Technical Considerations for Genicular Nerve Radiofrequency Ablation: Optimizing Outcomes

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ABSTRACT

Genicular nerve radiofrequency ablation has emerged as a treatment option for patients with painful knee osteoarthritis who have failed conservative management but who may not qualify or wish to avoid a surgical procedure. Radiofrequency ablation techniques targeting the genicular nerves have evolved as our understanding of the anatomy of the anterior knee joint capsule has become more defined. The article aims to review the basic anatomy of the anterior knee joint and both the traditional and revised approaches to nerve ablation.

INTRODUCTION

Genicular nerve radiofrequency ablation (RFA) has emerged as a treatment option for patients with painful knee osteoarthritis who have failed conservative management but who may not qualify or wish to avoid a surgical procedure. The first controlled study that led to increased utilization of genicular RF ablation identified three primary targets for denervation: the superior medial genicular nerve (SMGN), superior lateral genicular nerve (SLGN) and the inferior medial genicular nerve (IMGN).[1] The original technique described by Choi *et al* suggested the optimal targets for capturing the SMGN, SLGN, IMGN were at the junction between the femoral or tibial shaft and the femoral epicondyles and medial tibial condyle, respectively (figure 1A,B). The needles were inserted approximately 3/4 of the distance across the femoral shaft for the SMGN and SLGN and approximately 2/3 across the tibial shaft for the IMGN.[1 2]

A number of clinical trials have been performed using traditional or cooled RF, targeting these original landmarks, with variability in results.[3–5] While these studies indicate that genicular nerve RF is a relatively safe and effective procedure in some patients, there is a sizeable proportion of patients who may not receive adequate relief. Furthermore, several well-designed, placebo-controlled trials failed to demonstrate efficacy when targeting solely the original three nerves advocated by Choi *et al*.[1 6–8] Recent studies have demonstrated that the innervation of the knee joint is more complex than originally thought. There are 10 nerves innervating the anterior knee joint and 14 in total; thus, the question emerges as to whether targeting additional nerves and improving the accuracy of the targets will further increase the effectiveness of genicular RFA.[9 10] Notably, a recent exploratory analysis from a prospective study suggests that targeting additional nerves improves outcomes.[11]

Recent neuroanatomical studies and genicular RFA technique implications

Recent cadaveric studies have further delineated the complexity of neuroanatomy, enhancing our knowledge of the innervation of the anterior knee joint, and allowing for more precise localization of RFA targets.[9 10] These studies indicate that the original technique targets only 3 of the 10 nerves innervating the anterior knee joint; therefore, many of the articular nerve branches innervating the knee joint remain uncaptured when using the traditional technique. These studies also demonstrated that articular nerve branches terminated in all four quadrants of the knee: superior lateral, superior medial, inferior lateral, and inferior medial so that strategies that target only three of the quadrants may fail to capture approximately 25% of the nociceptive input to the anterior knee joint (table 1).

Furthermore, the origin of these nerves differs in some patients from the origin described in earlier studies. Fonkoue *et al* describe the origin of these nerves shown in box 1. It is also important to acknowledge that anatomic variations exist. Tran *et al* delineated this variation by mapping the exact course of each nerve, unique to each dissection, contributing to anterior knee innervation.[9]

Fonkoue *et al* identified five consistent and easily targetable articular branches innervating the knee joint capsule. These targets include the SMGN, SLGN and IMGN, as well as the recurrent fibular nerve (RFN) and the infrapatellar branch of saphenous nerve (IPBSN).[10] The investigators examined the accuracy of new anatomical landmarks for genicular nerve block by injecting 0.5 mL of methylene blue after fluoroscopically guided needle placement. After the injections, the limbs were dissected to evaluate the accuracy of the injections based on the location of blue dye in the tissues. The injections were considered accurate if the dye caused the nerve to be stained blue. The authors concluded that using the new targets resulted in 100% accuracy of needle placement for the SMGN, IMGN, RFN, IPBSN and 90% for the SLGN.[10] In addition, no major nerve trunk or blood vessel was found to be dyed with blue ink during the dissection.

