations of anticipated lesion geometries with each technique are shown in yellow. White dashed lines represent potential variations of the SMGN, NVM, SLGN, and TABCFN based on neuroanatomical descriptions. Note the genicular nerve variations coursing most superfically to the femoral periosteal surface, which are captured only with technique **(C)**. GNRFA = genicular nerve radiofrequency ablation; NVM = nerve to vastus medialis; RF = radiofrequency; SLGN = superior lateral genicular nerve; SMGN = superior medial genicular nerve; TABCFN = terminal articular branch of the common fibular nerve. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

discretion of the treating physician. To anesthetize the skin and subcutaneous tissues superficial to the targeted genicular nerve, 1 % lidocaine was used. GNRFA was performed under multiplanar fluoroscopic guidance to ensure accurate needle placement (Fig. 3).

2.2.3. *SMGN and NVM electrode placements*

In an AP fluoroscopic view, two dual-tined electrode RFA needles were inserted at approximately 45-degree angles relative to the medial aspect of the knee, at the level of the transition from the medial femoral shaft to the medial femoral epicondyle (Fig. 3A). In a lateral fluoroscopic

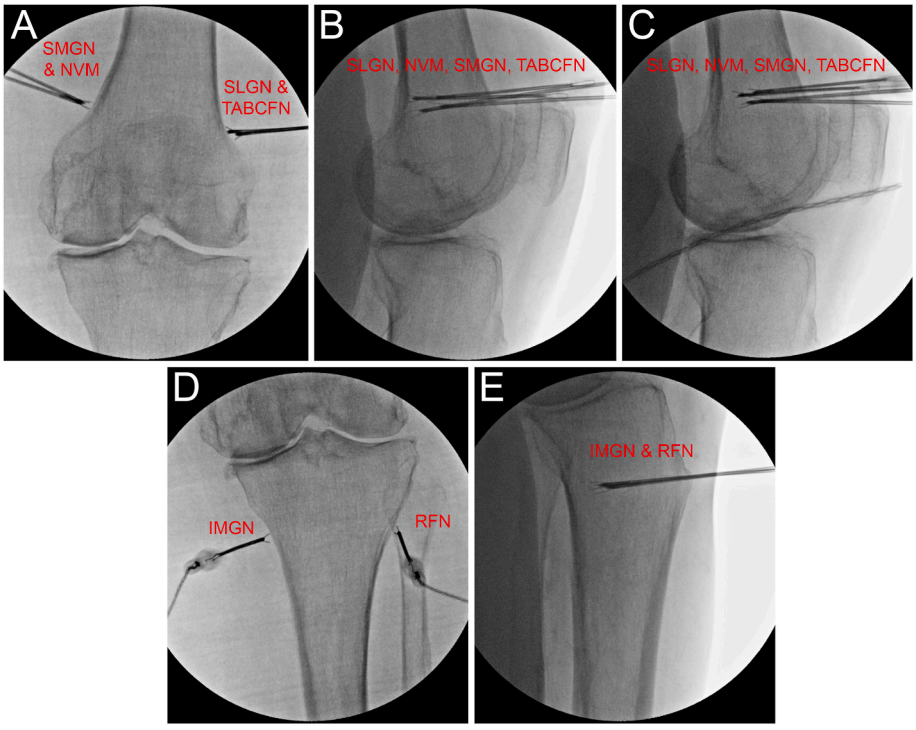

Fig. 3. **(A)** Anterior-posterior (AP) view of electrode positions with tines deployed in the goal position for bipolar lesioning, targeting the SMGN, NVM, SLGN, and TABCFN; note the relatively perpendicular angle of approach towards the periosteal surface of the femoral shaft to epicondyle junction, such that the radiofrequency lesions extend into tissue more superficial to periosteum when compared to a relatively parallel approach that may miss genicular nerve variations that "float" superficial to the periosteum. **(B)** Lateral view of electrode positions with tines deployed in the goal posterior positions for bipolar lesioning, targeting posterior variations of the SMGN, NVM, SLGN, and TABCFN. **(C)** Lateral view of electrode positions with tines deployed in the goal anterior position relative to the goal posterior position for bipolar lesioning targeting more anterior variations of the SMGN, NVM, SLGN, and TABCFN. **(D)** AP view of electrode positions with tines deployed in the goal position for monopolar lesioning, targeting the IMGN and RFN. **(E)** Lateral view of electrode positions with tines deployed in the goal position for monopolar lesioning, targeting the IMGN and RFN.
IMGN = inferior medial genicular nerve; NVM = nerve to vastus medialis; SLGN = superior lateral genicular nerve; SMGN = superior medial genicular nerve; RFN = recurrent fibular nerve; TABCFN = terminal articular branch of the common fibular nerve.

