Effects or anaesthesia method and tourniquet use on recovery following total knee arthroplasty : a randomised controlled study

Palanne, Riku

2020-11

Palanne , R , Rantasalo , M , Vakkuri , A , Madanat , R , Olkkola , K T , Lahtinen , K , Reponen , E , Linko , R , Vahlberg , T & Skants , N 2020 , ' Effects or anaesthesia method and tourniquet use on recovery following total knee arthroplasty : a randomised controlled study ' , British Journal of Anaesthesia , vol. 125 , no. 5 , pp. 762-772 . https://doi.org/10.1016/j.bja.2020.03.036

http://hdl.handle.net/10138/331981
https://doi.org/10.1016/j.bja.2020.03.036

BJA

British Journal of Anaesthesia, xxx (xxx): xxx (xxxx)

doi: 10.1016/j.bja.2020.03.036
Advance Access Publication Date: xxx
Clinical Investigation

CLINICAL INVESTIGATION

Effects of anaesthesia method and tourniquet use on recovery following total knee arthroplasty: a randomised controlled study

Riku Palanne[1,2,†], Mikko Rantasalo[3,†], Anne Vakkuri[1], Rami Madanat[3,4], Klaus T. Olkkola[5], Katarina Lahtinen[1], Elina Reponen[1], Rita Linko[1], Tero Vahlberg[6] and Noora Skants[1,*]

[1]Department of Anaesthesiology, Intensive Care and Pain Medicine, Peijas Hospital, HUS Helsinki University Hospital, Helsinki, Finland, [2]Department of Anaesthesiology and Intensive Care, Central Finland Central Hospital, Jyväskylä, Finland, [3]Department of Orthopaedics and Traumatology, Arthroplasty Center, Peijas Hospital, HUS Helsinki University Hospital, Helsinki, Finland, [4]Terveystalo Kamppi, Helsinki, Finland, [5]Department of Anaesthesiology, Intensive Care and Pain Medicine, University of Helsinki and HUS Helsinki University Hospital, Helsinki, Finland and [6]Department of Clinical Medicine, Biostatistics, University of Turku and Turku University Hospital, Turku, Finland

*Corresponding author. E-mail: noora.skants@hus.fi

†R. Palanne and M. Rantasalo contributed equally to this article.

Abstract

Background: We investigated the effects of spinal and general anaesthesia and surgical tourniquet on acute pain and early recovery after total knee arthroplasty (TKA).

Methods: Patients (n=413) were randomised to four parallel groups: spinal anaesthesia with or without tourniquet, and general anaesthesia with or without tourniquet. The primary outcome was patient-controlled i.v. oxycodone consumption over 24 postoperative hours.

Results: Results from 395 subjects were analysed. Median i.v. oxycodone consumption did not differ between the four groups (spinal anaesthesia without [36.6 mg] and with tourniquet [38.0 mg], general anaesthesia without [42.3 mg] and with tourniquet [42.5 mg], P=0.42), between spinal (37.7 mg) and general anaesthesia (42.5 mg) groups (median difference −3.1, 95% confidence interval [CI] −7.4 to 1.2, P=0.15) and between tourniquet and no-tourniquet groups (40.0 *vs* 40.0 mg, median difference −0.8, CI −5.1 to 3.5, P=0.72). Vomiting incidence was higher with spinal than with general anaesthesia (21% [42/200] *vs* 13% [25/194], CI 1.05 to 3.1, P=0.034). The mean haemoglobin decrease was greater without than with tourniquet (−3.0 *vs* −2.5 g dl^{-1}, mean difference −0.48, CI −0.65 to −0.32, P<0.001). No differences were observed in pain, pain management, incidences of blood transfusions, in-hospital complications, or length of hospital stay.

Conclusions: For TKA, spinal and general anaesthesia with or without tourniquet did not differ in 24-h postoperative opioid consumption, pain management, blood transfusions, in-hospital complications, and length of hospital stay. Vomiting incidence was higher in the spinal than in the general anaesthesia group. Tourniquet use caused smaller decreases in haemoglobin levels.

Clinical trial registration: EudraCT 2016-002035-15.

Keywords: acute pain; analgesia; general anaesthesia; knee arthroplasty; knee replacement; opioid; spinal anaesthesia; tourniquet

Received: February 4, 2020; **Accepted:** 27 March 2020

Editor's key points

- Poorly controlled acute pain may have adverse consequences, including delayed recovery and increased chronic pain. It is important, therefore, to use perioperative regimens that provide optimal analgesia with minimal side-effects.
- Although some current recommendations advocate using spinal anaesthesia for total knee arthroplasty, this current RCT found no clear evidence of benefit compared with general anaesthesia.
- Tourniquet use did not impact on pain and was associated with less reduction in haemoglobin levels.
- Current guidelines, which may be based partly on retrospective database analyses, should reflect these new RCT findings, taking into account individual patient characteristics. Longer-term follow-up of pain and analgesic use would be of additional interest.

Severe knee osteoarthritis that is unresponsive to conservative treatment is effectively managed with total knee arthroplasty (TKA).[1] This operation is among the most common inpatient procedures in Europe and the USA.[2,3] However, pain after TKA is intense and often persists for more than 6 months.[4] One risk factor for chronic postoperative pain is the severity of acute pain after surgery.[5,6] This encourages efforts towards maximal postoperative pain treatment. Surgery increases a patient's risk for becoming a chronic opioid user, which emphasises the need for well-designed studies examining pain-reducing perioperative protocols and postoperative pain management.[7,8]

The aim of modern fast-track protocols is to reduce the length of stay and enhance ambulation and general rehabilitation without increasing complications and costs.[9–11] A systematic review published in 2016 found only one RCT that compared the effects of spinal and general anaesthesia on pain after fast-track TKA.[12] In this trial, general anaesthesia was associated with better outcomes: patients reported less pain after the sixth postoperative hour, needed considerably less opioids, and had less nausea, vomiting and dizziness, and shorter lengths of stay.[13] Current recommendations, however, favour spinal anaesthesia over general anaesthesia for TKA because of lower rates of complications. Nevertheless, these recommendations are based on registry studies, and the level of evidence is low.[14–17]

A surgical tourniquet is commonly used in TKA.[18] Its use is considered to expedite the operation, facilitate the cementing of components, provide a better visual surgical field, and reduce blood loss.[19–23] Some studies favour TKA without a tourniquet because of decreased postoperative pain, reduced length of stay, and lower rates of complications, such as thromboembolic events, and skin, soft tissue, and nerve damage.[22–26] Thus, the advantages of tourniquet use remain controversial.[27,28]

In this study, we simultaneously investigated three modalities concerning TKA. Primarily, we aimed to reproduce the findings of the previous randomised trial regarding the effects of spinal and general anaesthesia.[13] Secondly, we evaluated the role of the tourniquet on early recovery after TKA. Thirdly, we investigated whether different combinations of anaesthesia and tourniquet regimens would lead to differences in recovery. We hypothesised that spinal anaesthesia and general anaesthesia, the use and absence of a tourniquet, and the combinations of these would not differ in their effects on early recovery.

