Anatomical study of the innervation of posterior knee joint capsule: implication for image-guided intervention

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ABSTRACT

Background and objectives Peripheral nerve block is an important component of the multimodal analgesia for total knee arthroplasty. Novel interventional techniques of ultrasound-guided nerve block supplying the posterior knee joint capsule require knowledge of the innervation of the posterior capsule. The objectives of this cadaveric study were to determine the course, frequency, and distribution of the articular branches innervating the posterior knee joint capsule and their relationships to anatomical landmarks.

Methods Fifteen lightly embalmed specimens were meticulously dissected. The origin of articular branches was identified, their frequency recorded, and the course documented in relation to anatomical landmarks. The capsular distribution of articular branches was documented and a frequency map generated.

Results In all specimens, articular branches from the posterior division of the obturator and tibial nerves were found to supply the posterior capsule. Additionally, articular branches from common fibular nerve and sciatic nerve were found in eight (53%) and three (20%) specimens, respectively. The capsular distribution of tibial nerve spanned the entire posterior capsule. The posterior division of obturator nerve supplied the superomedial aspect of the posterior capsule overlapping with the tibial nerve. The superolateral aspect of the posterior capsule was innervated by the tibial nerve and, when present, the common fibular/sciatic nerves.

Conclusions Frequency map of the course and distribution of the articular branches and their relationship to anatomical landmarks form an anatomical basis for peripheral nerve block approaches that provide analgesia to the posterior knee joint capsule.

INTRODUCTION

In the USA, 705 649 knee replacements were performed in 2011,1 with an anticipated increase to 3.48 million by 2030.2 Pain following total knee arthroplasty (TKA) can be severe and limit early mobilization and recovery.3,4 Femoral nerve blocks (FNBs) and adductor canal blocks (ACBs) are two of the most commonly performed peripheral nerve blocks (PNBs) as part of non-opioid multimodal analgesia following TKA.5 These approaches target the nerve supply to the anterior knee joint capsule. More recently, novel approaches targeting the nerve supply to the posterior capsule have also been added to supplement FNBS and ACBS following TKA.6–7

In the context of effective TKA clinical pathway, PNBs focus on maximizing analgesic effects while minimizing motor blockade. To achieve this, a detailed understanding of the sensory supply of the knee joint is crucial as indicated by the increasing number of investigations and publications on this topic.8–18 Previous anatomical studies of innervation of the posterior knee joint capsule are scarce, with only two studies reporting the frequency of innervation by each nerve (table 1). The objectives of this cadaveric study were (1) to determine the nerve supply to the posterior capsule, (2) to document the course and frequency of the nerves innervating the posterior capsule, and (3) to identify bony and soft-tissue landmarks in close proximity to the articular branches that are visible using ultrasound and/or fluoroscopy.

METHODS

Fifteen lightly embalmed cadaveric specimens with a mean age of 72.4±22.9 years (8M/7F) were used in this study. Sample size calculation was not possible due to lack of previous data. Specimens with visible evidence of pathology, previous surgery, or trauma were excluded. Dissection of nerves was carried out using a ×3.5 magnification lens.

Following removal of the skin, superficial and deep fascia, the obturator (ON), sciatic (SCN), common fibular (CFN), and tibial (TN) nerves were traced to their termination to identify any articular branches innervating the posterior knee joint capsule. The exposure of each nerve will be outlined below.

Obturator nerve

The sartorius, gracilis, and adductor longus were reflected to expose the adductor brevis. The anterior division of the obturator nerve (AON) and its branches were meticulously dissected to their distal termination. Next, the adductor brevis was released from its distal attachment to expose the posterior division of the obturator nerve (PON). The origin of PON from the ON was identified. Similar to the AON, the PON and its branches were traced distally to their termination. Any branches extending into the popliteal fossa were followed to their termination after dissection of branches from the SCN, CFN, and TN.

Sciatic, common fibular, and tibial nerves

The SCN was identified at the inferior border of the semimembranosus and semitendinosus to expose the SCN at its bifurcation into...

