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Clinical Investigation

CLINICAL INVESTIGATION

Adductor canal versus femoral triangle anatomical locations for continuous catheter analgesia after total knee arthroplasty: a multicentre randomised controlled study

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Abstract

Background: Adductor canal (AC) catheters are being used to provide continuous postoperative analgesia after total knee arthroplasty (TKA) surgery. There are anatomical arguments that most AC catheters are being inserted into the femoral triangle (FT) compartment of the thigh rather than the AC compartment. The clinical relevance of this is unknown with respect to motor weakness, quality of analgesia, and opioid consumption. We hypothesised that AC catheters provide superior functional mobilisation on postoperative Day 1 after TKA as measured using the Timed Up and Go (TUG) test.

Methods: In this multinational, multicentre, double-blinded RCT, catheters were inserted under ultrasound guidance into the anatomical AC and FT compartments. The standardised protocol included spinal anaesthesia without intrathecal morphine, fixed catheter infusion rates, and oral analgesia.

Results: Of 151 subjects recruited, 75 were in the AC group and 76 in the FT group. There was no statistically significant difference in TUG on postoperative Day 1 between AC (38 [29–55] s) and FT subjects (44 [32–64] s) (median [inter-quartile range]); $P=0.11$). There was no difference in TUG Day 2, AC (38 [27–53] s) *vs* FT (42 [31–59] s); $P=0.66$. There were no statistically significant differences for secondary endpoints of pain level, effectiveness of pain relief, interference of functional activities and interpersonal relationships by pain, and opioid consumption between groups.

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Conclusions: There were no differences in immediate postoperative functional mobility, analgesia, and opioid consumption provided by catheters inserted into the AC *vs* FT locations for TKA surgery.
Clinical trial registration: ANZCTR12617001421325.

Keywords: adductor canal; continuous catheter infusion; femoral triangle; postoperative analgesia; regional anaesthesia; total knee arthroplasty

Editor's key points

- The authors used sonographically-defined anatomical landmarks for catheter placement to provide analgesia after knee replacement surgery (probably resulting in improved location of catheters compared with previous work).
- Functional mobilisation was comparable between the adductor canal and femoral triangle locations for postoperative catheter infusions of local anaesthetic.

Pain management after total knee arthroplasty (TKA) is a balance between optimising analgesia and providing early mobilisation after surgery.[1] Currently, there is much interest in performing continuous regional anaesthesia via peripheral catheters,[2] where the goal is to provide sensory block whilst simultaneously minimising motor weakness. One location that is attractive for blockade is the adductor canal, first described sonographically by Manickam and colleagues,[3] and later developed as a continuous catheter technique by Lund and colleagues[4] and Jaeger and colleagues[5] for TKA surgery. The postulated advantage was to provide analgesia as comparable as possible to femoral nerve blocks without the associated quadriceps muscle weakness, which might limit the postoperative early mobilisation and rehabilitation.

Previous publications on 'adductor canal blocks' have inconsistently reported the location of where this local anaesthesia has been deposited.[4–8] One source of confusion may be attributable to performing these blocks using surface anatomical landmarks, introducing inaccuracies as a result of inter-individual variability, as opposed to defining the anatomy using reproducible ultrasound landmarks. Another source of confusion is subsequent new publications detailing the contents and anatomical borders of the adductor canal compartment *vs* the more proximal location of the femoral triangle compartment.[9,10] In retrospect, previous studies claiming 'adductor canal catheter' insertions were likely distal femoral triangle catheters.[4–8]

The clinical relevance of this anatomically based argument remains uncertain. Adductor canal catheters (as anatomically defined using sonographic characteristics by Bendtsen and colleagues[9]) may result in superior motor strength compared with femoral triangle placement as a result of avoiding the proximal spread of local anaesthesia towards the femoral nerve.[11] Furthermore, the quality of analgesia may be improved in adductor canal catheters because of the blockade of sensory fibres involved in posterior knee capsule innervations, as a result of local anaesthesia spread into the popliteal fossa.

