Feasibility of an ultrasound-guided approach to radiofrequency ablation of the superolateral, superomedial and inferomedial genicular nerves: a cadaveric study

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ABSTRACT

Introduction Genicular nerve radiofrequency (RF) denervation appears to be a promising treatment for knee pain in patients with degenerative osteoarthritis of the knee, when candidates are not suitable for arthroplasty. This study aimed to assess the accuracy and reliability of ultrasound-guided placement of RF cannulas in cadavers for genicular nerve treatment, by measuringthe needle-to-nerve proximity.

Materials and methods Five soft-fix human cadavers were included in this study, totaling 10 knees (meanage 93.8 years). Using the ultrasound-guided technique,which we have described previously, RF cannulas were directed toward the superolateral genicular nerve(SLGN), the superomedial genicular nerve (SMGN) and the inferomedial genicular nerve (IMGN). Indocyaninegreen (ICG) dye (0.1 mL) was infiltrated. An anatomical dissection was performed and the distance from the center of the ICG mark to the genicular nerve concerned was measured.

Results The mean distances from the center of the ICG mark to the SLGN, SMGN and IMGN were 2.33 mm(range 0.00–6.05 mm), 3.44 mm (range 0.00–10.59mm) and 1.32 mm (range 0.00–2.99 mm), respectively. There was no statistical difference in distances from the center of the ICG mark to the targeted nerve between the different nerves (p=0.18).

Conclusion The results of this study demonstrate that ultrasound-guided treatment of the genicular nerves is feasible. However, for RF ablations, there are some limitations, which mostly can be overcome by using appropriate RF ablation settings.

INTRODUCTION

Degenerative osteoarthritis (OA) of the knee is a common disease in the elderly population.[1] Population-based studies confirm that OA is a major public health issue across the world, as they report that symptomatic knee OA is present in 20%–30% of the population aged >65 years.[2,3] The prevalence of knee OA is rapidly increasing due to changing demographics, such as increased life expectancy and obesity.[4,5] Chronic knee joint pain is a common clinical symptom leading to disability, restricted movement, psychological distress and impaired quality of life.[6,7] Most patients (with mild symptoms) respond to conservative treatments, such as physical therapy, nonsteroidal anti-inflammatory drugs, intra-articular hyaluronic acid or steroid injection.[8,9] Although with severe symptoms, total knee arthroplasty (TKA) is a possible option.[10,11] However, patient dissatisfaction after TKA may be as high as 15%,[10] and this may be related to persistent post-surgical pain.

The anatomical course of the genicular branches innervating the anterior knee capsule has been widely described, although there is a lack of consensus in the literature.[12–18]

Three of the branches that innervate the anterior knee are the superolateral genicular nerve (SLGN), the superomedial genicular nerve (SMGN) and the inferomedial genicular nerve (IMGN), which supply this region alongside many other nerves (figure 1). Each of these nerves have many different patterns of origin, thus resulting in variation of the course of these nerves.[17] The IMGN, which innervates the inferomedial part of the anterior knee capsule, is formed by a branch coming from the tibial nerve.[13,17] The SMGN is described as forming from the femoral[17] or tibial nerve[13] and supplies the superomedial aspect of the knee. The SLGN is formed from either the sciatic nerve or the common peroneal nerve and supplies the superolateral quadrant.[17]

The most commonly used technique is radiofrequency (RF) ablation of the SLGN, SMGN and IMGN, although sometimes other genicular nerves can be targeted, and other types of interventions may be used.[19–32] Given the mere sensory function of these nerves, they are suitable targets for denervation techniques of the knee in patients who are not eligible for TKA or refuse this type of surgery.

Traditionally, the positioning of the RF cannulas is fluoroscopy guided, but after the introduction of ultrasound, a variety of ultrasound-guided approaches have been described.[13,14,21,25,26,29,30,33,34]

Even though both techniques are well described, not all patients have successful results from RF ablation, even after positive diagnostic nerve blocks. Several hypotheses may explain results. First, only three of the genicular nerves innervating the anterior knee capsule are targeted using this technique. Second, the patient may have inappropriately high expectations regarding the analgesic efficacy of RF ablation, which may lead to a perceived failure of the intervention. Finally, both the fluoroscopic and the ultrasound-guided approaches lack reliability due to variation in the nerve's course or factors determining lesion size.