view, these needles were advanced in parallel until they contacted the periosteum of the medial femoral epicondyle such that the more posterior electrode was positioned at the posterior aspect of the medial femoral condyle, and the second was positioned approximately 15 mm anterior to the first. The electrode tines were deployed, 1–1.5 mL of 1 % lidocaine was administered through each RFA needle cannula, and a bipolar lesion was placed in this position (Fig. 3B) after confirming appropriate electrode position in the AP fluoroscopic view (Fig. 3A).

Subsequently, the tines were retracted, and in a lateral fluoroscopic view, the RFA needles were redirected such that the needle originally located at the posterior aspect of the medial femoral epicondyle was positioned approximately 15 mm anterior to its original location. The second needle was then repositioned approximately 15 mm anterior to the more posterior needle (approximately 30 mm anterior to the posterior aspect of the medial femoral epicondyle), thus creating a contiguous ablation zone covering the posterior 40–50 % of the medial femoral epicondyle. The electrode tines were deployed, 1–1.5 mL of 1 % lidocaine was administered through the more anterior RFA cannula, and a bipolar lesion was placed in this position (Fig. 3C) after confirming appropriate electrode position in the AP fluoroscopic view (Fig. 3A).

2.2.4. SLGN and TABCFN electrode placements

In an AP fluoroscopic view, two dual-tined electrode RFA needles were inserted at approximately 45-degree angles relative to the lateral aspect of the knee, at the level of the transition from the lateral femoral shaft to the lateral femoral epicondyle (Fig. 3A). In a lateral fluoroscopic view, these needles were advanced in parallel until they contacted the periosteum of the lateral femoral epicondyle such that the more posterior electrode was positioned at the posterior aspect of the lateral femoral condyle, and the second was positioned approximately 15 mm anterior to the first. The electrode tines were deployed, 1–1.5 mL of 1 % lidocaine was administered through each RFA needle cannula, and a bipolar lesion was placed in this position (Fig. 3B) after confirming appropriate electrode position in the AP fluoroscopic view (Fig. 3A).

Subsequently, the tines were retracted, and in a lateral fluoroscopic view, the RFA needles were redirected such that the needle originally located at the posterior aspect of the lateral femoral epicondyle was positioned approximately 15 mm anterior to its original location. The second needle was then repositioned approximately 15 mm anterior to the more posterior needle (approximately 30 mm anterior to the posterior aspect of the lateral femoral epicondyle), thus creating a contiguous ablation zone covering the posterior 40–50 % of the transition from the lateral femoral shaft to the lateral femoral epicondyle. The electrode tines were deployed, 1–1.5 mL of 1 % lidocaine was administered through the more anterior RFA cannula, and a bipolar lesion was placed in this position (Fig. 3C) after confirming appropriate electrode position in the AP fluoroscopic view (Fig. 3A).

In our practice, we commonly perform needle placements to target the SLGN and TABCFN concurrently with the SMGN and NVM (Fig. 3).

2.2.5. IMGN electrode placement

In an AP fluoroscopic view, a dual-tined electrode RFA needle was inserted at the level of the transition from the medial tibial shaft to the medial tibial epicondyle starting from a position on the skin approximately 1 cm medial to periosteum and advanced to periosteum (Fig. 3D). In a lateral fluoroscopic view, this needle was then advanced to a point approximately 75 % of the diameter of the tibia (closer to the posterior aspect of the medial tibial epicondyle). The electrode tines were deployed, 1–1.5 mL of 1 % lidocaine was administered through the RFA needle cannula, and a monopolar lesion was placed in this position (Fig. 3E) after confirming appropriate electrode position in the AP fluoroscopic view (Fig. 3D).