We thus designed a multicentre, multinational, double-blinded RCT to determine whether adductor canal catheters reduce the risk of leg weakness *vs* femoral triangle catheters. Ultrasound landmarks were used to define the neuroanatomy of the thigh, providing verification that the catheter was inserted in the appropriate anatomical space. Our primary endpoint used the Timed Up and Go (TUG) test as a clinically and functionally relevant outcome, and secondary endpoints were pain levels measured using the modified Brief Pain Inventory (Short Form), and opioid consumption.

Methods

This prospective, multicentre, randomised controlled, 1:1 allocation, parallel-armed, double-blinded, intention-to-treat, superiority trial was approved by the Sydney Local Health District Human Research Ethics Committee (HREC/17/RPAH/457). The clinical trial registration was with the Australian New Zealand Clinical Trials Registry (ANZCTR12617001421325). The study was performed in five sites: Institute of Rheumatology and Orthopaedics, Camperdown; Royal Prince Alfred Hospital, Sydney; Sir Charles Gairdner Hospital, Perth; Joondalup Health Campus, Perth (Australian sites, Perth ethics approval RGS0000000623); Middlemore Hospital, Auckland (New Zealand approval 18/NTA/2); and Virginia Mason Medical Center, Seattle, WA (USA approval IRB17-103).

Eligible patients were adults older than 18 yr, electively admitted for unilateral primary TKA surgery. Exclusion criteria included revision surgery, bilateral surgery, unicompartment surgery, previous enrolment in the study, and chronic opioid use defined as $\geq$20 mg oral morphine equivalent daily dose (oMEDD) on average in the 4 weeks before surgery. All sites used the opioid conversion calculator endorsed by the Australian and New Zealand College of Anaesthetists, Faculty of Pain Medicine to convert opioid consumption to an oral morphine dose.[12]

After written informed consent, eligible patients were recruited into the study. All recruiting centres received sequentially numbered opaque envelopes unique for each site. Each site's allocation sequence was computer generated and randomised using a block size of four. On the day of surgery, and before insertion of the catheter, a site research team member opened their next envelope to allocate subjects to either adductor canal or femoral triangle group. Figure 1 illustrates the study flow diagram.

Standardised anaesthesia and surgery protocol

A pragmatic, standardised protocol was followed at all sites. I.V. access and monitoring were established before a single-shot