Methods

This was a single-centre, open-label, parallel, four-arm RCT. A detailed study description of this RCT has been published.[29]

Ethics and trial registration

This study is in agreement with the World Medical Association's Declaration of Helsinki. Helsinki University Hospital's Ethics Committee, Surgery (ref: HUS1703/2016; June 8, 2016) and the Finnish Medicines Agency Fimea (ref: KL72/2016; May 20, 2016) approved this study. Every patient gave written informed consent. The study was registered to EudraCT (2016-002035-15; May 12, 2016) according to the instructions of the Finnish Medicines Agency Fimea.

Participants

Patients undergoing TKA at the publicly funded Arthroplasty Centre of Helsinki University Hospital, Finland, were eligible for the study. We included consenting patients, aged 18–75 yr, with BMI $\leq$40 kg m^{-2}, ASA physical status class 1–3, severe knee osteoarthritis (Kellgren–Lawrence grade 3–4), failure of conservative treatment, and eligibility for TKA. We excluded patients with prior major surgery, severe malalignment of the target knee, or severe flexion or extension deficits. Other reasons for exclusion were contraindication to the study's medication or anaesthesia regimen, ongoing use of strong opioids, and a need for bridging anticoagulation. We excluded patients who were unable to understand written study information in Finnish or Swedish, and patients who were cognitively impaired, under guardianship, or pregnant.[29]

Randomisation and blinding

A physician not participating in the study created the numbered, sealed, and non-translucent randomisation envelopes. Each patient was randomised (allocation ratio 1:1:1:1) into one of the four parallel groups: spinal anaesthesia with tourniquet, spinal anaesthesia without tourniquet, general anaesthesia with tourniquet, and general anaesthesia without tourniquet. The envelopes were opened no more than 2 h before the surgery by nurses independent of the study. Blinding the patients or medical staff was not feasible.[29]

Perioperative care

Subjects were medicated, anaesthetised, operated on, monitored, cared for, and discharged according to a standardised protocol previously described in detail.[29]

Spinal anaesthesia was induced with 15 mg isobaric bupivacaine (Bicain spinal 5 mg ml^{-1}; Orion, Espoo, Finland), and patients were lightly sedated with propofol infusion (maximum of 4 mg kg^{-1} h^{-1}). General anaesthesia was managed with target-controlled infusions of propofol (Schnider formula, effect site target 4 μg ml^{-1} adjusted to 3–8 μg ml^{-1} to achieve GE Entropy level of 30–50; GE Healthcare Finland Oy, Helsinki, Finland) and remifentanil (Minto formula, effect site target 1 ng ml^{-1}, adjusted to 1–8 ng ml^{-1} according to heart rate and blood pressure). At the beginning of wound closure, general anaesthesia subjects received i.v. oxycodone 0.1 mg kg^{-1} (ideal body weight [IBW]). In the

tourniquet groups, the pressure level of the tourniquet was 250 mm Hg and the maximum usage time was 2 h. Every subject received i.v. tranexamic acid 1 g and ondansetron 4 mg. Surgery was performed in all cases through midline incision and medial parapatellar arthrotomy with the cemented Triathlon® Total Knee System (Stryker, Kalamazoo, MI, USA) with patella resurfacing. Local infiltration analgesia with ropivacaine (2 mg ml^{-1}, 150 ml), ketorolac (30 mg ml^{-1}, 1 ml), and epinephrine (0.1 mg ml^{-1}, 5 ml) was injected with a systematic multipuncture technique, followed by ropivacaine (2 mg ml^{-1} 50 ml) injection into the subcutaneous wound edges.

Pain management comprised paracetamol (1 g) and ibuprofen (400 mg for subjects with IBW lower than 60 kg; 600 mg for subjects with IBW greater than 60 kg; and 800 mg for subjects younger than 65 yr and IBW greater than 80 kg) administered three times daily p.o. During the first 24 postoperative hours, subjects could self-administer i.v. oxycodone (maximum of four doses of 0.04 mg kg^{-1} for IBW per hour, lock-up time 10 min) with a patient-controlled analgesia device (CADD-Legacy® PCA pump; Smiths Medical, Kent, UK). After discontinuation of patient-controlled analgesia, patients received one oral dose of extended-release oxycodone (5 mg for subjects with IBW under 50 kg, 10 mg for subjects with IBW 50–75 kg, and 15 mg for subjects with IBW greater than 75 kg), and immediate-release oxycodone was allowed on request (orally 5 mg for subjects with IBW less than 50 kg, 10 mg for subjects with IBW 50–75 kg, and 15 mg for subjects with IBW exceeding 75 kg, or if unable to digest the tablets i.m. 4 mg for subjects with IBW less than 50 kg, 8 mg for subjects with IBW 50–75 kg, and 12 mg for subjects with IBW greater than 75 kg). Oral tramadol (50 mg, one to two tablets) or a combination of paracetamol and codeine (500/30 mg, one to two tablets) commenced from the second postoperative day for a maximum of three times daily. Oral pregabalin (75–300 mg one to two times a day) was used as rescue analgesic if the above-mentioned additional immediate-release oxycodone was not sufficient. The last rescue method was peripheral insertion of regional anaesthesia. The use of rescue methods was based on the anaesthesiologists' assessments.