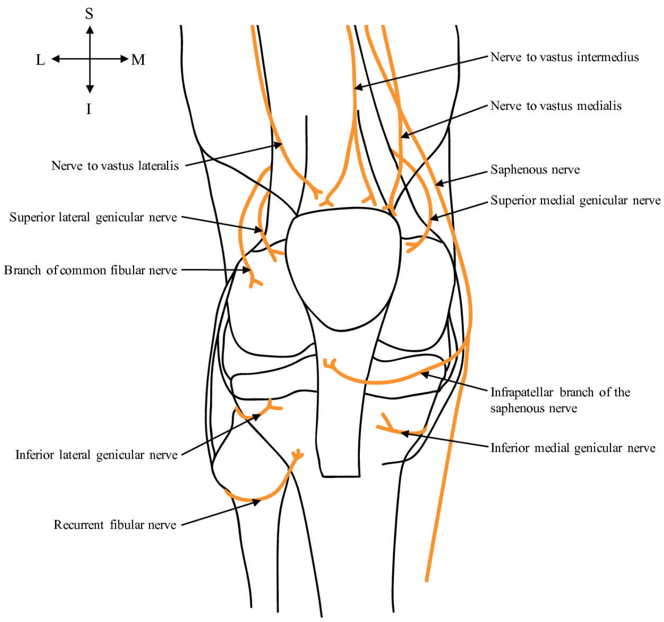

Figure 1 Innervation of the anterior knee capsule. I, inferior; L, lateral; M, medial; S, superior.

We previously described an ultrasound-guided technique for targeting the genicular nerves.[33 34] However, both needle positioning and the required lesion size need to be considered in the evaluation of this approach. To test our hypothesis that this ultrasound-guided approach leads to successful ablation of the genicular nerves, we performed a cadaver study to evaluate both needle positioning and lesion size in relation to the different genicular nerves.

MATERIAL AND METHODS

The study was performed at the Anatomy Teaching Facility of St George's, University of London. Approval for the study was granted by the St George's Research Ethics Committee. Seven soft-fix human cadavers without any external signs of prior knee intervention or trauma were randomly chosen. The volume of embalming solution used varied between individuals, depending on body mass index and vascularity of the donor. Therefore, knee circumference varied and was not measured prior to the trial, as it was thought not to affect the results. Two of these cadavers were used for pilot trials and the remaining five for the main study.

Pilot trials

Since the initial aim of the study was to determine the actual RF lesion size in relation to the different genicular nerves in a cadaver, the investigators first performed a pilot trial using one cadaver. In both knees of the cadaver, the SLGN, SMGN and IMGN were targeted using the technique for ultrasound-guided needle placement for genicular nerve ablation, as described below. In order to create the largest RF lesion size possible, we used straight, 16G, 10 mm active tip, 100 mm long RF cannulas (NeuroTherm, Wilmington, Massachusetts, USA). A thermal lesion of 80°C was applied for a duration of 90 s with an RF generator (NT 1100, NeuroTherm). Dissection was performed with the RF cannulas manually fixed in place to determine the location and the size of the lesion. However, no lesion could be appreciated in any of the targeted nerves. We concluded that applying a thermal lesion on these cadavers is not useful to answer our research question.

In a second pilot trial, simulation of the position of the active tip of the RF cannula by injecting a small volume of dye through the RF cannula was attempted. Indocyanine green (ICG) dye (ICG-PULSION, 5 mg/mL) was determined to be suitable for this study. We used straight, 22G, 10 mm active tip, 100 mm long RF cannulas (NeuroTherm) since this is commonly used in daily practice of many clinicians. In one cadaver, the RF cannulas were placed bilaterally on the target points for genicular nerve ablation with the ultrasound-guided technique described below. Three different volumes of ICG were compared: 0.2 mL on both SGMNs, 0.15 mL on both SLGNs, and 0.1 mL on both IMGNs. After dissection, a clear ICG mark was noted within close proximity of the targeted genicular nerve in each region. The authors concluded that simulating the RF cannula tip position with ICG would be the most reliable method to answer the research questions and that a volume of 0.1 mL of ICG would be sufficient.

Main study

First, one of the investigators (BV) identified the sonographic target points for RF ablation of the SLGN, the SMGN and the IMGN. The cadavers were examined in the supine position using a high-resolution ultrasound, with a 15–6 MHz linear transducer (Sonosite, Edge Ultrasound System, Bothell, Washington, USA) (figure 2).

For the SLGN, the transducer was placed in a coronal plane on the lateral side of the femoral shaft. The transducer was then translated distally and centered to the junction between the lateral femoral epicondyle and the shaft. The probe-to-junction distance was assessed with ultrasound. An out-of-plane RF cannula placement was performed perpendicular to the center of the probe at the assessed probe-to-junction distance. With the RF cannula in this position, the transducer was turned 90° into the transverse plane, until the RF cannula was in an in-plane position. In this position, the target point was determined as the center of the junction site in the transverse plane. The RF cannula was further advanced to this target point with an in-plane approach.