A more recent study by Fonkoue *et al* compared the accuracy of classical and revised techniques for fluoroscopically guided genicular nerve RFA in cadaveric models.[12] The authors employed a technique using non-diffusible ink to create a black mark at the site of the lesion as opposed to previous studies which used injectable fluid, thus potentially increasing the accuracy of the target site. The authors concluded that the revised targets are more accurate than current targets for RFA of

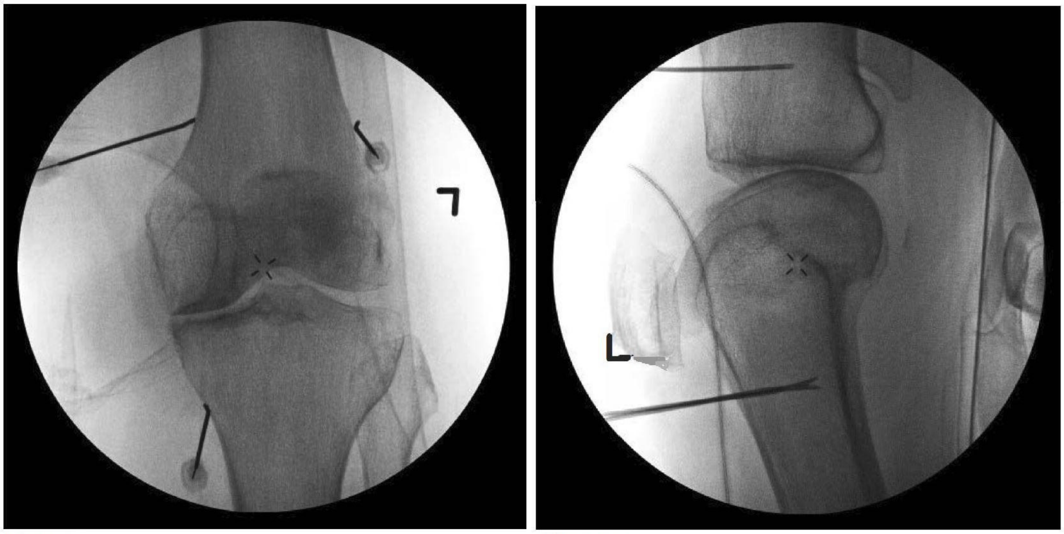

Figure 1 Final needle position for the 'classic' approach in (A) anterior-posterior and (B) lateral views of the superior medial and lateral genicular nerves and the inferior medial genicular nerve depicting proper alignment of the condyles. In (B) the radiofrequency (RF) cannula shafts are superimposed in this true lateral fluoroscopic view, although the two RF cannula shafts can be seen diverging closer to the patella and more superficially.

the SLGN (71%) and SMGN (100%) and that the targets for the RFN and IPBSN (not included in the classic technique) are 100% accurate.[12]

Presently, there is a lack of consensus regarding the origin and best landmarks for the SMGN. In the specimens dissected by Fonkoue *et al*, the SMGN was a branch from the NVM and not from the tibial nerve as previously suggested by Choi *et al*.[1] Furthermore, in a letter in response to Fonouke *et al*, Tran *et al* questioned the need for a comprehensive revision to the classic landmarks, particularly with regard to the SMGN and the SLGN, suggesting the revised approach did not consider other branches of these nerves, thus questioning the reported accuracies.[2]

Table 2 provides a summary of the revised targets for anterior knee joint denervation.

Prognostic blocks

There is controversy surrounding the use of genicular blocks prior to genicular RF as emerging studies suggest that commonly described protocols provide limited prognostic value. Recent studies demonstrate that over 80% of patients who receive genicular nerve blocks respond to genicular RFA, thus questioning the prognostic value.[3–5 13] In addition, a randomized trial by McCormick *et al* found no improvement in genicular nerve RFA success rates following use of 1 mL prognostic local anesthetic blocks with a 50% threshold to be considered 'positive' compared with no prognostic block.[13] Furthermore, lumbar facet studies suggest RFA outcomes appear similar in studies that used prognostic blocks and those that did not use blocks.[14] Alternatively, early evidence suggests that the prognostic value of genicular blocks may be improved through new landmarks, reduced local anesthetic volume to provide more target-specificity and an increased threshold to consider a block 'positive' (80%–100%).[13] However, the prognostic value of such protocol adjustments has yet to be validated and may add costs. Future research may identify a genicular nerve block protocol that provides prognostic value and is capable of reducing overall healthcare costs.