Table 1 Previous cadaveric studies of the innervation of posterior knee joint capsule

<table>
<thead>
<tr>
<th>Study</th>
<th>Presence</th>
<th>Origin</th>
<th>Presence</th>
<th>Origin/course</th>
<th>Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gardner8 1948 (n=11)</td>
<td>11/11</td>
<td>A. Tibial portion of sciatic nerve B. Popliteal fossa</td>
<td>9/11</td>
<td>ns/through adductor magnus</td>
<td>1/11*</td>
</tr>
<tr>
<td>Kennedy et al9 1982 (n=15)</td>
<td>✓</td>
<td>A. Above knee joint B. Popliteal fossa</td>
<td>✓</td>
<td>ns/with femoral artery into popliteal fossa</td>
<td>x</td>
</tr>
<tr>
<td>Horner and Dellon10 1994 (n=45)</td>
<td>✓</td>
<td>A. 10–25 cm above joint line</td>
<td>✓</td>
<td>Hunter’s canal/adductor hiatus</td>
<td>x</td>
</tr>
<tr>
<td>Orduña Valls et al16 2017 (n=25)</td>
<td>✓</td>
<td>A. Popliteal fossa</td>
<td>✓</td>
<td>Mid-femoral/through adductor magnus</td>
<td>x</td>
</tr>
<tr>
<td>Runge et al18 2017 (n=10)</td>
<td>10/10</td>
<td>ns</td>
<td>10/10</td>
<td>ns/adductor magnus, hiatus and canal</td>
<td>x</td>
</tr>
</tbody>
</table>

*Anastomosed with saphenous nerve.

The CFN and TN. The CFN was followed distally to the head of fibula and the TN to the inferior border of the popliteal fossa, while maintaining the integrity of any nerve branches.

Next, branches of ON, SCN, CFN, and TN that entered the popliteal fossa were skeletonized by removal of the fatty tissue lobules. The popliteal artery and vein were exposed as deeper fatty tissue was removed. The popliteal artery and vein were traced from the adductor hiatus to the junction of the medial and lateral heads of gastrocnemius, and the superior and inferior genicular vessels were followed medially and laterally to the margins of the popliteal fossa. The isolated popliteal and genicular vessels were carefully excised to enable dissection of the fine nerve branches to their termination. The origin and termination of articular branches, innervating the posterior knee joint capsule, were documented. All specimens were photographed, the course of each articular branch mapped, and the area of innervation of the posterior capsule was recorded. Bony and soft-tissue landmarks were determined for each articular branch innervating the posterior capsule.

Data analysis and frequency mapping

The distribution of articular branches innervating the posterior capsule was recorded and their frequency quantified. The course of each articular branch was traced and consolidated onto a 3D skeletal model to generate a frequency map (Paint.Net, dotPDN LLC, Redmond, Washington, USA; Maya 2016, Autodesk, San

Figure 1  Cadaveric dissections of articular branches supplying the posterior knee joint capsule in three different specimens, posterior views. (A) CFN, SBTN, and IBTN. Note that PON has not been exposed. (B) CFN, PON, SBTN, and IBTN, popliteal vessels intact. (C) CFN, PON, and IBTN, popliteal vessels removed. Note absence of SBTN and posterior branch of CFN in this specimen. BF, biceps femoris; CFN, main common fibular nerve; IBTN, inferior branch of the TN; LG, lateral head of gastrocnemius; MG, medial head of gastrocnemius; PON, posterior division of the obturator nerve; SBTN, superior branch of the TN; ST, semitendinosus; TN, main tibial nerve; *, femoral condyle. Reprinted with permission from Philip Peng educational series.
Rafael, California, USA; Amira for Life Sciences, Thermo Scientific, Waltham, Massachusetts, USA). Based on the frequency map and dissected specimens, the most consistent bony and soft-tissue landmarks to localize each articular branch were determined.

RESULTS
The articular branches providing innervation to the posterior knee joint capsule came from the PON, SCN, CFN, and TN.