To identify the SMGN, the transducer was placed in a coronal plane on the medial side of the femoral shaft. The transducer was then translated distally and centered to the junction between the medial femoral epicondyle and the shaft. The probe-to-junction distance was assessed with ultrasound. An out-of-plane RF cannula placement was performed perpendicular to the center of the probe at the assessed probe-to-junction distance. With the RF cannula in this position, the transducer was turned 90° into the transverse plane, until the RF cannula was in an in-plane position. In this position, the target point was determined as the center of the junction site in the transverse plane. The RF cannula was further advanced to this target point with an in-plane approach.

For the IMGN, the transducer was placed in a coronal plane on the medial side of the tibial shaft. The transducer was then translated proximally and centered to the junction between the medial tibial epicondyle and the shaft. The probe-to-junction distance was assessed with ultrasound. An out-of-plane RF cannula placement was performed perpendicular to the center of the probe at the assessed probe-to-junction distance. With the RF cannula in this position, the transducer was turned 90° into the transverse plane, until the RF cannula was in an in-plane position. In this position, the target point was determined as the center of the junction site in the transverse plane. The

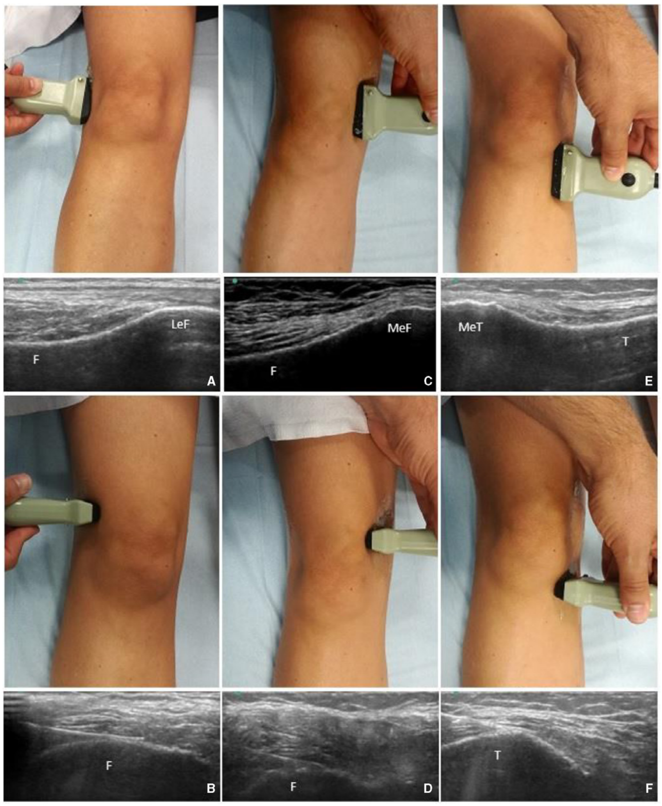

Figure 2 Probe positioning (in healthy volunteer) and ultrasound images (in cadaver) with the RF cannula in the final position. (A) target point for the SLGN in the coronal plane. (B) Final position of the RF cannula for the SLGN in the transverse plane. (C) Target point for the SMGN in the coronal plane. (D) Final position of the RF cannula for the SMGN in the transverse plane. (E) Target point for the IMGN in the coronal plane. (F) Final position of the RF cannula for the IMGN in the transverse plane. Left is proximal, right is distal (A,C,E); left is anterior, right is posterior (B,D,E). F, femur; IMGN, inferomedial genicular nerve; LeF, lateral epicondyle femur; MeF, medial epicondyle femur; MeT, medial epicondyle tibia; RF, radiofrequency; SLGN, superolateral genicular nerve; SMGN, superomedial genicular nerve; T, tibia.

RF cannula was further advanced to this target point with an in-plane approach.

Straight, 22G, 10 mm active tip, 100 mm long RF cannulas (NeuroTherm) were inserted in an in-plane ultrasound approach toward each target point. When the investigator thought he had correctly placed the needle, 0.1 mL ICG was infiltrated under real-time ultrasound guidance.

Finally, after completion of all 30 injections (six injections per cadaver), a skilled anatomist with 4 years of dissection experience (JT) performed a meticulous dissection of the cadavers to determine the location of the ICG in relation to the genicular nerves (figure 3). No magnification lens was used during this dissection. The skin and subcutaneous fat were first reflected. For the superior medial and superior lateral quadrants, the muscle was cut along the border of the rectus femoris, distally toward the injection site and patella, and transversely superior and inferior to the injection site. The muscle was carefully reflected to leave the underlying fat, dye and genicular nerves intact. For the inferior medial quadrant, the fascia overlying the IMGN was reflected to locate the nerve lying inferior to the medial tibial condyle.