Patient positioning, preparation and imaging

The patient is supine with the knee flexed 25–30 degrees using a bolster. This angle is used in order to reduce the suprapatellar joint space so as to decrease the possibility of capsular trespass with an RF needle and to provide an unobstructed lateral view of the knee, as the contralateral knee is maintained in extension on the table. The knee is prepped and draped in the usual fashion. The femur is visualized in a true anterior-posterior (AP) fluoroscopic view in order to use skin entry points that target the genicular nerves at the relevant locations cephalad to the

Table 1 Summary of anterior joint innervation

Superior medial quadrant	Nerve to vastus medialis Nerve to vastus intermedius (NVI): medial branch Superior medial genicular nerve
Superior lateral quadrant	Nerve to vastus lateralis NVI: lateral branch Superior lateral genicular nerve Articular branch of the common fibular nerve
Inferior medial quadrant	Inferior medial genicular nerve Some specimens infrapatellar branch of saphenous nerve
Inferior lateral quadrant	Inferior lateral genicular nerve Recurrent fibular nerve

Based on recent neuroanatomical dissection studies.[9 10]

Box 1 Origins of articular nerve branches innervating the anterior knee joint

- Nerves to the vastus medialis and lateralis are derived from the femoral nerve.
- The superior medial genicular nerve (nerve to vastus medialis).[9 10]
- The inferior medial genicular nerve is a branch from the tibia or directly from the sciatic nerve.
- The superior lateral genicular nerve can derive from the sciatic nerve (common fibular fibers or the common fibular nerve).

Table 2 Summary of revised targets for anterior knee joint denervation

Superior lateral genicular nerve	Lateral femoral condyle, 9/10th of the distance across the femoral shaft, 4 mm superficial to periosteum AND lateral femoral condyle, ½ the distance across the femoral shaft, 2 mm superficial to periosteum.
Superior medial genicular nerve	Medial femoral condyle, 9/10th the distance across the femoral shaft, 2 mm superficial to periosteum.
Nerve to vastus medialis (medial branch)	From target for SMGN, withdraw to 1/3 the diameter of the femoral shaft, 1 cm superficial to periosteum.
Vastus intermedius: medial branch	5 cm superior to the upper patellar pole and 5 mm toward midline from the medial border of the femoral shaft, 2 mm superficial to periosteum.
Nerve to the vastus lateralis	Targeted 5 cm superior to upper patella, 5 mm toward midline from lateral border of femur, 1 cm superficial to periosteum.
Vastus intermedius: lateral branch	Similar to NVL except needle positioned deeper (2 mm superficial to periosteum).
Infrapatellar branch of the saphenous nerve	A point on a longitudinal line 4 cm medial to the apex of patella and the tibial tuberosity, at the transverse level of the tibial tuberosity, 2 mm superficial to periosteum.
Recurrent fibular nerve	Lateral tibial condyle at the cranio-caudal level of the lower 1/3 of the fibular head, 2 mm anterior to the fibular head in a lateral view, 2 mm superficial to periosteum.
Inferior medial genicular nerve	Medial tibial condyle, 9/10th the distance across the tibial shaft.
Inferior lateral branch genicular nerve	Targeted at the lower border of the femoral epicondyle or upper border of tibial condyle at approximately one-half to three-quarters depth to the posterior border, 2 mm superficial to periosteum.