2.2.6. RFN electrode placement

In an AP fluoroscopic view, a dual-tined electrode RFA needle was inserted at the level of the transition from the lateral tibial shaft to the lateral tibial epicondyle starting from a position on the skin approximately 1 cm lateral to periosteum and advanced to periosteum (Fig. 3D). In a lateral fluoroscopic view, this needle was then advanced to a point approximately 75 % of the diameter of the tibia (closer to the posterior aspect of the lateral tibial epicondyle). The electrode tines were deployed, 1–1.5 mL of 1 % lidocaine was administered through the RFA needle cannula, and a monopolar lesion was placed in this position (Fig. 3E) after confirming appropriate electrode position in the AP fluoroscopic view (Fig. 3D).

2.2.7. RFA generator settings and post-procedural care

For all bipolar lesions, an RFA generator time of 2 min and 30 s was used at a temperature of 85 °C. These generators settings create complete bipolar lesions in chicken breast tissue with an intra-electrode distance of 20 mm when using dual-tined Nimbus® electrodes (Fig. 4). For all monopolar lesions, an RFA generator time of 90 s was used at a temperature of 90 °C. After lesions were completed, the RFA needles were removed and the skin dressed. Patients were monitored for post-procedure complications for 30 min in the recovery area.

2.3. Outcomes

The primary study outcome was the proportion of patients with ≥50 % NRS pain score reduction from baseline in the index knee. Secondary outcomes included mean NRS pain score reduction, as well as the respective proportions of patients with ≥2-point NRS reduction and PGIC scores of 6 or 7 (consistent with “much improved” or “very much improved”) and patient self-reported satisfaction with the procedure (on a 5-point Likert scale, with 1 corresponding to “very dissatisfied” and 5 to “very satisfied”). We also examined post-procedure opioid analgesic use, the number of patients who went on to receive partial or total knee arthroplasty (TKA), and adverse events associated with the GNRFA procedure.

2.4. Statistical analysis

Data were analyzed using descriptive statistics for baseline demographic, clinical, and procedural characteristics, with calculations of frequencies/proportions for categorical variables and means/standard deviations for continuous variables. Additionally, 95 % confidence intervals (CIs) were calculated along with responder rates for categorical

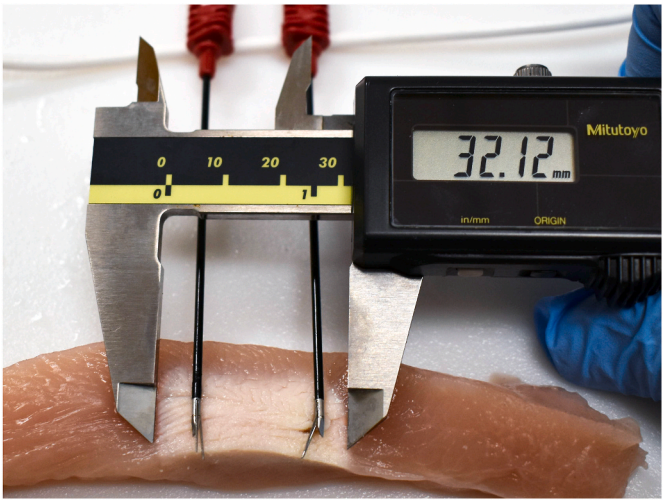

Fig. 4. Image showing the zone of coagulation within chicken breast tissue following bipolar lesioning using dual-tined Nimbus® electrodes with an intra-electrode distance of 20 mm, a radiofrequency generator time of 2 min and 30 s (30-s ramp time), and a temperature setting of 85 °C. The length of the zone of coagulation is approximately 32 mm as measured by digital calipers.

study outcomes.