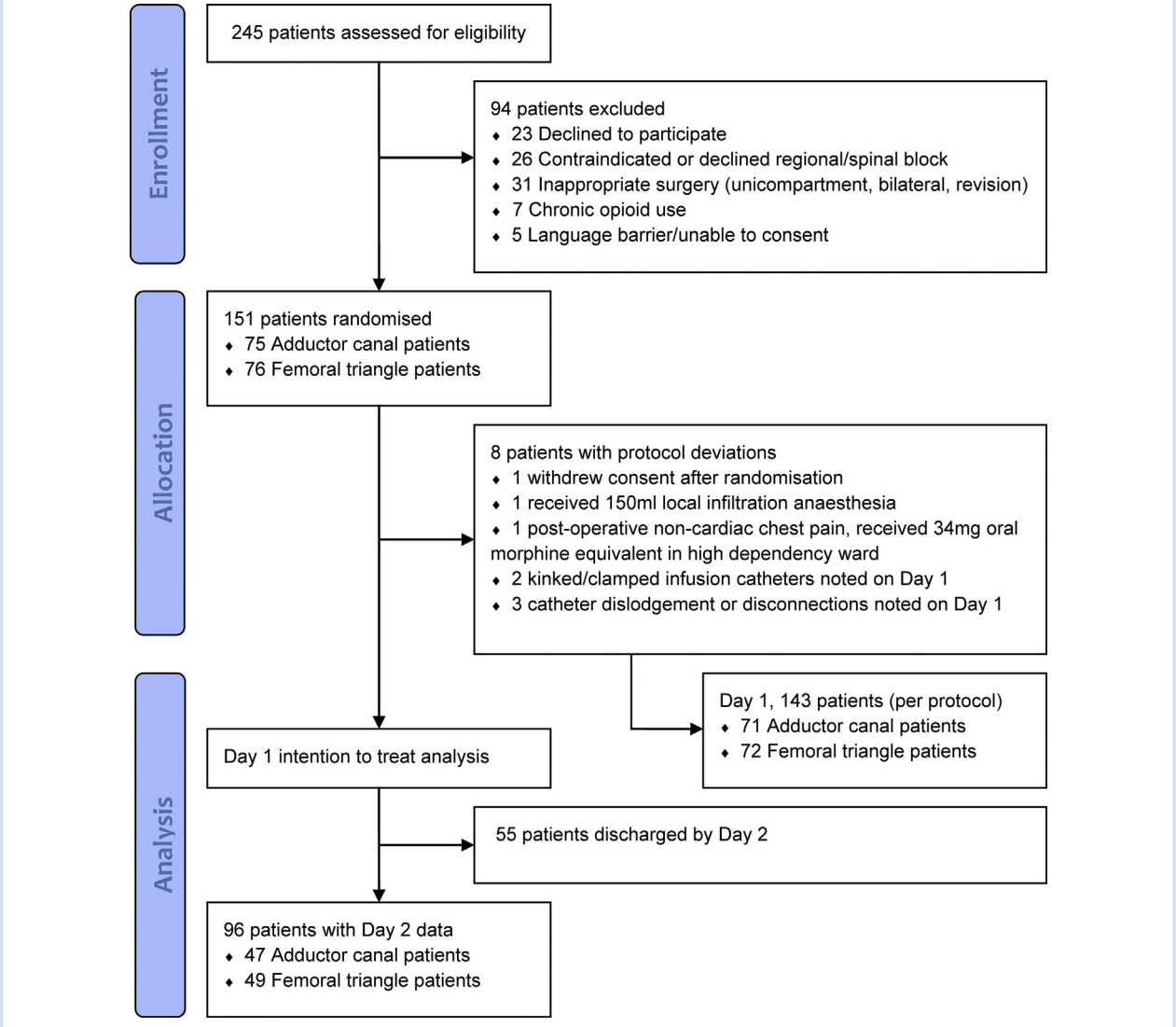

Fig. 1. CONSORT study flow diagram.

subarachnoid block using plain bupivacaine 0.5%, 2.0–3.0 ml. Intrathecal morphine was not allowed. Procedural anxiolysis and conscious sedation was provided using midazolam 1–3 mg, at the discretion of the anaesthetist. TKA surgery was performed under spinal anaesthesia alone, supplemented by intraoperative sedation using propofol 0.5–1.5 μg ml^{-1} target-controlled infusion, titrated to modified Wilson score <3. I.V. fentanyl boluses were used to augment sedation, at the discretion of the anaesthetist. If not contraindicated, all patients received preoperative single doses of paracetamol 1 g, a non-steroidal anti-inflammatory (e.g. oral celecoxib 200 mg), gabapentin 600 mg, tranexamic acid 1 g, and an intraoperative dose of i.v. dexamethasone 8 mg. Clonidine, ketamine, or tramadol was not allowed. Postoperative oral opioids for acute pain were prescribed as per individual site policies; all doses were converted to oMEDD for comparison. All patients also received regular paracetamol and oral nonsteroidal anti-inflammatory medications (if not contraindicated) for the study period.

Surgeons infiltrated the posterior knee with plain ropivacaine 0.2%, 100 ml under direct vision. Other aspects of surgery were left to the discretion of the orthopaedic team.