Based on Sperry *et al* and Conger *et al*,[18 22] with revisions on reference of updated neuroanatomical investigation.[9 10] These descriptions outline the location of each nerve, but not necessarily the exact position of the radiofrequency electrode. When conventional RFA technology is used, the cannula tip should be positioned at the location described but also with careful attention to parallel electrode placement in relation to the nerve in order to provide the greatest likelihood of neural capture. Alternatively, if RFA technology with forward projecting lesion geometry is used, the physician must account for the distance of tissue capture beyond the electrode tip, such that the lesion territory captures the nerve at the point described above. In this case, the angle of approach in relation to the target nerve does not necessarily need to be parallel to the nerve (ie, can be perpendicular to the nerve), as is the case with conventional RFA technology.
RFA, radiofrequency ablation.

femoral condyles; this generally requires cephalad tilt of the C-arm. Subsequently, when planning the skin entry point for the inferior medial genicular nerve, a true AP view generally requires caudal tilt of the C-arm in order to 'square off' the tibial plateau.

Radiofrequency electrode placement of proposed new targets

Targeting of each genicular nerve (described below, 10 nerves in total, 11 lesions in total) is based on the neuroanatomy of the knee, as described by Tran *et al* and Fonkoue *et al*.[9 10] We suggest a total of four skin entry points so as to minimize discomfort and soft tissue trauma for the patient. The same skin entry point used to target the superior lateral genicular nerve can be used to target the nerve to the vastus lateralis and the lateral branch of the nerve to vastus intermedius. Similarly, the same skin entry point used to target the superior medial genicular nerve and nerve to the vastus medialis can be used to target the medial branch of the nerve to the vastus intermedius. The same skin entry point used to target the inferior medial genicular nerve can be used to target the infrapatellar branch of the saphenous nerve. Finally, the same skin entry zone targeting the inferior lateral nerve can be used to target the recurrent fibular nerve. To maximize the likelihood of nerve capture, we recommend using electrode sizes (18-gage or larger) and heating parameters (≥80°C for at least 90 s) similar to those recommended in the international facet guidelines.[14] We recommend confirming RF cannula placement in AP and lateral views at each site after placing the RF cannula and prior to lesioning. Follow lesioning parameters in the following sections for targeting of each genicular nerve (figure 2A–C).

Superior lateral genicular nerve

The existence of multiple branches of the SLGN increases the variability of the most accurate target for the SLGN. Fonkoue *et al* advocate for targeting the area connecting the posterior cortex of the femur shaft and the superior edge of the lateral condyle, advising adding both a proximal and distal lesion to improve capture rate.[10 12] They do remark, however, that for this target the needle should not be advanced too far (ie, behind the femur) to avoid injectate spread to the common fibular nerve (CFN) (figure 2A,B). Tran *et al* postulate the SLGN courses with the superior lateral genicular artery, just proximal to the superior border of the lateral femoral condyle, before terminating in the joint capsule and the existence of inferior branches.[2] Thus, they conclude that the classic approach and the revised approach capture different branches,[2] thus potentially necessitating the need to target both areas.