Outcomes

The primary outcome was the cumulative i.v. oxycodone consumption via a patient-controlled analgesia device during the first 24 postoperative hours.[13,30]

Secondary outcomes included pain and nausea in the recovery room and 24 h after operation, as assessed by subjects using a numerical rating scale (NRS; where 0 denotes no pain/nausea and 10 indicates worst imaginable pain/nausea), vomiting during the first 24 h, and the use of anti-emetics, oral oxycodone, and other analgesics, and the need for regional anaesthesia during the hospital stay. The secondary outcome measures also comprised differences in preoperative and first postoperative day haemoglobin values, need for blood transfusions, postoperative in-hospital complications (all identifiable aberrations derived from study case report forms and electronic patient records evaluated by an anaesthesiologist), and length of hospital stay (defined as the time from the end of the surgery to discharge). We also documented the time when the following discharge criteria were fulfilled: pain is under control with oral medication, patient can urinate, ambulation is safe, surgical wound effusion is minimal, patient understands the postoperative instructions on care and medication, patient is able to take care of themselves or appropriate help is available, and prescriptions for medications and all documents for benefits are given to the patient.

Statistical analyses

We calculated sample sizes (two-tailed tests, alpha 0.05, 80% power) with parametric methods to compare the mean differences between groups and expanded the results by 16% to adjust for possible non-parametric analyses, as reported in detail previously.[29] For primary outcome measures, the results reported by Harsten and colleagues[13] were used to approximate the opioid consumption of TKA patients. We defined 20% difference in opioid consumption as clinically significant. The minimum sample size for nonparametric between two-group comparisons was calculated as 104 per group. The minimum sample size for four-group nonparametric overall difference was calculated as 71 per group. For the NRS, the minimal clinically significant change was defined as 1.0.[31]

We expressed the data as means with standard deviations for normally distributed variables, medians with inter-quartile ranges for non-normally distributed variables, and frequencies with percentages for categorical variables. For normally distributed variables, we conducted comparisons between the four groups with one-way analysis of variance and Tukey's method in further pairwise comparisons. Non-normally distributed variables were analysed using the Kruskal–Wallis test and the Mann–Whitney *U*-test with Bonferroni adjustments in pairwise comparisons. Comparisons between two groups (spinal *vs* general anaesthesia and with tourniquet *vs* without tourniquet) were done with the independent samples *t*-test and the Mann–Whitney *U*-test.

We examined categorical data with the χ^2 test or Fisher's exact test for comparisons between the four groups, using Bonferroni adjustments in pairwise group comparisons, and binary logistic regression in comparisons between two groups. The results are reported as mean difference (95% confidence interval [CI]), Hodges–Lehmann estimate for median difference (95% CI), and odds ratio (95% CI).

We also conducted adjusted analyses, as prespecified in the study protocol.[29] We adjusted the comparisons between the spinal and general anaesthesia groups for the use of the tourniquet, and the comparisons between the groups with and without the tourniquet for the anaesthesia method. We performed adjusted analyses with a linear model for normally distributed variables, with a stratified Mann–Whitney *U*-test for non-normally distributed variables, and with logistic regression for categorical variables.

We did not impute for missing values because of the low number of missing values. We used SAS 9.4 (SAS Institute Inc., Cary, NC, USA) for the stratified Mann–Whitney *U*-test and IBM SPSS Statistics 25 (IBM Corp., Armonk, NY, USA) for all other analyses.

Results

Subjects, randomisation, and allocation concealment

The study period was from October 3, 2016 to December 23, 2018. We evaluated a total of 2783 knee arthroplasty patients, and 413 of these signed the informed consent form