Catheter insertion and management protocol

The adductor canal or femoral triangle regional anaesthesia continuous catheter was inserted after successful spinal anaesthesia. This occurred either immediately after spinal block or at the end of surgery, depending on the policy at each recruitment site. The actual timing of insertion was recorded so that data collection follow-up was standardised at all sites. All catheters were inserted under full aseptic technique and were performed using a real-time ultrasound-guided in-plane approach. An end lumen catheter (non-fenestrated) was used for all subjects. The target anatomical location was initially hydro-dissected with a total of plain ropivacaine 0.2%, 15 ml,

before the catheter was inserted to leave 2 cm of the catheter in the hydro-dissected space.

In the adductor canal group, the proximal end of the adductor canal was identified using ultrasound as the position where the medial border of the *adductor longus* muscle intersects with the medial border of the sartorius muscle in the operated thigh. The adductor canal was followed using ultrasound for a further 2 cm caudad, where the *adductor magnus* and semimembranosus muscles have become visible.[9,13] The adductor canal catheter was inserted at this anatomical location. In the femoral triangle group, the catheter was inserted in the midpoint of the femoral triangle. The apex of the femoral triangle was first located using ultrasound, seen where the sartorius muscle forms a roof over the *vastus medialis* and *adductor longus* muscles. The proximal end of the femoral triangle is the anterior superior iliac spine. The midpoint of a line connecting the distal and proximal ends of the femoral triangle was noted. The femoral triangle catheter was inserted at this anatomical location. Examples of both locations are illustrated in Fig 2. All catheters were connected to portable infusion pumps programmed and locked for continuous 8 ml h^{-1} infusion of plain ropivacaine 0.2%, commencing immediately once the subject reached the PACU.

Data collection

The TUG test was used for the primary endpoint. The TUG is a frequently used test of mobilisation measuring the time required for a subject to stand from a chair, walk to a 3 m mark, turn around, and return to the chair to sit. The TUG postoperative Day 1 (TUG_1) data collection was performed at 22 to 26 h after catheter insertion. A secondary endpoint was the TUG on postoperative Day 2 (TUG_2), defined as 46 to 50 h from catheter insertion, if the subject was still admitted and not discharged to rehabilitation.

At the same Days 1 and 2 time points, the modified Brief Pain Inventory (Short Form) was administered. Pain severity, pain relief, and pain interference scores were, respectively, calculated as the percentage of worst pain experienced, the level of pain relief, and the functional inhibition of daily activity/interpersonal relationships attributable to the severity of pain. Similarly, oMEDD consumption was calculated from the regular and breakthrough opioids used by the subject on Day 1 ($oMEDD_1$) and on Day 2 ($oMEDD_2$) if still admitted.

Data quality

To ensure blinding of staff and research data collectors, skin fixation of the catheter utilised wide opaque adhesive dressings placed longitudinally over the anteromedial thigh, thereby obscuring both possible insertion sites for the adductor canal or femoral triangle locations. Data collectors were not involved with the intraoperative clinical care.

As this study is dependent on precise catheter positioning, ultrasound images were recorded of the needle, distribution of the hydro-dissection volume, and catheter *in situ*. Images were identified only with study participant numbers, and electronically sent to one author (AC) who independently confirmed the anatomical position against group allocation. For adductor canal locations, a hydro-dissection plane tracking posteriorly within the canal was a confirmation that the spread was below the vasto-adductor membrane. AC was not involved with subject recruitment or data collection, and prepared the randomised allocation sequence to be distributed to all sites.

The TUG tests were administered by trained research assistants and physiotherapists, and repeated at all sites by using didactic instructions and a standardised data collection form.[14] TUG results are highly reproducible,[15,16] have been used in TKA studies, and published data are available,[6,15] and early postoperative TUG results are meaningful because of the association with longer-term functional ability.[17,18]