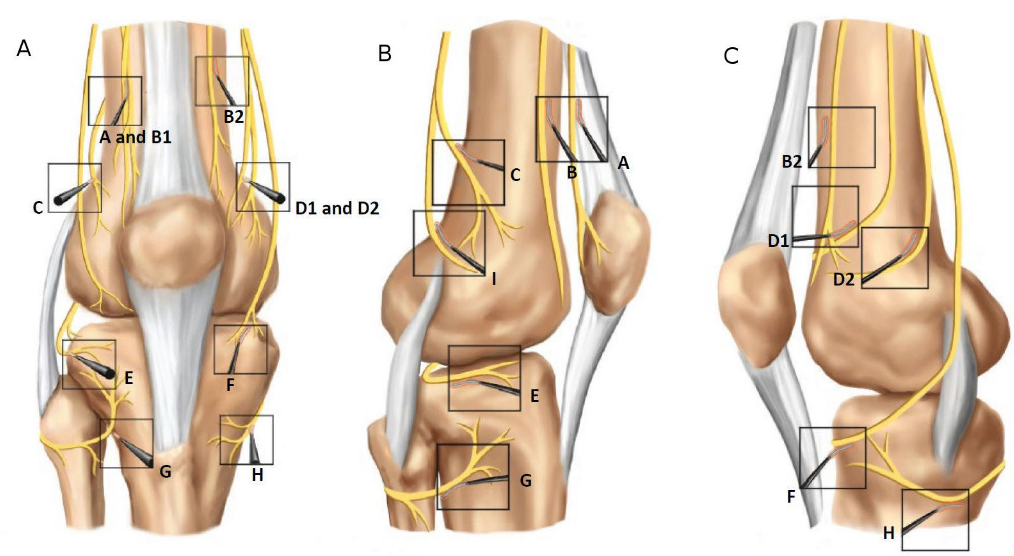

Figure 2 Innervation of the anterior knee joint with target nerves. (A) Anterior view, (B) lateral view, (C) medial view. (A) Nerve to vastus lateralis, B1. Lateral branch of nerve to vastus intermedius, B2 medial branch nerve to vastus intermedius, C. Superior lateral genicular nerve, D1. Nerve to vastus medialis, D2. Superior medial genicular nerve, E. Inferior lateral genicular nerve, F. Infrapatellar branch of saphenous, G. Recurrent fibular nerve, H. Inferior medical genicular nerve, I. Terminal articular branch of the common fibular nerve.

Procedure

- AP view: advance RF cannula to the confluence of lateral femoral shaft and epicondyle (figure 2A—C).
- Lateral view: advance RF cannula until tip is 9/10th across the width of the femoral shaft (nearly at the posterior aspect of the femur) and adjacent to the periosteum (figure 2B—C).
- First lesion: after placement of RF electrode, confirm active tip is 2 mm superficial to periosteum.
- Second lesion: withdraw electrode until active tip is ½ way across the femoral shaft and 2 mm superficial to periosteum.

Superior medial genicular nerve and the nerve to the vastus medialis

Review of multiple studies suggest that the SMGN has multiple branches. Fonkoue *et al* suggest that most of the branches of the SMGN can be captured at a point a few millimeters anterior to the adductor tubercle[10] (figure 2A,C). Tran *et al* postulate that a lesion at the classic target may be needed to capture the more proximal branches of the SMGN.[15]

Procedure

- AP view: advance RF cannula to the confluence of the medial femoral shaft and the medial epicondyle (figure 2A—D2, D1).
- Lateral view: advance RF cannula 9/10 across the femoral shaft (nearly at the posterior aspect of the femur) and adjacent to the periosteum (figure 2A—D2).
- First lesion: after placement of RF electrode, confirm active tip is 2 mm superficial to periosteum.
- Second lesion: withdraw electrode until active tip is 1/3 of the way across the femoral shaft and 1 cm superficial to periosteum (figure 2A—D1).

Nerve to the vastus lateralis and nerve to vastus intermedius (lateral branch)

Procedure

- AP view:
  - Using same cannula entry point as SLGN, the RF cannula is withdrawn to subcutaneous tissue and then advanced to a point approximately 5 cm cephalad to superior aspect of the patella and approximately 5 mm toward midline from the lateral border of the femoral shaft (this prevents encountering/traumatizing the quadriceps tendon) (figure 2A—A, B1).
  - Advance RF cannula until it lightly contacts periosteum.
- Lateral view:
  - Confirm positioning of the lateral branch of the NVI (figure 2B—B1).
- First lesion (to capture lateral branch to NVI): after inserting RF electrode confirm active tip is 2 mm superficial to periosteum.
- Second lesion (to capture lateral branch of the NVL): RF cannula is withdrawn until the active tip is located at similar depth as the quadriceps tendon, approximately 1 cm superficial to periosteum.

Nerve to the vastus intermedius: medial branch

Procedure

- AP view:
  - Using same skin entry point as SMGN and NVM, the RF cannula is withdrawn to subcutaneous tissue and then advanced to a point approximately 5 cm cephalad to the superior aspect of the patella and 5 mm toward the medial border of the femoral shaft (prevents encountering the quadriceps tendon) (figure 2A—B2).
  - Advance RF cannula until it gently contacts periosteum (figure 2C—B2).
- Lateral view:
  - Confirm position.
- Lesion: after inserting RF electrode confirm active tip is 2 mm superficial to periosteum.