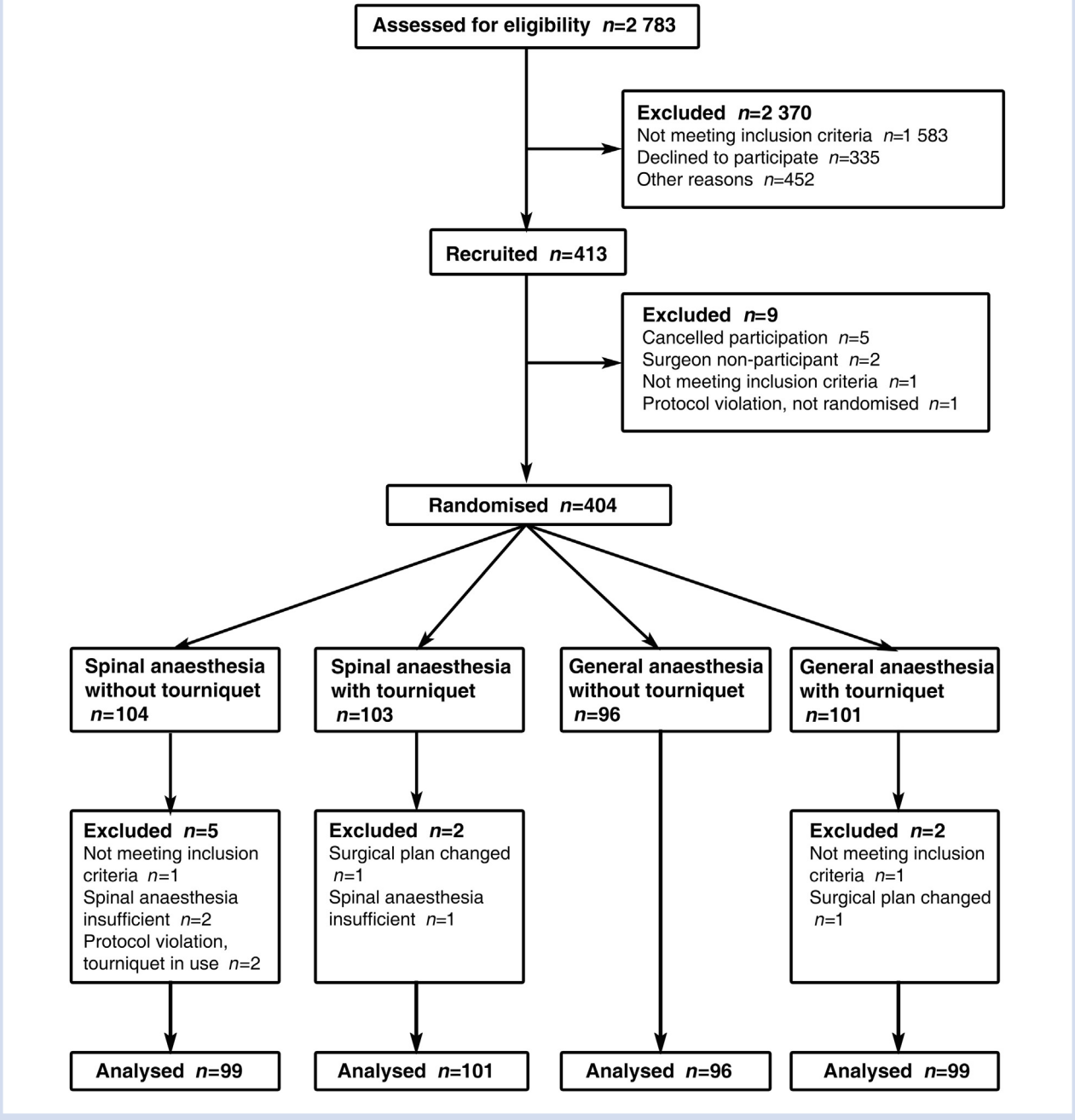

Fig 1. CONSORT flow diagram. CONSORT, Consolidated Standards of Reporting Trials.

(recruitment exclusion criteria are reported in Supplementary Table S1). The number of subjects ultimately analysed was 395 (Consolidated Standards of Reporting Trials [CONSORT] flow diagram; Fig. 1). Owing to postponed or cancelled surgeries or cancelled study participation, 15 randomisation envelopes were opened and discarded without use. Subject characteristics are presented in Table 1. The patients were treated by 15 experienced arthroplasty surgeons and 33 anaesthesiologists.

Comparisons of four groups: spinal anaesthesia with tourniquet, spinal anaesthesia without tourniquet, general anaesthesia with tourniquet, and general anaesthesia without tourniquet

The total amount of i.v. oxycodone consumption during the first 24 h, other pain management, and the pain scores 24 h after operation were not significantly different among the four

Table 1 Subject characteristics by study group. Values are number (%) unless specified otherwise. ASA, American Society of Anesthesiologists, COPD, chronic obstructive pulmonary disease; eGFR, estimated glomerular filtration rate by Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) formula; IQR, inter-quartile range; SD, standard deviation. †Data missing from two patients. ‡Data missing from one patient. Sleep apnoea patients also include those with suspected disease.

Characteristic	Spinal anaesthesia ($n = 200$)	General anaesthesia ($n = 195$)	No tourniquet ($n = 195$)	Tourniquet ($n = 200$)	Spinal anaesthesia without tourniquet ($n = 99$)	Spinal anaesthesia with tourniquet ($n = 101$)	General anaesthesia without tourniquet ($n = 96$)	General anaesthesia with tourniquet ($n = 99$)
Age, mean (SD)	64 (7)	64 (7)	64 (7)	64 (7)	63 (8)	64 (7)	65 (7)	63 (7)
Female sex	131 (66)	120 (62)	117 (60)	134 (67)	58 (59)	73 (72)	59 (61)	62 (62)
BMI, mean (SD) (kg m^{-2})	30.7 (4.5)	30.1 (4.3)	30.2 (4.3)	30.6 (4.4)	30.8 (4.4)	30.7 (4.6)	29.7 (4.2)	30.5 (4.3)
Current smoking	26 (13)	19 (10)	23 (12)	22 (11)	13 (13)	13 (13)	10 (10)	9 (9)
Alcohol use (median doses/week (IQR))	1.0 (0–3.9)	1.0 (0–4.0)†	1.0 (0–4.0)‡	1.0 (0–4.0)‡	1.5 (0–4.0)	1.0 (0–3.3)	0.5 (0–4.0)‡	1.5 (0–5.1)‡
Diabetes mellitus	30 (15)	35 (18)	27 (14)	38 (19)	14 (14)	16 (16)	13 (14)	22 (22)
Medication for hypertension	110 (55)	106 (54)	97 (50)	119 (60)	46 (46)	64 (63)	51 (53)	55 (56)
Coronary artery disease	6 (3)	9 (5)	13 (7)	2 (1)	4 (4)	2 (2)	9 (9)	0
Transient ischemic attack or stroke	6 (3)	5 (3)	6 (3)	5 (3)	3 (3)	3 (3)	3 (3)	2 (2)
Antithrombotic medication	38 (19)	43 (22)	43 (22)	38 (19)	18 (18)	20 (20)	25 (26)	18 (18)
Asthma or COPD	30 (15)	24 (12)	27 (14)	27 (14)	14 (14)	16 (16)	13 (14)	11 (11)
Sleep apnoea	18 (9)	21 (11)	15 (8)	24 (12)	8 (8)	10 (10)	7 (7)	14 (14)
eGRF, mean (SD) (ml min^{-1} 1.73 m^{-2})	85 (12)	88 (11)	86 (12)	87 (12)	85 (13)	85 (12)	87 (11)	88 ± 11
Cancer or ongoing adjuvant treatment	4 (2)	3 (2)	5 (3)	2 (1)	3 (3)	1 (1)	2 (2)	1 (1)
Depression	14 (7)	13 (7)	12 (6)	15 (8)	7 (7)	7 (7)	5 (5)	8 (8)
Reason for operation								
Primary osteoarthritis	184 (92)	185 (95)	183 (94)	186 (93)	91 (92)	93 (92)	92 (96)	93 (94)
Rheumatoid or psoriatic arthritis	9 (5)	3 (2)	6 (3)	6 (3)	4 (4)	5 (5)	2 (2)	1 (1)
Post-traumatic osteoarthritis	4 (2)	4 (2)	4 (2)	4 (2)	3 (3)	1 (1)	1 (1)	3 (3)
Other	3 (2)	3 (2)	2 (1)	4 (2)	1 (1)	2 (2)	1 (1)	2 (2)
ASA physical status								
1	18 (9.0)	18 (9.2)	16 (8.2)	20 (10.0)	8 (8.1)	10 (9.9)	8 (8.3)	10 (10.1)
2	120 (60.0)	124 (63.6)	125 (64.1)	119 (59.5)	63 (63.6)	57 (56.4)	62 (64.6)	62 (62.6)
3	62 (31.0)	53 (27.2)	54 (27.7)	61 (30.5)	28 (28.3	34 (33.7)	26 (27.1)	27 (27.3)