The distance of the presumed location of the tip of the RF cannula (defined as the center of the ICG mark) to the genicular nerve concerned (SLGN, SMGN and IMGN) and the width of the genicular nerves were measured with an electronic digital caliper (Powerfix, London, UK).

Nerve staining was defined as contact of the ICG with the genicular nerve concerned and was judged by two independent researchers.

Statistical analysis

Statistical analysis was performed using Statistica V.13 (TIBCO Software, Palo Alto, California, USA). Staining of a nerve was considered a categorical variable; proportions of all nerves were compared using a χ^2 test. Distances from the ICG mark to the nerve were described as means (range). Analysis of variance was used for the detection of intergroup differences. $P<0.05$ was considered statistically significant.

RESULTS

Ten knees were successfully injected and dissected according to the protocol. Three male and two female cadavers were used. The mean age was 93.8 years.

The mean distances from the center of the ICG mark to the SLGN, SMGN and IMGN were 2.33 mm (range 0.00–6.05 mm), 3.44 mm (range 0.00–10.59 mm) and 1.32 mm (range 0.00–2.99 mm), respectively (figure 4). There was no statistical difference in distances from the center of the ICG mark to the targeted nerve between the different nerves ($p=0.18$).

With an injection of 0.1 mL ICG, the proportion of stained nerves was similar for the SLGN, SMGN and IMGN (8/10, 7/10 and 9/10, respectively) ($p=0.5$).

In this study, during dissection of the lateral aspect of the knee of one cadaver, two branches of the SLGN were noted near the dye, but one was spared in the block.

DISCUSSION

This anatomical study demonstrates that an ultrasound-guided approach of the genicular nerves consistently leads to a close needle-to-nerve proximity. Both the distance to the stain of the

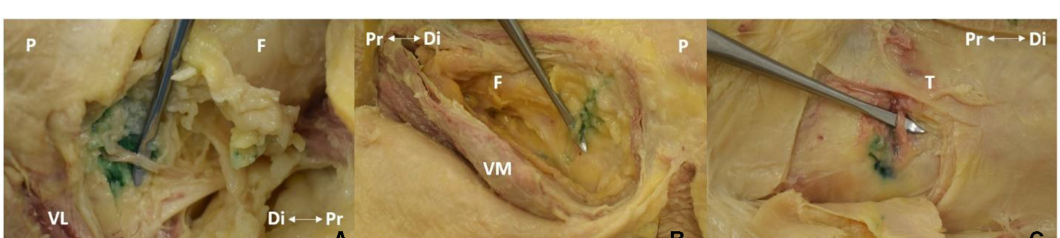

Figure 3 Dissection of the genicular nerves following infiltration of indocyanine green dye. (A) Left superolateral genicular nerve. (B) Left superomedial genicular nerve. (C) Left inferomedial genicular nerve. Di, distal; F, femur; P, patella; Pr, proximal; T, tibia; VL, vastus lateralis; VM, vastus medialis.

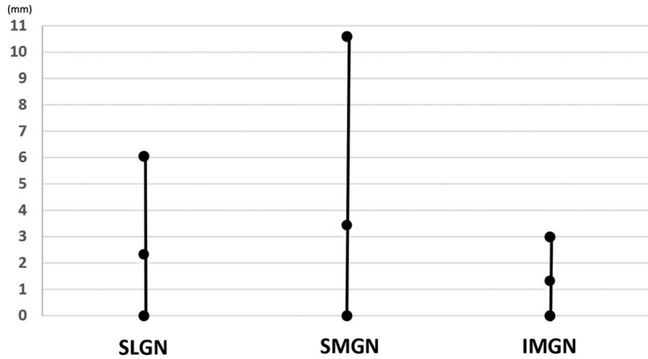

Figure 4 Mean distance and range from genicular nerves (in mm) (p=0.18). IMGN, inferomedial genicular nerve; SLGN, superolateral genicular nerve; SMGN, superomedial genicular nerve.

nerve and the incidence of staining of the targeted nerves were similar for the three targeted nerves, indicating that this ultrasound approach is applicable in clinical practice for the SLGN, SMGN and IMGN.