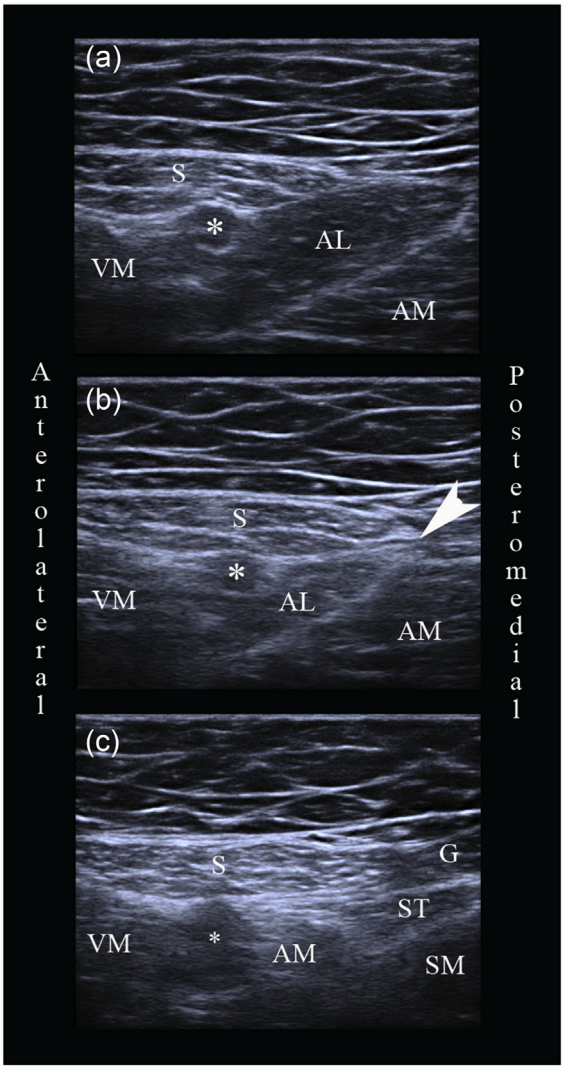

Fig. 2. Ultrasound images of the (a) midpoint of the femoral triangle, (b) apex of the femoral triangle, and (c) the adductor canal 2 cm distal to the apex. White arrowhead denotes the intersection of the sartorius and *adductor longus* muscles at the apex of the femoral triangle. Femoral triangle catheters were inserted at the position of (a), and adductor canal catheters inserted at the position of (c). *, femoral artery; AL, *adductor longus*; AM, *adductor magnus*; G, gracilis; S, sartorius; SM, semimembranosus; ST, semitendinosus; VM, *vastus medialis*.

Sample size and statistical analysis

Postoperative Day 1 TUG data are available from a RCT of continuous catheter analgesia on quadriceps strength and analgesia in TKA by Jaeger and colleagues.[6] To show a clinically significant 20% difference in TUG time between the adductor canal and femoral triangle catheter groups, with power 0.80 and two-tailed significance of <0.05, each group required 64 subjects. To account for withdrawals, the sample size was increased to 70 subjects and 140 subjects in total.

All continuous endpoints and patient characteristic data were confirmed as not normally distributed using the Shapiro–Wilk test. These results were therefore analysed with the Mann–Whitney test and categorical data with the χ^2 test. We performed both intention-to-treat and per-protocol analyses. An analysis was performed using SPSS version 24 (IBM Corp., Armonk, NY, USA). The statistical significance was determined by a two-tailed analysis; $P<0.05$.

Results

Two hundred and forty-five patients were screened for eligibility and 94 patients were excluded, with 151 subjects recruited and randomised for this study. Protocol deviations occurred in eight patients (Fig. 1). There were no statistically different subject characteristic or intraoperative anaesthesia factors between the adductor canal and femoral triangle groups (Table 1). The median (inter-quartile range [IQR]) age of subjects was 67.4 yr (61–74), had a BMI of 32 (29–37), and the majority were classified as ASA physical status 2 before surgery. Spinal anaesthesia was effective for all subjects using intrathecal plain bupivacaine 0.5%, median (IQR) dose 2.5 mg (2.5–2.7). There were no differences between groups with regard to intraoperative fentanyl use, 0 μg (0–0); the duration of surgery, 90 min (78–112); and in the use of postoperative walking aids.