Table 2 Comparisons of four groups. Values present median [inter-quartile range], number of patients (%), or mean (standard deviation). Patients assessed pain by numerical rating scale (scores 0–10, where 0=no pain and 10=worst imaginable pain). *P<0.001 for the comparison with the general anaesthesia without tourniquet group and the general anaesthesia with tourniquet group. ¥P=0.043 for the comparison with the spinal anaesthesia without tourniquet group and P=0.001 for the comparison with the spinal anaesthesia with tourniquet group. †P<0.001 for the comparison with the spinal anaesthesia with tourniquet group and the general anaesthesia with tourniquet group. ‡P=0.004 for the comparison with the spinal anaesthesia with tourniquet group and P=0.002 for the comparison with the general anaesthesia with tourniquet group. PCA, patient-controlled analgesia.

Variable	n	Spinal anaesthesia without tourniquet (n = 99)	Spinal anaesthesia with tourniquet (n = 101)	General anaesthesia without tourniquet (n = 96)	General anaesthesia with tourniquet (n = 99)	P-value
I.V. oxycodone by PCA during the first 24 h (mg)	395	36.6 [24.0–55.2]	38.0 [26.0–61.6]	42.25 [27.2–63.5]	42.5 [28.6–62.5]	0.42
Oral oxycodone during hospital stay (mg)	395	30.0 [20.0–40.0]	30.0 [20.0–40.0]	30.0 [20.0–40.0]	30.0 [20.0–40.0]	0.94
Pregabalin given as rescue analgesic, no. (%)	395	12 (12.1)	15 (14.9)	8 (8.3)	10 (10.1)	0.51
Femoral nerve or adductor canal block placed, no. (%)	395	2 (2.0)	0	0	1 (1.0)	0.38
Pregabalin prescribed/ dose increased upon discharge, no. (%)	395	6 (6.1)	4 (4.0)	2 (2.1)	5 (5.1)	0.59
Strong opioid continued after hospital discharge, no. (%)	395	3 (3.0)	1 (1.0)	1 (1.0)	0	0.31
Pain in recovery room at rest	389	0 [0.0–0.0]*	0 [0.0–0.0]*	2.0 [0.0–3.0]	2.0 [0.0–3.6]	<0.001
Pain supine at rest 24 h after operation	395	3.5 (2.1)	3.7 (2.1)	3.1 (2.3)	3.1 (2.3)	0.14
Pain after flexing hip to 45° with straight knee 24 h after operation	395	5.4 (2.7)	5.9 (2.3)	5.1 (2.5)	5.1 (2.3)	0.07
Pain after flexing knee to 45° 24 h after operation	392	6.3 (2.2)	6.5 (2.1)	5.7 (2.6)	6.2 (2.2)	0.11
Pain after walking 5 m 24 h after operation	376	5.6 (2.2)	5.7 (2.0)	5.1 (2.4)	5.2 (2.3)	0.22
Nausea in recovery room, no. (%)	394	1 (1.0)	2 (2.0)	6 (6.3)	6 (6.1)	0.11
Nausea 24 h after operation, no. (%)	394	41 (41.4)	49 (48.5)	32 (33.3)	23 (23.5)¥	0.002
Patient vomited during the first 24 h, no. (%)	394	20 (20.2)	22 (21.8)	15 (15.6)	10 (10.2)	0.13
Anti-emetic given after operation, no. (%)	395	38 (38.4)	43 (42.6)	37 (38.5)	27 (27.3)	0.14
Change in haemoglobin (postoperative − preoperative, g dl^{-1})	393	−3.1 (0.86)†	−2.5 (0.77)	−2.9 (0.81)‡	−2.5 (0.79)	<0.001
Red blood cell transfusion, no. (%)	395	3 (3.0)	1 (1.0)	1 (1.0)	1 (1.0)	0.70
Time to fulfil hospital discharge criteria (h)	325	49.0 [46.0–69.0]	49.0 [47.0–69.0]	50.0 [46.0–70.0]	48.0 [45.0–69.8]	0.55
Actual hospital length of stay (h)	395	54.0 [48.0–72.0]	52.0 [50.0–72.0]	53.0 [49.0–73.0]	52.0 [48.0–72.0]	0.43

groups (Table 2). The number of patients with nausea (NRS ≥1) at the time point of 24 h after surgery was significantly higher in both spinal anaesthesia groups than in the general anaesthesia with tourniquet group (Table 2).

Decreased haemoglobin levels were more profound in the groups without tourniquet (Table 2), but the need for red blood cell transfusions did not differ between groups. The incidence of postoperative in-hospital complications (Supplementary Table S2a), time to fulfil hospital discharge criteria, and the actual length of hospital stay were not significantly different between the groups (Table 2).

Spinal *vs* general anaesthesia comparisons

The cumulative intake of i.v. oxycodone during the first 24 h, and other pain management, did not differ significantly

Table 3 Spinal *vs* general anaesthesia comparisons. Values present median [inter-quartile range] or mean (standard deviation) unless specified otherwise. CI, confidence interval; PCA, patient-controlled analgesia. Patients assessed pain by numerical rating scale (scores 0–10, where 0=no pain and 10=worst imaginable pain). *P*-values are adjusted with use of surgical tourniquet. †Hodges–Lehmann estimate for median difference. ‡Mean difference.