Obturator nerve
The posterior knee joint capsule was innervated, in all 15 specimens, by articular branches of PON. No articular branches from the AON were found to supply the posterior capsule.

The PON had numerous motor branches to the adductor muscles, but only one branch was found to extend distally to supply the posterior capsule (figures 1B,C and 2). This articular branch coursed, deep to adductor longus, on the anterior surface of adductor magnus to the adductor hiatus. The articular branch coursed through the adductor hiatus, with the femoral artery and vein, to enter the popliteal fossa. In the popliteal fossa, the PON coursed along the anteromedial aspect of the popliteal artery in 14 specimens and posterior to the popliteal artery in one specimen (figure 2A,B). In all 15 specimens, at the level of the femoral condyles, the articular branch further divided into two to three terminal branches that supplied the superomedial aspect of the posterior capsule.

Common fibular and sciatic nerves
Articular branches to the posterior knee joint capsule were found in 11 of 15 specimens—8 originated from the CFN and 3 from the SCN, with the same course and termination (figures 1A,B and 2). Regardless of origin, the articular nerve divided into anterior and posterior branches to innervate the anterolateral and posterolateral capsule, respectively. In four specimens, neither the CFN nor SCN had articular branches innervating the posterior knee joint capsule (figure 1C). When present, the posterior branch coursed distally, lateral to the popliteal vein, to terminate in the superolateral aspect of the posterior capsule as one to two articular branches. The posterior branch was located at the level of the lateral femoral condyle just prior to terminating in the capsule.

Tibial nerve
The TN innervated the posterior knee joint capsule in all 15 specimens (figures 1 and 2). The articular branches were found either originating proximal or distal to the superior border of the medial femoral condyle and were referred to as the superior branch of the TN (SBTN) and inferior branch of the TN (IBTN), respectively. Only the IBTN was found in eight specimens (figure 2) and both SBTN and IBTN were found together in seven specimens (figure 1B).

The IBTN was shorter than the SBTN and, after originating from the TN, coursed transversely to the intercondylar region, between the medial and lateral femoral condyles, where it divided into three to five articular branches (figures 1C and 2C). As SBTN coursed distally, it was located medial, lateral, or between the popliteal artery and vein. At the intercondylar region, the SBTN divided into two to three articular branches that terminated in the posterior capsule. When IBTN and SBTN were both present, their articular branches interdigitated to form a plexus located on the posterior knee joint capsule.

Frequency map
The IBTN supplied the entire posterior capsule in eight specimens. However, when SBTN was present (n=7), it supplied

Figure 2  Exposure of the course of articular branches. (A) PON, SCN, and TN, popliteal vessels intact. Note the absence of SBTN in this specimen. (B) Proximal course of PON exposed by separation of the adductor magnus, indicated by double-sided arrow. Note the absence of SBTN in this specimen. (C) Enlargement of area indicated by yellow box in (B). Popliteal vessels removed to expose termination of PON, CFN, and TN in posterior capsule. ADH (dashed white line), adductor hiatus; ADM, adductor magnus; BF, biceps femoris; CFN, main common fibular nerve; LG, lateral head of gastrocnemius; MG, medial head of gastrocnemius; PA, popliteal artery; PON, posterior division of the obturator nerve; PV, popliteal vein; SBTN, superior branch of the TN; SCN, sciatic nerve; SM, semimembranosus; ST, semitendinosus; TN, main tibial nerve; *, femoral condyle. Reprinted with permission from Philip Peng educational series.
The TN and PON are the two major contributors to the innervation of the posterior knee joint capsule as demonstrated by the current study and the previous literature.8–10, 16–18 Additionally, Gardner found the AON anastomosed with the saphenous nerve (1 out of 11 specimens) and “accompanied the femoral artery into the popliteal space and thence to the back of the knee joint” leading to the suggestion that the AON also supplied the posterior capsule.8

Consistent with findings of Gardner and Runge et al,8,18 we also found TN innervation in 100% of specimens. The posterior articular branch of TN has been reported to variably originate either superior to the knee joint or within the popliteal fossa (table 1). In the current study, we have quantified the frequency of origin of the IBTN and SBTN. In eight specimens, there was one branch, the IBTN, which originated from the TN distal to the medial femoral condyle, and in seven specimens, there were two branches, SBTN arising proximal and IBTN distal to the superior border of the femoral condyles.