3. Results

Fourteen patients (69.1 ± 12.6 years of age; 71.4 % female) underwent 16 GNRFA procedures as treatment for native knee pain due to osteoarthritis using the described protocol between April and December 2024 and agreed to complete the standardized follow-up outcomes survey. Baseline demographic and clinical characteristics of participants are presented in Table 1. In this cohort, the average time to follow-up was 9.0 ± 1.5 months post-GNRFA. Mean NRS pain scores at follow-up decreased by 2.9 ± 3.1 points from a baseline average of 6.7 ± 1.6 points. At follow-up, 50.0 % ($n = 8/16$; 95 % CI: 28.0, 72.0) and 62.5 % ($n = 10/16$; 95 % CI: 38.6, 81.5) of participants reported ≥50 % and ≥2-point NRS score reductions from baseline, respectively (Table 2). Similarly, 56.3 % ($n = 9/16$; 95 % CI: 33.2, 76.9) of participants met the responder definition on PGIC by reporting scores consistent with "much improved" or "very much improved" (Table 3).

Approximately half ($n = 9/16$; 56.3 %) of participants had a prior history of GNRFA treatment in the index knee. An additional exploratory analysis revealed no significant differences in responder rates for any categorical outcome measure between first-time versus repeat GNRFA procedures ($p > 0.05$; Table S1).

The mean score for patient-reported satisfaction with the procedure (on a 1–5 scale where 1 = "very dissatisfied" and 5 = "very satisfied") was 3.9 ± 1.2 points (range: 2–5) at average follow-up. Of the two participants using opioid analgesics at baseline, one individual had ceased opioid medication use at mean follow-up. No participants initiated opioid medication use or went on to receive TKA by the time of follow-up survey. No adverse events occurred during the procedures, and no complications were reported at follow-up.

Table 1
Participant demographics, clinical, and procedure-related variables.

Categorical variable	No. (%)
Gender ($n = 14$)	
Male	4 (28.6)
Female	10 (71.4)
Current smoker ($n = 14$)	
Yes	0 (0.0)
No	13 (100.0)
Unknown	*1*
Opioid use at baseline ($n = 16$)	
Yes	2 (12.5)
No	14 (87.5)
Antidepressant/anxiolytic medication use at baseline ($n = 14$)	
Yes	5 (35.7)
No	9 (64.3)
Duration of pain ($n = 14$)	
≤ 1 year	1 (7.7)
2–5 years	6 (46.2)
≥ 6 years	6 (46.2)
Unknown	*1*
Worst compartment KL grade ($n = 16$)	
1	3 (18.8)
2	1 (6.3)
3	3 (18.8)
4	9 (56.3)
History of knee replacement in index knee ($n = 16$)	
Yes	0 (0.0)
No	16 (100.0)
GNRFA laterality ($n = 16$)	
Left	8 (50.0)
Right	8 (50.0)
Number of GNRFAs prior to the index procedure ($n = 16$)	
0	7 (43.8)
1	4 (25.0)
≥2	5 (31.2)
Age in years ($n = 14$; mean ± SD)	69.1 (12.6)
BMI in kg/m^2 ($n = 14$; mean ± SD)	31.6 (7.4)
Baseline NRS score ($n = 16$; mean ± SD)	6.7 (1.6)
Follow-up time in months ($n = 16$; mean ± SD)	9.0 (1.5)

GNRFA = genicular nerve radiofrequency ablation; NRS = numerical rating scale; SD = standard deviation.

Table 2
Pain score reduction.

Outcome	Yes	No	95 % CI (yes)
≥50 % NRS reduction	8 (50.0)	8 (50.0)	28.0, 72.0
≥2-point NRS reduction	10 (62.5)	6 (37.5)	38.6, 81.5

CI = confidence interval; NRS = numerical rating scale.

Table 3
Patient global impression of change.

Outcome	Yes	No	95 % CI (yes)
≥6 on PGIC	9 (56.3)	7 (43.8)	33.2, 76.9

CI = confidence interval; PGIC = Patient Global Impression of Change.
Note: PGIC scores ≥6 indicate at least "much improved".

4. Discussion

This cross-sectional cohort study evaluated clinical outcomes of a novel comprehensive GNRFA protocol using dual-tined electrodes to 6 genicular nerves. The approach, which expands upon traditional GNRFA protocols by increasing the number of treated nerves and incorporating larger volume lesions, may offer more thorough interruption of nociceptive signaling from the knee joint. Our findings suggest that this technique is associated with meaningful reductions in pain and high patient-reported satisfaction in a real-world clinical setting. At an average follow-up time of approximately 9 months, 50.0 % and 62.5 % of participants had ≥50 % and ≥2-point NRS pain score reductions from baseline, respectively, while 56.3 % reported PGIC scores ≥6 indicating they were at least "much improved".