Variable	*n*	Spinal anaesthesia ($n = 200$)	General anaesthesia ($n = 195$)	Difference (95% CI)	Odds ratio (95% CI)	Unadjusted *P*-value	Adjusted *P*-value
I.V. oxycodone by PCA during the first 24 h (mg)	395	37.7 [25.3–57.4]	42.5 [27.6–62.5]	−3.1 (−7.4 to 1.2)†		0.15	0.14
Oral oxycodone during hospital stay (mg)	395	30.0 [20.0–40.0]	30.0 [20.0–40.0]	0.0 (0.0–5.0)†		0.58	0.58
Pregabalin given as rescue analgesic, no. (%)	395	27 (13.5)	18 (9.2)		1.53 (0.82–2.89)	0.18	0.18
Femoral nerve or adductor canal block placed, no. (%)	395	2 (1.0)	1 (0.5)		1.96 (0.18–21.8)	0.58	0.58
Pregabalin prescribed/ dose increased upon discharge, no. (%)	395	10 (5.0)	7 (3.6)		1.41 (0.53–3.8)	0.49	0.49
Strong opioid continued after hospital discharge, no. (%)	395	4 (2.0)	1 (0.5)		3.96 (0.44–35.7)	0.22	0.22
Pain in recovery room at rest	389	0.0 [0.0–0.0]	2.0 [0.0–3.0]	−2.0 (−2.5 to −2.0)†		< 0.001	<0.001
Pain supine at rest 24 h after operation	395	3.6 (2.1)	3.1 (2.3)	0.5 (0.1–0.9)‡		0.025	0.025
Pain after flexing hip to 45° with straight knee 24 h after operation	395	5.7 (2.5)	5.1 (2.4)	0.6 (0.1–1.1)‡		0.021	0.021
Pain after flexing knee to 45° 24 h after operation	392	6.4 (2.2)	6.0 (2.4)	0.4 (−0.01 to 0.9)‡		0.055	0.053
Pain after walking 5 m 24 h after operation	376	5.7 (2.1)	5.2 (2.3)	0.5 (0.02–0.9)‡		0.039	0.039
Nausea in recovery room – no. (%)	394	3 (2.5)	12 (6.2)		0.23 (0.06–0.83)	0.025	0.025
Nausea 24 h after operation – no. (%)	394	90 (45.0)	55 (28.4)		2.07 (1.36–3.14)	< 0.001	<0.001
Patient vomited during the first 24 h – no. (%)	394	42 (21.0)	25 (12.9)		1.80 (1.05–3.09)	0.034	0.034
Anti-emetic given after operation – no. (%)	395	81 (40.5)	64 (32.8)		1.39 (0.92–2.10)	0.11	0.11
Change in haemoglobin (postoperative – preoperative, (g dl^{-1})	393	−2.8 (0.86)	−2.7 (0.82)	−0.1 (−0.3 to 0.1)‡		0.30	0.29
Red blood cell transfusion, no. (%)	395	4 (2.0)	2 (1.0)		1.97 (0.36–10.9)	0.44	0.44
Time to fulfil hospital discharge criteria (h)	325	49 [46–69]	49 [45–70]	0.0 (−1.0 to 1.0)†		0.84	0.86
Actual hospital length of stay (h)	395	53 [49–72]	53 [48–72]	0.0 (−1.0 to 2.0)†		0.58	0.56

between the spinal and general anaesthesia groups (Table 3). Subjects in the spinal anaesthesia group reported less pain in the recovery room, whereas the pain scores 24 h after surgery were statistically lower in the general anaesthesia group (Table 3). The difference at 24 h, however, was below the predefined clinically significant change.

The number of subjects with nausea in the recovery room was significantly higher in the general anaesthesia group. The incidence of nausea at the time point of 24 h after surgery, in contrast, was higher in the spinal anaesthesia group, as was the incidence of vomiting within 24 h after operation (Table 3). The difference in the number of subjects receiving anti-emetics was non-significant (Table 3).

The decreases in haemoglobin levels and the need for blood transfusions did not differ between the groups (Table 3). No difference in the incidence of postoperative in-hospital complications (Supplementary Table S2b), median time for fulfilling hospital discharge criteria, and the actual length of stay (Table 3) between the two groups were detected.

Table 4 No tourniquet *vs* tourniquet comparisons. Values presented as median [inter-quartile range] or mean (standard deviation) unless specified otherwise. Patients assessed pain by a numerical rating scale (scores 0–10, where 0 = no pain and 10 = worst imaginable pain). *P*-values are adjusted with anaesthesia method. CI, confidence interval; PCA, patient-controlled analgesia. †Hodges–Lehmann estimate for median difference. ‡Mean difference.

Variable	*n*	No tourniquet ($n = 195$)	Tourniquet ($n = 200$)	Difference (95% CI)	Odds ratio (95% CI)	Unadjusted *P*-value	Adjusted *P*-value
I.V. oxycodone by PCA during the first 24 h (mg)	395	40 [26.0–57.5]	40 [27.3–62.0]	−0.8 (−5.1 to 3.5)†		0.72	0.71
Oral oxycodone during hospital stay (mg)	395	30.0 [20.0–40.0]	30.0 [20.0–40.0]	0.0 (0.0–0.0)†		0.77	0.79
Pregabalin given as rescue analgesic, no. (%)	395	20 (10.3)	25 (12.5)		0.80 (0.43–1.49)	0.48	0.48
Femoral nerve or adductor canal block placed, no. (%)	395	2 (1.0)	1 (0.5)		2.06 (0.19–22.9)	0.56	0.56
Pregabalin prescribed/ dose increased upon discharge, no. (%)	395	8 (4.1)	9 (4.5)		0.91 (0.34–2.40)	0.85	0.84
Strong opioid continued after hospital discharge, no. (%)	395	4 (2.1)	1 (0.5)		4.17 (0.46–37.6)	0.20	0.20
Pain in recovery room at rest	389	0.0 [0.0–2.0]	0.0 [0.0–2.1]	0.0 (0.0–0.0)†		0.61	0.65
Pain supine at rest 24 h after operation	395	3.3 (2.2)	3.4 (2.3)	−0.1 (−0.5 to 0.4)‡		0.78	0.78
Pain after flexing hip to 45° with straight knee 24 h after operation	395	5.3 (2.6)	5.5 (2.3)	−0.2 (−0.7 to 0.3)‡		0.36	0.36
Pain after flexing knee to 45° 24 h after operation	392	6.0 (2.4)	6.4 (2.2)	−0.3 (−0.8 to 0.1)‡		0.19	0.18
Pain after walking 5 m 24 h after operation	376	5.4 (2.3)	5.5 (2.2)	−0.1 (−0.5 to 0.4)‡		0.71	0.72
Nausea in recovery room, no. (%)	394	8 (4.0)	7 (3.6)		0.90 (0.32–2.53)	0.84	0.85
Nausea 24 h after operation, no. (%)	394	72 (36.2)	73 (37.4)		1.06 (0.70–1.59)	0.80	0.79
Patient vomited during the first 24 h, no. (%)	394	35 (17.9)	32 (16.1)		1.14 (0.67–1.93)	0.62	0.62
Anti-emetic given after operation, no. (%)	395	75 (38.5)	70 (35.5)		1.16 (0.77–1.75)	0.48	0.48
Change in haemoglobin (postoperative − preoperative, g dl^{-1})	393	−3.0 (0.84)	−2.5 (0.78)	−0.48 (−0.65 to −0.32)‡		< 0.001	<0.001
Red blood cell transfusion, no. (%)	395	4 (2.1)	2 (1.0)		2.07 (0.38–11.5)	0.40	0.40
Time to fulfil hospital discharge criteria (h)	325	50 [46–70]	49 [46–69]	1.0 (−1.0 to 2.0)†		0.28	0.28
Actual hospital length of stay (h)	395	54 [49–72]	52 [49–72]	1.0 (−1.0 to 2.0)†		0.36	0.35