The contribution of PON innervation is important and was reported in 82% of specimens (n=9/11) by Gardner,8 in 100% of specimens (n=10/10) by Runge et al,18 and 100% of specimens (n=15/15) in the current study. Additionally, in the current study, the PON was found to course through the adductor hiatus consistent with previous studies.8,10 No other study, except Gardner, has suggested or found AON innervation to the posterior knee joint capsule.8

In the current study, we found that articular branches of the PON and TN interdigitated to form a fine plexus prior to terminating in the posterior knee joint capsule. This interdigitation has also been described by Gardner and Kennedy et al as a “dense plexus” and a “popliteal plexus” by Horner and Dellon.8–10 In addition, a posterior branch of CFN/SCN, when present (n=11), also provided articular branches to the plexus. Interestingly, this branch has been only mentioned by Rüdinger in 1857, but not in subsequent studies.19

We have defined the localization of the articular branches supplying the posterior knee joint capsule in relationship to bony and soft-tissue landmarks. The articular branches of PON have been described by Gardner as “descending on the popliteal vessels… Its subsequent distribution is variable” and the TN by Kennedy et al as “variable within the popliteal fossa”.8,9 In the current study, we localized the articular branches of PON in close proximity to the popliteal artery at the level of the medial femoral condyle, the CFN/SCN by the popliteal vein at the level of the lateral femoral condyle, and the TN by the superior border of the femoral condyles and the intercondylar fossa.

Our study provides an anatomical basis for the “Interspace between the Popliteal Artery and the Capsule of the posterior Knee (iPACK) block” recently described by Sanjay Sinha.20 The iPACK block targets the articular branches innervating the posterior knee joint by administration of local anesthetic into the interspace between the popliteal artery and posterior capsule of the knee. The presence of the CFN/SCN, TN, and PON articular branches to the posterior capsule, as demonstrated in this study, highlights the anatomical targets for the iPACK block. Presently, only one randomized trial has been published to show that combined ACB and iPACK block provides superior analgesia to ACB alone.21 Our study also suggests that the injection along the line joining the superior aspect of the two femoral condyles may anesthetize most of the posterior articular branches.

The limitation of our study is related to the small number of dissections, which is a characteristic of detailed anatomical

DISCUSSION

The present study is the first comprehensive cadaveric investigation detailing the innervation of the posterior knee capsule—the courses and the frequencies of each articular branches, and their relationship with the bony and soft-tissue landmarks that are discernible with ultrasound and/or fluoroscopy.

Figure 3 Frequency map of the innervation of the posterior knee joint, posterior view. Arrows indicate course of (1) superior lateral geniculate nerve and anterior branch of common fibular nerve/sciatic nerve; (2) inferior medial geniculate nerve; (3) recurrent fibular nerve. Dashed line: attachment of knee joint capsule. Reprinted with permission from Philip Peng educational series.
research. This reflects the labor-intensive and time-consuming process involved in exposing the fine sensory nerves innervating the posterior knee joint capsule. Other anatomical variations are possible. However, the frequency map compiled in the current study suggests the innervation pattern is consistent.

The importance of understanding the innervation of the knee joint is essential to develop an optimal analgesic block for TKA with minimal-to-no motor blockade. Optimizing pain control has been shown to improve rehabilitation outcomes and decrease the length of hospital stay. Despite these advantages, posterior knee joint analgesic blocks are still in development. Our results add to the literature regarding the innervation of the posterior knee joint by describing its nerve supply relative to bony and soft-tissue landmarks. This information serves as the anatomical basis that will be useful for further work on image-guided PNBs targeting the posterior knee joint capsule.

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Ethics approval Approval was received from the University of Toronto Health Sciences Research Ethics Board (approval no. 27210).

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