These findings are comparable to results of a prior cross-sectional cohort study by our research group evaluating outcomes of GNRFA at the same institution [27]. In an analogous real-world population, Caragea et al. observed that 47.8 % and 59.0 % of 134 study participants reported ≥50 % and ≥2-point NRS reductions, respectively, at an average follow-up of nearly two years post-procedure [27]. Almost all (96.3 %) of the procedures included in that study utilized internally cooled (versus conventional) RFA technology, which is also capable of producing large lesions with a perpendicular approach. Five or more genicular nerves were targeted in a majority (61.2 %) of cases. Additional investigation is necessary to establish the long-term durability of treatment effects with the novel GNRFA protocol we have described here.

To our knowledge, this study is the first to specifically report on the effectiveness of GNRFA using dual-tined electrodes to target genicular nerves. A recent anatomical study by Fonkoué et al. revealed that the knee joint receives sensory innervation from 14 distinct nerves, with 10 of these supplying the anterior capsule [5]. This finding indicates a more complex innervation pattern than previously understood, which has piqued interest in targeting additional nerves to improve GNRFA outcomes.

We developed the described GNRFA technique in response to the observation of suboptimal outcomes in a prior cohort using electrode placement relatively parallel to the femoral epicondyle periosteal surface with the same probe type [28]. In that initial study, the responder rate for ≥50 % pain relief was 33 % at an average follow-up of 10.6 ± 4.0 months. Those results were consistent with findings reported by Malaithong et al., who also used a bipolar technique with parallel approach to the femoral epicondyle periosteal surface and reported similarly limited effectiveness that did not significantly differ from sham RFA followed by steroid injection [22]. These findings highlight the

importance of electrode orientation, as genicular nerves that innervate the superior-anterior knee joint are often situated within soft tissue superficial to the periosteum [32]. By advancing electrodes along a more perpendicular trajectory towards the femoral epicondyles, we observed a higher responder rate (50 %), supporting this method as the preferred approach when using dual-tined technology, pending larger confirmatory comparative study.

Our findings are also consistent with studies employing expanded lesioning strategies. A pragmatic RCT by Chen et al. evaluated a four-nerve GNRFA protocol utilizing cooled RF technology [17]. In that study, 68 % and 65 % of participants reported ≥50 % pain reduction at 6 and 12 months, respectively. Similarly, a retrospective cross-sectional study by Shi et al. using conventional monopolar GNRFA to target an average of 5 nerves per patient found that 56 % of patients went on to experience ≥50 % pain reduction at 6 months [26]. Although these studies did not utilize a dual-tined RFA electrode, they still align with our results, suggesting that protocols targeting five or more nerves may be more effective, particularly when used with RFA technologies capable of producing larger lesion volumes.

4.1. Limitations

The primary limitation of this study is its cross-sectional design, which, while reflective of real-world clinical practice, lacks the control and randomization necessary to establish the effect attributable to RFA compared to a sham procedure or alternative RFA targeting. This design also introduces potential recall, information, and response bias due to reliance on patient-reported outcomes collected via telephone follow-up. The use of phone-based follow-up further limits post-procedure evaluation to subjective measures such as pain and PGIC, without objective assessment of functional outcomes. Follow-up was limited to a single cross-sectional timepoint, so longitudinal outcome trends could not be assessed. Additionally, the sample size of 14 patients limits the statistical power and generalizability of the findings. Lastly, external validity may be constrained by the fact that the study cohort was comprised of patients treated at a single academic medical center, and the influence of unmeasured confounding factors cannot be entirely ruled out. However, given the relatively limited data in the literature regarding using dual-tined RFA electrodes with targeting of ≥5 genicular nerves, our results provide additional insights. Future randomized controlled trials with larger sample sizes and extended follow-up periods are warranted to validate these preliminary findings and better inform clinical decision-making.

5. Conclusion

This study provides preliminary data that GNRFA using dual-tined electrodes targeting 6 genicular nerves provides meaningful pain relief and high patient satisfaction. Our findings align with recent anatomical insights and clinical studies, which highlight the complexity of knee joint innervation and the importance of comprehensive nerve targeting to optimize outcomes. Further randomized controlled trials with larger cohorts are warranted to confirm these results and optimize procedural protocols for long-term efficacy and safety.