The use of ultrasound has some advantages in comparison with fluoroscopy. First, there is no risk of harmful ionizing radiation for patients or healthcare providers. Second, the ultrasound-guided approach provides better visualization of soft tissues (vessels, muscles, ligaments and tendons), which therefore enhances the procedural safety, and anatomical landmarks can easily be used to enhance accuracy of RF cannula positioning. Finally, ultrasound devices are cheaper to purchase and maintain than fluoroscopy devices.

The most valid method to determine the needle-tip position and the lesion size following RF lesion under experimental conditions is thought to be the application of the lesion in a cadaver and dissection with the RF cannula fixed in position. Although this method was attempted during one of the pilot setups as described above, no lesion could be appreciated after dissection. We speculate this is related to the embalming technique (soft-fix human cadavers), postmortem changes and the heterogenicity of the tissue (fat, muscle or ligament) at the target point. In some other trials, fresh cadavers were used and RF lesions were applied in homogeneous tissues.[35 36] However, these trials had a different methodology and did not involve genicular nerves.

The use of dye as a surrogate for needle-tip position has limitations as every infiltrated solution will choose the path of least resistance, and thus may spread in between tissue planes and also beyond the tip of the RF cannula. To overcome this potential source of error, we used a small volume of dye (0.1 mL). This created only a small mark of dye in the tissue. It is deemed reasonable to accept that the center of this mark is considered the final position of the tip of the RF cannula.

The course of the nerves in this study is constituent with descriptions of the course of the nerves in previous studies. However, a variation of the SLGN was noted, which suggests that locating the SLGN more superiorly may be advantageous.

With dye volumes as low as 0.1 mL, we could appreciate a close needle-to-nerve proximity. Clinicians use larger volumes (1.0–2.5 mL)[19 21 22 25 28 31 32] for diagnostic genicular nerve blocks, so it can be assumed that an injection with larger volumes would lead to an even higher success rate in blocking the genicular nerve concerned, although with this technique, needles with suitable ultrasound visibility have to be used by the clinicians to deliver the medication at the aimed target.

However, when applying RF ablation, the distance of the needle to the nerve is of paramount importance. Therefore, even with suboptimal needle placement, a diagnostic block using 1.0–2.5 mL of local anesthetics might be successful where an RF ablation with a similar needle placement could be unsuccessful.

Due to the methodology of this trial, the authors agree that it is not possible to assess the angle of the RF cannula in relation to the long axis of the targeted genicular nerve. This is important as with monopolar RF ablation the lesion beyond the tip of the cannula is limited. Consequently, the reliability of successful RF ablation with monopolar RF is limited. Lesion size and thus successful RF ablation can be improved by increasing the RF settings, such as the cannula diameter, time or temperature of the denervation. We also believe the consistency and the ratio of successful RF ablations may be improved with cooled RF, given its specific properties: creating a spherical lesion that propagates beyond the tip of the RF cannula.[37]

There are also some limitations regarding the use of cadavers. First, in cadavers, there is an absence of blood flow through the arteries, which can be used as a helpful landmark in the ultrasound-guided placement of the RF cannulas and therefore raises the success rate of this technique. Research on Thiel embalmed cadavers has been able to simulate arterial blood pressure; this genicular denervation method may be adapted for use in further research to increase the validity of the findings.[38] Second, in cadavers, there is no possibility to determine the sensory stimulation threshold of the genicular nerve concerned, which is known to aid in determining the exact location of the nerve and to increase the success rate of the procedure in clinical settings.

CONCLUSION

The results of this study demonstrate that an ultrasound-guided approach to target the genicular nerves (SLGN, SMGN and IMGN) is feasible with a close needle-to-nerve proximity, indicating potential success in denervation procedures. Infiltrations and diagnostic blocks provide sufficient spread, certainly with the relatively larger volumes of local anesthetics in clinical practice, compared with the volume used in this study. For RF ablations, there are limitations. Adjusted settings for monopolar RF ablation or cooled RF ablation can increase the ratio of successful genicular nerve denervation.

There is a great scope for more anatomical research conducted on fresh cadavers to determine the exact RF lesion size. Also, more research is required to describe the different variations of the anatomical course of the genicular nerves. Additionally, further clinical investigations are required to explore the clinical utility of this technique.

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Contributors AK conceived the original idea of this trial and supervised the project. AK and BV did the literature research on the clinical aspect of genicular nerve denervation. JT performed the literature research on the anatomy of the genicular nerves. The protocol was written by BV. Planning, execution and data collection of the experiment were carried out by BV and JT. MD performed the statistical analysis. BV took the lead in writing the manuscript. All authors equally provided critical feedback and helped shape the research, analysis and manuscript.

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Competing interests None declared.

Patient consent for publication Not required.

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