Comparisons between the spinal and general anaesthesia groups, after adjusting for the use of a tourniquet, revealed similar results for the adjusted and unadjusted analyses (Table 3, Supplementary Table S2b).

Tourniquet *vs* no-tourniquet comparisons

The use of i.v. and oral pain medication, rescue analgesia or regional anaesthesia, and pain scores did not differ at any time point between the tourniquet and no-tourniquet groups. This was also the case with the use of anti-emetics and the incidence of nausea and vomiting (Table 4).

Haemoglobin decrease was more profound in the no-tourniquet group (Table 4). None of the subjects received red blood cell transfusions during the surgery, nor did the groups differ significantly in their need for postoperative red blood cell transfusions.

No differences were noted in the incidence of postoperative in-hospital complications (Supplementary Table S2c), median time for fulfilling hospital discharge criteria, or the actual length of stay.

Comparisons between the tourniquet and no-tourniquet groups after adjusting for the anaesthesia technique revealed similar results for the adjusted and unadjusted analyses (Table 4, Supplementary Table S2c).

Discussion

In this prospective, randomised study on 395 subjects undergoing TKA, we did not find a difference in opioid use during the first 24 postoperative hours, irrespective of the anaesthesia method or use of the tourniquet. Subjects had no differences in their need for oral opioids, rescue analgesics, or regional anaesthesia during the in-hospital period. At 24 h after operation, spinal anaesthesia subjects reported more pain than general anaesthesia patients, but these differences failed to meet clinical relevance (defined *a priori* as NRS difference exceeding 1.0).

The incidence of nausea in the recovery room was lower in the spinal anaesthesia group. Conversely, the incidence of vomiting and nausea 24 h after operation was lower in the general anaesthesia group. Despite these differences, the use of anti-emetics did not differ between anaesthesia groups. The use of a tourniquet was associated with a lower decrease in haemoglobin level, but the need for blood transfusions remained unaffected. The incidence of in-hospital complications and the length of hospital stay did not differ significantly in any of the comparisons. Comparison of the four groups showed no superiority of one anaesthesia and tourniquet combination over the other.

The strengths of this study include its large sample size and prospective randomised design. The drop-out rate after recruitment, at 4.4%, was minimal for a large-scale clinical trial.[32] We used wide-range inclusion criteria to accommodate as many patients as possible. Our study comprised multiple doctors, a large staff, had a modern fast-track protocol with multimodal pain management and early mobilisation, and it is up to date. Thus, we consider the results repeatable and generalisable, with some limitations, taking into account our study's inclusion criteria.

Our study has some limitations. Neither subjects nor personnel were blinded, as the patient was clearly under general or regional anaesthesia and the wound obviously bled or did not bleed during surgery. After surgery, personnel were instructed not to discuss the anaesthesia method used or the use of a tourniquet with patients. Nevertheless, subjects might have exchanged their opinions with each other, which could have affected patient-reported outcomes. The recruitment rate of 15% reflects the recruitment difficulties previously described for publicly funded trials.[32] Of all evaluated patients, 57% did not fulfil the recruitment criteria (21% of patients older than 75 yr), 16% were not recruited because of organisational reasons (e.g. study personnel not available), and 12% refused to participate in the study. Nevertheless, the characteristics of our study population are in line with average TKA patients in the Finnish Arthroplasty Register.[33] Furthermore, our study was underpowered for detection of possible differences in the incidence of rare complications, such as intensive care admission or mortality (both with a prevalence of 1:1000[14]). The randomised regimens, however, are all in routine clinical use and have acceptable risk profiles.

Our study had more than three times the number of participants compared with the previous randomised trial of 120 patients investigating differences between spinal and general anaesthesia in TKA.[13] We could not verify the advantages (e.g. opioid-sparing effect) of general anaesthesia, as reported by this other trial.[13] One reason for this difference between the results could be that the increased sample size decreased the CI and margin of error.

Vomiting has a profound effect on patient experience. It may delay discharge from the recovery room or hospital and increase the risk for re-admission.[34] Our results are in line with the other randomised trial concerning the higher incidence of nausea and vomiting in the spinal anaesthesia group on the first postoperative day.[13] This brings into question whether the current guideline recommendation to use regional anaesthesia to decrease the risk of postoperative nausea and vomiting is applicable to TKA patients.[35] Further studies investigating the effect of general *vs* spinal anaesthesia on postoperative nausea and vomiting are warranted.