Inferior medial genicular nerve and the infrapatellar branch of the saphenous nerve

The IMGN and IPBSN innervate the inferior-medial quadrant of the knee. While Fonokoue *et al* report accuracy using the classic technique to target the IMGN,[10] other investigators advocate for a more inferior and posterior approach to target the nerve at a site of less variability and to decrease risk of adverse events, including damage to the pes anserine tendons and/or footprint, and skin burns).[9 16 17] We propose a lesion point posterior to the medial collateral ligament to decrease the risk of cutaneous burn.

Procedure

- AP view:
  - Advance RF cannula to confluence of medial tibial shaft and tibial flare with slight cephalad projection (figure 2A—H and F).
- Lateral view:
  - Advance RF cannula ¾ the distance across tibial shaft (figure 2B—H and F).
- First lesion (IMGN): after inserting the RF electrode confirm the distal end of the active tip is 4 mm superficial to periosteum.
- Second lesion (IPBSN):
  - Re-stylet the RF cannula. Re-direct the distal tip so it is located at a point on a longitudinal line 4 cm medial to the apex of patella and the tibial tuberosity, at the transverse level of the tibial tuberosity (use of ultrasound guidance and/or sensory stimulation testing may be necessary to localize the nerve or multiple lesions may be needed).
  - After inserting the RF electrode confirm the distal end of the active tip is 2 mm superficial to periosteum.

Recurrent fibular nerve

Fonkoue *et al* contend that theirs was the first study to describe a new approach to safely target the RFN without lesioning the CFN. Depending on the pain pattern, RFN may be important in denervating nociceptive input from the inferior lateral quadrant of the knee.[10] Previous authors have stated that it is not safe to lesion the RFN due to its close proximity to the CFN, but Fonkoue *et al* assert that this misunderstanding arose because previous authors assumed the target location for RF of the RFN would be on the fibular neck where the RFN originates. This assertion also fails to consider that widely accepted indications for RFA such as lumbar and cervical facet joint pain, and sacroiliac joint pain, require electrode placement in close proximity to nerves that carry motor fibers, with the risk mitigated by motor stimulation.[14] Instead, Fonkoue *et al* propose targeting the RFN at its distal end just before it reaches the articular capsule. At this location, the RFN is far enough away from the CFN to prevent inadvertent lesioning. They proffer that this nerve could be safely targeted 1 cm below Gerdy's tubercle deep on the periosteum. Injection at this area results in 100% accuracy without diffusion to the CFN[10] (figure 2A,B). The authors of this review have tested the feasibility of this

Table 3 Reported complications of genicular nerve radiofrequency ablation

Complication (n)	Outcome	Tips to avoid complication
Hemarthrosis (1)[23]	Total knee arthroplasty necessary	Monitor for signs of excessive bleeding.
Peri-articular hematoma (2)[23]	No significant sequelae	Monitor for signs of excessive bleeding. Hold pressure as needed.
Septic arthritis (1)[24]	Parenteral antibiotics and total knee arthroplasty necessary	Use sterile technique including face mask and gloves.
Skin burn (1)[17]	No significant sequelae, risk increased with revised targets	Ensure adequate depth >20 mm of active tip beneath skin surface.
Pes anserine tendon footprint injury (1)[16]	No significant sequelae	

technique in clinical practice, with no evidence of foot drop or CFN injury.[18]

Procedure

- AP view: advance the RF cannula to the lateral tibial flare at the craniocaudal level of the lower 1/3 of the fibular head (figure 2A—G).
- Lateral view: reposition the RF cannula so the tip is 2 mm anterior to the fibular head (ie, about 2/3 across the distance of the tibia) (figure 2B—G).
- Lesion: after inserting the RF electrode confirm the distal end of the active tip is approximately 2 mm superficial to the periosteum.