For the primary outcome of TUG times on Day 1 after surgery, there were no statistically significant differences between groups, with adductor canal subjects requiring a median (IQR) of 38 (29–55) s *vs* femoral triangle subjects requiring 44 (32–64) s; $P=0.11$ (Table 2). Similarly, there were no differences in TUG Day 2 times: adductor canal, 38 (27–53) s *vs* femoral triangle, 42 (31–59) s; $P=0.66$.

When the 143 subjects were analysed on a per-protocol basis, there was no statistically significant difference for the primary outcome, with adductor canal subjects requiring a median (IQR) of 38 (28–57) s *vs* femoral triangle subjects requiring 44 (33–65) s; $P=0.08$. There were also no differences in TUG Day 2 times: adductor canal, 39 (28–53) s *vs* femoral triangle, 42 (31–59) s; $P=0.72$.

All other secondary endpoints were not statistically significantly different between groups, with all *P*-values >0.25, indicating no difference between the adductor canal and femoral triangle groups (Table 2). Opioid consumption was equivalent and remained unchanged over both postoperative days. For all subjects, the oMEDD consumption was 60 (38–100) mg on Day 1, and 60 (34–100) mg on Day 2. The subjects reported pain scores of 50% (30–61%) on Day 1, and 47% (33–60%) on Day 2. Nonetheless, the effectiveness of pain relief was high: overall 80% (50–90%) on Day 1, and 80% (50–90%) on Day 2. The extent that pain interfered with functional activities and interpersonal relationships was low: overall 25% (5–40%) on Day 1, and 20% (10–40%) on Day 2.

Discussion

In this randomised, double-blinded, multicentre study, we found no difference in immediate functional mobility or analgesia provided by catheters inserted with strict ultrasound parameters into the adductor canal *vs* femoral triangle locations for TKA surgery. The subjects did not demonstrate a statistically significant difference in time taken to complete the TUG tests in the first two postoperative days. There was no difference between the two anatomical locations for opioid consumption, pain levels, degree of pain relief, and impact on functional daily activities.

The use of peripheral regional anaesthesia catheters to provide continuous postoperative analgesia after TKA has received considerable research interest. One difficulty in evaluating previous studies has been the mislabelling of the anatomical locations, with authors claiming to perform 'adductor canal' catheters when careful reading of the methodology describes a femoral triangle insertion. Compared with surface anatomy landmarks, ultrasound is more reliable in delineating the neuroanatomy of the thigh, and has been recently described.[13]

Table 1 Subject and intraoperative characteristics. Results expressed as median (inter-quartile range). Days refer to postoperative day. PUF, pickup frame; WRF, walking roller frame.

	All subjects (*n*=151)	Randomisation group		*P*-value
		Adductor canal (*n*=75)	Femoral triangle (*n*=76)	
Age (yr)	67 (61–74)	66 (60–74)	68 (63–73)	
Sex (M/F) (%)	77/74 (51/49)	40/35 (53/47)	37/39 (49/51)	
BMI (kg m^{-2})	32.1 (28.7–36.8)	31.6 (27.9–35.6)	32.9 (29.0–38.5)	
ASA physcial status (1/2/3) (%)	10/115/26 (7/76/17)	6/59/10 (8/79/13)	4/56/16 (5/74/21)	
Intrathecal plain bupivacaine volume (ml)	2.5 (2.5–2.7)	2.5 (2.5–2.8)	2.5 (2.5–2.6)	
Intraoperative i.v. fentanyl (μg)	0 (0–0)	0 (0–0)	0 (0–0)	
Duration of surgery (min)	90 (78–112)	90 (79–104)	90 (78–120)	
Walking assistance, Day 1 (walking stick/PUF/WRF/other) (%)	0/9/133/9 (0/6/88/6)	0/1/70/4 (0/1/93/6)	0/8/63/5 (0/10/83/7)	0.05
Walking assistance, Day 2 (walking stick/PUF/WRF/other) (%)	2/18/56/20 (2/19/58/20)	0/5/33/9 (0/11/70/19)	2/13/23/11 (4/27/47/22)	0.06