Funding

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Conflict of interest statement

Zachary L. McCormick, MD serves on the Board of Directors of the International Pain and Spine Intervention Society (IPSIS), has research grants from Avanos Medical, Boston Scientific, Relievant Medsystems, Saol Therapeutics, Spine Biopharma, SPR Therapeutics, Stratus Medical (paid directly to the University of Utah), and also consultancies with Avanos Medical, Saol Therapeutics, Stryker, and OrthoSon (relationships ended). Alexandra E. Fogarty, MD serves on the IPSIS Board of Directors. Aaron Conger, DO received research grant funding from Stratus LLC (paid directly to the University of Utah).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inpm.2025.100656.

References

[1] Vanneste T, Belba A, Oei GTML, et al. 9. Chronic knee pain. Pain Pract 2025 Jan;25(1):e13408. https://doi.org/10.1111/papr.13408. Epub 2024 Sep 1. PMID: 39219017; PMCID: PMC11680467.
[2] Garstang SV, Stitik TP. Osteoarthritis: epidemiology, risk factors, and pathophysiology. Am J Phys Med Rehabil 2006 Nov;85(11 Suppl):S2–11. https://doi.org/10.1097/01.phm.0000245568.69434.1a. quiz S12-4. PMID: 17079976.
[3] Conger A, Gililland J, Anderson L, Pelt CE, Peters C, McCormick ZL. Genicular nerve radiofrequency ablation for the treatment of painful knee osteoarthritis: current evidence and future directions. Pain Med 2021 Jul 25;22(Suppl 1):S20–3. https://doi.org/10.1093/pm/pnab129. PMID: 34308957.
[4] Tran J, Peng PWH, Lam K, Baig E, Agur AMR, Gofeld M. Anatomical study of the innervation of anterior knee joint capsule: implication for image-guided intervention. Reg Anesth Pain Med 2018 May;43(4):407–14. https://doi.org/10.1097/AAP.0000000000000778. PMID: 29557887.
[5] Fonkoué L, Behets C, Kouassi JK, et al. Distribution of sensory nerves supplying the knee joint capsule and implications for genicular blockade and radiofrequency ablation: an anatomical study. Surg Radiol Anat 2019 Dec;41(12):1461–71. https://doi.org/10.1007/s00276-019-02291-y. Epub 2019 Jul 23. PMID: 31338537.
[6] Franco CD, Buvanendran A, Petersohn JD, Menzies RD, Menzies LP. Innervation of the anterior capsule of the human knee: implications for radiofrequency ablation. Reg Anesth Pain Med 2015 Jul-Aug;40(4):363–8. https://doi.org/10.1097/AAP.0000000000000269. PMID: 26066383.
[7] Fonkoue L, Behets CW, Steyaert A, et al. Accuracy of fluoroscopic-guided genicular nerve blockade: a need for revisiting anatomical landmarks. Reg Anesth Pain Med 2019;44:950–8.
[8] Fonkoue L, Behets CW, Steyaert A, et al. Current versus revised anatomical targets for genicular nerve blockade and radiofrequency ablation: evidence from a cadaveric model. Reg Anesth Pain Med 2020;45:603–9.
[9] McCormick ZL, Cohen SP, Walega DR, Kohan L. Technical considerations for genicular nerve radiofrequency ablation: optimizing outcomes. Reg Anesth Pain Med 2021 Jun;46(6):518–23. https://doi.org/10.1136/rapm-2020-102117. Epub 2021 Jan 22. PMID: 33483425.
[10] Choi WJ, Hwang SJ, Song JG, et al. Radiofrequency treatment relieves chronic knee osteoarthritis pain: a double-blind randomized controlled trial. Pain 2011 Mar;152(3):481–7. https://doi.org/10.1016/j.pain.2010.09.029. Epub 2010 Nov 4. PMID: 21055873.
[11] McCormick ZL, Reddy R, Korn M, et al. A prospective randomized trial of prognostic genicular nerve blocks to determine the predictive value for the outcome of cooled radiofrequency ablation for chronic knee pain due to osteoarthritis. Pain Med 2018 Aug 1;19(8):1628–38. https://doi.org/10.1093/pm/pnx286. PMID: 29300971.
[12] Sarı S, Aydın ON, Turan Y, Özlülerden P, Efe U, Kurt Ömürlü İ. Which one is more effective for the clinical treatment of chronic pain in knee osteoarthritis: radiofrequency neurotomy of the genicular nerves or intra-articular injection? Int J Rheum Dis 2018 Oct;21(10):1772–8. https://doi.org/10.1111/1756-185X.12925. Epub 2016 Aug 12. PMID: 27515095.
[13] Davis T, Loudermilk E, DePalma M, et al. Prospective, multicenter, randomized, crossover clinical trial comparing the safety and effectiveness of cooled radiofrequency ablation with corticosteroid injection in the management of knee pain from osteoarthritis. Reg Anesth Pain Med 2018 Jan;43(1):84–91. https://doi.org/10.1097/AAP.0000000000000690. PMID: 29095245; PMCID: PMC5768219.
[14] Davis T, Loudermilk E, DePalma M, et al. Twelve-month analgesia and rescue, by cooled radiofrequency ablation treatment of osteoarthritic knee pain: results from a prospective, multicenter, randomized, cross-over trial. Reg Anesth Pain Med 2019 Feb;16. https://doi.org/10.1136/rapm-2018-100051. rapm-2018-100051. Epub ahead of print. PMID: 30772821.
[15] Hunter C, Davis T, Loudermilk E, Kapural L, DePalma M. Cooled radiofrequency ablation treatment of the genicular nerves in the treatment of osteoarthritic knee pain: 18- and 24-month results. Pain Pract 2020 Mar;20(3):238–46. https://doi.org/10.1111/papr.12844. Epub 2019 Nov 14. PMID: 31605667; PMCID: PMC7078815.
[16] Chen AF, Khalouf F, Zora K, et al. Cooled radiofrequency ablation compared with a single injection of hyaluronic acid for chronic knee pain: a multicenter, randomized clinical trial demonstrating greater efficacy and equivalent safety for cooled radiofrequency ablation. J Bone Joint Surg Am 2020 Sep 2;102(17):1501–10. https://doi.org/10.2106/JBJS.19.00935. PMID: 32898379.
[17] Chen AF, Khalouf F, Zora K, et al. Cooled radiofrequency ablation provides extended clinical utility in the management of knee osteoarthritis: 12-month