Procedure

Inferior lateral genicular nerve

- AP view: advance RF cannula at the lower end of the femoral epicondyle or just below the upper border of the tibial condyle (figure 2A—E).
- Lateral view: reposition the cannula tip at a location 2/3 the depth of the femur or tibia (figure 2B—E).
- Perform motor testing to ensure safe distance away from common peroneal nerve.
- Lesion: confirm distal end of active tip of RF electrode is 2 mm superficial to periosteum.

Radiofrequency lesioning parameters

Lesion geometry differs based on the RFA technology employed secondary to alterations in physics. In thermal RFA, high-frequency alternating current is used to create ionic agitation and friction resulting in focal heating of the surrounding tissue. Focal heating applied to a nerve results in local destruction and Wallerian degeneration of nerve axons.[19] The ability to ablate target tissue while sparing non-targeted tissues depends on variables such as local tissue characteristics as well as factors that influence energy delivery. A major factor limiting lesion size is high tissue impedance which can result from charring or desiccation of surrounding tissue.

Internal cooling affords the ability to increase the energy delivery to the tissue while relatively mitigating the limitations of charring.[20] However, more research is needed to investigate differences in effectiveness between the cooled and conventional RFA modalities.

Additional factors impacting lesion size include fluid modulation, electrode/cannula gage, active tip length, lesion temperature, use of bipolar lesioning and duration of lesioning time.[20] Studies suggest that conventional RF lesion size is enhanced by pre-injection of 1% lidocaine in 0.7% NaCl, while pre-injection of corticosteroids has been associated with decreased lesion size.[21] Increased lesioning time decreases lesion variability and may be associated with the creation of larger lesions.[21] Larger lesions can theoretically increase the likelihood of capturing the targeted structure; however, care must be taken if methods are employed to create larger lesions in order to limit damage to non-targeted tissue.[17]

Electrode orientation is also an important factor in the degree of nerve destruction incurred.[14] Thus, one may propose that conventional RFA of genicular nerves may also result in higher likelihood of genicular nerve ablation if a near-parallel, in relation to the nerve, technique is employed. In contrast, a perpendicular approach would be well-suited to use with internally cooled electrodes.

With respect to the lesion locations described above, when using conventional RFA technology, we recommend using electrode sizes of 18-gage or larger with a 10 mm active tip and heating parameters >80°C for at least 90 s, similar to those recommended in the international facet guidelines.[14] If RFA technology is used that produces forward-projecting lesion geometry, adjustments must be made. In the case of an internally cooled electrodes, we recommend using an electrode with a 4 mm active tip and a lesion time of 165 s after temperature ramp up if using three electrodes; the radiofrequency generator is set to a temperature of 60°C in order to produce an intralesional temperature of at least 80°C. Other radiofrequency technologies may also be used, with appropriate protocol adjustment to account for the geometry of the resulting lesions discussed above.

Complications

Complications with genicular RF are rare regardless of the employed technique. Table 3 describes serious but rare complications that can occur and their reported sequelae.

CONCLUSIONS

In conclusion, RF denervation of the genicular nerves is generally considered safe, however complications can occur including bleeding, infection, pain at the procedure site and skin burn.

It is unknown at this time if it is necessary to denervate all of the nerves supplying the anterior knee joint to effectively reduce pain, or to target only those nerves providing nociceptive innervation to areas deemed painful (ie, precision medicine). More studies are needed to determine the most effective and pragmatic treatment methods. Although more research is likely required, RF for alleviation of osteoarthritis-related knee pain is a procedure that deserves consideration as a means to reduce opioid use, decrease pain and improve quality of life.

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Contributors All authors have met the criteria for #1 strictly speaking since they have at a minimum provided analysis and interpretation of data from studies reviewed. This is distinct (in my interpretation) from contribution in #2. Others have obviously worked more on the conception, design and acquisition. All authors have reviewed and revised the manuscript (#2). All authors have contributed

to and approved the final version or have been given the opportunity to do so (#3). All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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