Table 2 Primary and secondary endpoints. Results expressed as median (inter-quartile range). Pain severity, pain relief, and pain interference level are based on subset scores of the modified Brief Pain Inventory (Short Form). Days refer to postoperative day. oMEDD, oral morphine equivalent daily dose. *Higher score is worse pain, or greater interference with functional activities/interpersonal relationships. †Higher score is better pain relief.

	Randomisation group			P-value
	All subjects	Adductor canal	Femoral triangle	
Primary endpoint				
Timed Up and Go, Day 1 (TUG_1) (s)	41 (30–60)	38 (29–55)	44 (32–64)	0.11
Secondary endpoints				
Timed Up and Go, Day 2 (TUG_2) (s)	39 (28–57)	38 (27–53)	42 (31–59)	0.66
Morphine consumption, Day 1 ($oMEDD_1$) (mg)	60 (38–100)	60 (30–100)	60 (38–100)	0.99
Morphine consumption, Day 2 ($oMEDD_2$) (mg)	60 (34–100)	60 (30–100)	60 (38–101)	0.88
Modified Brief Pain Inventory scales				
Pain severity, Day 1* (%)	50 (30–61)	50 (33–61)	50 (30–63)	0.55
Pain severity, Day 2* (%)	47 (33–60)	47 (33–60)	47 (33–60)	1.00
Pain relief level, Day 1† (%)	80 (50–90)	75 (50–90)	80 (60–90)	0.25
Pain relief level, Day 2† (%)	80 (50–90)	80 (60–90)	80 (50–97)	0.70
Pain interference level, Day 1* (%)	25 (5–40)	25 (0–40)	30 (6–44)	0.32
Pain interference level, Day 2* (%)	20 (10–40)	25 (10–40)	20 (10–45)	0.83

Femoral triangle catheters would provide sensory block of the supra- and infra-patellar plexus from the saphenous nerve, the nerve to *vastus medialis*, and the medial femoral cutaneous nerve. This provides analgesia to the anteromedial knee. However, it raises the possibility of quadriceps muscle motor block, either through the cephalad spread up the femoral triangle or direct blockade of the nerve to *vastus medialis*. Unfortunately, in addition to its motor function, the nerve to *vastus medialis* significantly contributes to sensory innervation of the knee.[10]

In contrast, adductor canal catheters should avoid quadriceps motor weakness, as local anaesthesia distribution is thought to be restricted to distal postero-medial spread into the popliteal fossa. This more-distal distribution may have analgesic benefits attributable to the sensory block of the popliteal plexus and posterior branches of the obturator nerve.

The most appropriate anatomical location for continuous catheter placement for TKA has been the basis of two recently published trials. Sztain and colleagues[19] found better analgesia on postoperative Day 1 from femoral triangle catheters (similar ultrasound confirmed anatomical location to our study) *vs* the adductor canal location. Other endpoints, such as ambulation distance and opioid consumption, were not different between their groups. Our study differed in that our protocol was double blinded, a larger sample size, multicentre, all our patients received successful spinal anaesthesia, no further local anaesthesia boluses were allowed through the catheters, and the adductor canal catheter insertion site was specifically identified and verified using ultrasound.

In the second study by Meier and colleagues,[20] there was no difference in opioid consumption between 'proximal' *vs* 'distal' locations for catheter placement. However, the description of the anatomy is unclear, and the possibility exists that all catheters were actually placed within the femoral triangle compartment.[21] In our study, we pre-specified the collection of ultrasound imagery during the time of catheter insertion to allow the independent confirmation of correct anatomical location according to randomisation.