results from a prospective, multi-center, randomized, cross-over trial comparing cooled radiofrequency ablation to a single hyaluronic acid injection. BMC Musculoskelet Disord 2020 Jun 9;21(1):363. https://doi.org/10.1186/s12891-020-03380-5. PMID: 32517739; PMCID: PMC7285532.

[18] Lyman J, Khalouf F, Zora K, et al. Cooled radiofrequency ablation of genicular nerves provides 24-month durability in the management of osteoarthritic knee pain: outcomes from a prospective, multicenter, randomized trial. Pain Pract 2022 Jul;22(6):571–81. https://doi.org/10.1111/papr.13139. Epub 2022 Jun 29. PMID: 35716058; PMCID: PMC9541208.

[19] Santana-Pineda MM, Vanlinthout LE, Santana-Ramírez S, Vanneste T, Van Zundert J, Novalbos-Ruiz JP. A randomized controlled trial to compare analgesia and functional improvement after continuous neuroablative and pulsed neuromodulative radiofrequency treatment of the genicular nerves in patients with knee osteoarthritis up to one year after the intervention. Pain Med 2021 Mar 18;22 (3):637–52. https://doi.org/10.1093/pm/pnaa309. PMID: 33179073.

[20] Walega D, McCormick Z, Manning D, Avram M. Radiofrequency ablation of genicular nerves prior to total knee replacement has no effect on postoperative pain outcomes: a prospective randomized sham-controlled trial with 6-month follow-up. Reg Anesth Pain Med 2019 Apr 25. https://doi.org/10.1136/rapm-2018-100094. rapm-2018-100094. PMID: 31023931.

[21] Qudsi-Sinclair S, Borrás-Rubio E, Abellan-Guillén JF, Padilla Del Rey ML, Ruiz-Merino G. A comparison of genicular nerve treatment using either radiofrequency or analgesic block with corticosteroid for pain after a total knee arthroplasty: a double-blind, randomized clinical study. Pain Pract 2017 Jun;17(5):578–88. https://doi.org/10.1111/papr.12481. Epub 2016 Sep 19. PMID: 27641918.

[22] Malaithong W, Tontisirin N, Seangrung R, Wongsak S, Cohen SP. Bipolar radiofrequency ablation of the superomedial (SM), superolateral (SL) and inferomedial (IM) genicular nerves for chronic osteoarthritis knee pain: a randomized double-blind placebo-controlled trial with 12-month follow-up. Reg Anesth Pain Med 2022 Dec 21;48(4):151–60. https://doi.org/10.1136/rapm-2022-103976. Epub ahead of print. PMID: 36543391; PMCID: PMC9985752.

[23] Koshi E, Meiling JB, Conger AM, McCormick ZL, Burnham TR. Long-term clinical outcomes of genicular nerve radiofrequency ablation for chronic knee pain using a three-tined electrode for expanded nerve capture. Interv Pain Med 2021 Nov 19;1 (1):100003. https://doi.org/10.1016/j.inpm.2021.100003. PMID: 39301447; PMCID: PMC11411598.

[24] Koshi E, Cheney CW, Sperry BP, Conger A, McCormick ZL. Genicular nerve radiofrequency ablation for chronic knee pain using a three-tined electrode: a technical description and case series. Pain Med 2020 Dec 25;21(12):3344–9. https://doi.org/10.1093/pm/pnaa204. PMID: 32984887.

[25] Chen Y, Vu TH, Chinchilli VM, et al. Clinical and technical factors associated with knee radiofrequency ablation outcomes: a multicenter analysis. Reg Anesth Pain Med 2021 Apr;46(4):298–304. https://doi.org/10.1136/rapm-2020-102017. Epub 2021 Feb 8. PMID: 33558282.

[26] Shi W, Vu T, Annaswamy T, et al. Effectiveness comparison of genicular nerve ablation for knee osteoarthritic versus post-total knee arthroplasty pain. Int Pain Med 2024;3:100390. https://doi.org/10.1016/j.inpm.2024.100390.

[27] Caragea M, Woodworth T, Curtis T, et al. Genicular nerve radiofrequency ablation for the treatment of chronic knee joint pain: a real-world cohort study with evaluation of prognostic factors. Pain Med 2023 Dec 1;24(12):1332–40. https://doi.org/10.1093/pm/pnad095. PMID: 37428157.

[28] Mascoe JE, Tran J, Cooper AN, et al. An expanded genicular nerve radiofrequency ablation protocol for refractory knee pain using a dual-tined electrode: a technical description and observational cohort study. Abstract presented at: 2024 international pain and spine intervention society annual meeting; September 12, 2024; Boston, MA.

[29] Wright R, Allan K, Kraft M, Holley B. Radiofrequency ablation using a novel multitined expandable electrode: device description and research study. Minimally Invasive Surg Pain 2012;2:41–54.

[30] Nimbus multi-tined expandable electrode for radiofrequency ablation selected technique summary. https://marmaratibbiurunler.com.tr/wp-content/uploads/2016/01/338-0009-00-Rev-A-Nimbus-Technique-Guide.pdf. [Accessed 12 June 2025].

[31] Finlayson RJ, Thonnagith A, Elgueta MF, Perez J, Etheridge JB, Tran DQ. Ultrasound-guided cervical medial branch radiofrequency neurotomy: can multitined deployment cannulae be the solution? Reg Anesth Pain Med 2017 Jan/Feb;42(1):45–51. https://doi.org/10.1097/AAP.0000000000000506. PMID: 27776095.

[32] Tran J, Peng P, Agur A. Evaluation of nerve capture using classical landmarks for genicular nerve radiofrequency ablation: 3D cadaveric study. Reg Anesth Pain Med 2020 Nov;45(11):898–906. https://doi.org/10.1136/rapm-2020-101894. Epub 2020 Sep 14. PMID: 32928998.