The underlying presumption of our study is that the femoral triangle and adductor canal compartments are anatomically separate, with the dissimilar distribution of local anaesthesia between these two locations producing clinically relevant motor and analgesia differences. However, our results did not show a significant functional effect. There may be several reasons for this. Firstly, our current understanding of the neuroanatomy may be incomplete. Whilst *in vitro* cadaveric studies demonstrated that dye remained in their respective compartments,[22–24] an *in vivo* study showed that 20 ml of radio-opaque injectate in the femoral triangle compartment also spread posteriorly into the adductor canal compartment and popliteal fossa.[25] The cause for this may be the permeability of the vasto-adductor membrane. Although this structure has been described as thick and sufficiently inflexible to be implicated in neurovascular entrapment,[26] fenestrations by multiple vascular pedicles and nerves may allow the *in vivo* co-distribution of local anaesthesia between compartments even with the infusion volumes used in our study.[27]

Secondly, branches of the saphenous (infra-patellar, sartorial, and postero-medial) and nerve to *vastus medialis* (extra-muscular and i.m., and contributions to the deep patellar plexus) are within the adductor canal.[10] Sufficient blockade of these branches may provide a functionally comparable level of analgesia for patients irrespective of adductor canal and femoral triangle catheter location. Lastly, our study was powered for mobility, but may be insufficiently powered to find differences in our secondary opioid consumption and pain outcomes.

The clinical strength of our study is based on a multinational, pragmatic design using a standardised anaesthesia and surgical protocol. We avoided spinal opioids, and all breakthrough pain relief was provided by oral opioids. This allowed a calculation of analgesia consumption unbiased by the delayed action of intrathecal opioids and local anaesthesia boluses. Endpoints were collected based on time from catheter insertion, rather than a set time during the day. TUG testing was performed by trained research personnel blinded to catheter allocation and followed standardised instructions.

Our study also had limitations. Isolated quadriceps strength is better evaluated by dynamometry, whereas the TUG test is primarily a functional endpoint where multiple factors influence the time taken. We chose the TUG as a reproducible test, performed feasibly in a ward environment,

more clinically relevant than dynamometry, and used previously in studies of catheter infusions after TKA. Our TUG Days 1 and 2 results are comparable with those reported by Jaeger and colleagues[6] (TUG_1 ranged from 37 to 49 s), and by Biswas and colleagues[28] (TUG_2 ranged from 45 to 52 s). A significant proportion of patients were also discharged by postoperative Day 2, reducing the power of the Day 2 endpoints. This was known during study preparation, and is reflective of the current trends in TKA and anaesthesia that emphasise early mobilisation and discharge to rehabilitation. Our results are also based on a continuous catheter infusion rate and the adductor canal catheter inserted relatively close to the adductor hiatus. A single-shot adductor canal block, or a more distal catheter insertion, may result in clinically significant motor and analgesia differences. Finally, the surgical technique was not standardised, as this is a pragmatic trial reflective of current trends; our focus was on the analgesic technique for which anaesthetists have primary responsibility and influence on clinical outcomes.

In conclusion, we present data suggesting that, despite anatomically distinct locations, catheters inserted into the proximal part of the adductor canal did not show superior functional mobilisation, pain, and analgesia consumption, compared with catheters inserted into the midpoint of the femoral triangle. Further elucidation of the neuroanatomy of the thigh with respect to clinical outcomes after TKA is required. We recommend that precise descriptions are used in future studies to minimise the confusion between true adductor canal and femoral triangle locations, and to avoid relative terms, such as 'proximal' *vs* 'distal'. From a clinical perspective, the benefits from continuous catheter analgesia in TKA surgery are comparable regardless of location in the lower aspect of the thigh.

Authors' contributions

Study design: AC, AL, AJC, MJL, DA.
Statistical analysis: AC.
Manuscript preparation: AC.
Recruitment, data collection, and follow-up performed by the listed investigators of the Continuous Catheters in Adductor Canal versus Femoral Triangle study. All authors performed critical review of manuscript drafts and approved the final version.

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