Our study has some discrepancies with the results from previous database studies and systematic reviews. For example, previous studies suggested faster recovery and lower blood transfusion rates in spinal anaesthesia patients.[14,36] This discrepancy may reflect the smaller size of our study, but one cannot dismiss the considerable methodological problems associated with retrospective database studies. The lack of randomisation is the most obvious of these problems. A lack of information about the reasons why a certain regimen was chosen for each case is a major confounding factor. Furthermore, some studies were done before or during the implementation of modern treatment protocols and may thus be, at least partially, outdated. The conclusions of the database studies, however, have been used as the basis of suggested enhanced recovery protocols and consensus guidelines, even though the quality of the evidence is low.[14,16,17]

The use of a tourniquet had no effect on reported pain or the need for analgesia at any point, nor did it appear to have an effect on nausea and vomiting. Comparison between patients operated on with a tourniquet and without a tourniquet revealed that tourniquet use resulted in a more profound decrease in haemoglobin loss, as reported in a recent randomised trial conducted by Goel and colleagues[21] and in a systematic meta-analysis by Alcelik and colleagues[22] Nevertheless, the need for blood transfusions showed no differences, which is consistent with the results of other studies.[23,37] Previous data also suggested that a tourniquet could increase pain, soft tissue damage, muscle and nerve damage, skin problems, and length of stay.[22,23] In our study, the tourniquet and no-tourniquet groups did not differ in terms of pain, opioid consumption, tourniquet-related soft-tissue complications, falling, and length of stay.

Despite the implementation and development of fast-track protocols, such as multimodal analgesia, the acute and chronic postoperative pain occurring after TKA remains a problem. Postoperative pain results in increases in opioid consumption, length of stay, patient dissatisfaction, costs, and burden on the healthcare system and thus negatively affects the outcomes of TKA.[38–40] The vast number of these operations performed worldwide annually emphasises the importance of knowing whether one regimen has significant advantages over the other. This study is, so far, the largest RCT comparing the effects of spinal and general anaesthesia and tourniquet use in TKA. Our results concerning early recovery after TKA indicate that spinal and general anaesthesia, either with or without a tourniquet, are both acceptable methods.

Authors' contributions

Planning: AV, NS, MR, RP, ER, RL, KTO, RM, TV
Ethics approval: NS, AV
Registration: NS, RP
Funding KTO, NS, AV

Patient recruitment: RP, NS, MR, ER, KL
Patient care and evaluation: RP, NS, MR, RL, KL, Arja Mäkelä (research nurse)
Data collection: NS, RP, Arja Mäkelä, KL, MR
Data analysis: RP, TV, NS, MR
Data interpretation: RP, MR, NS, TV, RM, AV, KTO, ER, RL
Writing and editing: all authors

Acknowledgements

We thank Arja Mäkelä, our research nurse, for her invaluable contribution to this work. We thank Tatu Mäkinen, Eero Pesonen, and Vesa Kontinen for their kind advice related to the original study design. We also thank Pekka Kairaluoma, Eliisa Nissilä, all the surgeons and anaesthesiologists who participated, other healthcare staff in Helsinki University Peijas Hospital, and all the patients involved who made this study possible.

Declarations of Interest

The authors declare that they have no conflicts of interest.

Funding

HUS Helsinki University Hospital Grant (Y102011095) and HUS Helsinki University Hospital Finnish Government Science Grants (TYH2017239; TYH 2019113).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.03.036.

References

1. Jenkins PJ, Clement ND, Hamilton DF, Gaston P, Patton JT, Howie CR. Predicting the cost-effectiveness of total hip and knee replacement: a health economic analysis. *Bone Jt J* 2013; **95-b**: 115–21
2. Williams SN, Wolford ML, Bercovitz A. Hospitalization for total knee replacement among inpatients aged 45 and over: United States, 2000–2010. *NCHS Data Brief* 2015: 1–8
3. OECD. *Knee replacement surgery, 2014 (or nearest year). Access to Care*. Paris: OECD Publishing; 2016
4. Rice DA, Kluger MT, McNair PJ, et al. Persistent postoperative pain after total knee arthroplasty: a prospective cohort study of potential risk factors. *Br J Anaesth* 2018; **121**: 804–12
5. Fletcher D, Stamer UM, Pogatzki-Zahn E, et al. Chronic postsurgical pain in Europe: an observational study. *Eur J Anaesthesiol* 2015; **32**: 725–34
6. Puolakka PA, Rorarius MG, Roviola M, Puolakka TJ, Nordhausen K, Lindgren L. Persistent pain following knee arthroplasty. *Eur J Anaesthesiol* 2010; **27**: 455–60
7. Goesling J, Moser SE, Zaidi B, et al. Trends and predictors of opioid use after total knee and total hip arthroplasty. *Pain* 2016; **157**: 1259–65
8. Sun EC, Darnall BD, Baker LC, Mackey S. Incidence of and risk factors for chronic opioid use among opioid-naive patients in the postoperative period. *JAMA Intern Med* 2016; **176**: 1286–93
9. Kehlet H, Thienpont E. Fast-track knee arthroplasty — status and future challenges. *Knee* 2013; **20**: S29–33
10. Sutton 3rd JC, Antoniou J, Epure LM, Huk OL, Zukor DJ, Bergeron SG. Hospital discharge within 2 days following total hip or knee arthroplasty does not increase major-complication and readmission rates. *J Bone Jt Surg Am* 2016; **98**: 1419–28
11. Kehlet H. Fast-track hip and knee arthroplasty. *Lancet* 2013; **381**: 1600–2
12. Johnson RL, Kopp SL, Burkle CM, et al. Neuraxial vs general anaesthesia for total hip and total knee arthroplasty: a systematic review of comparative-effectiveness research. *Br J Anaesth* 2016; **116**: 163–76
13. Harsten A, Kehlet H, Toksvig-Larsen S. Recovery after total intravenous general anaesthesia or spinal anaesthesia for total knee arthroplasty: a randomized trial. *Br J Anaesth* 2013; **111**: 391–9
14. Memtsoudis SG, Cozowicz C, Bekeris J, et al. Anaesthetic care of patients undergoing primary hip and knee arthroplasty: consensus recommendations from the International Consensus on Anaesthesia-Related Outcomes after Surgery group (ICAROS) based on a systematic review and meta-analysis. *Br J Anaesth* 2019; **123**: 269–87
15. Weinstein SM, Baaklini LR, Liu J, et al. Neuraxial anaesthesia techniques and postoperative outcomes among joint arthroplasty patients: is spinal anaesthesia the best option? *Br J Anaesth* 2018; **121**: 842–9
16. Auyong DB, Allen CJ, Pahang JA, Clabeaux JJ, MacDonald KM, Hanson NA. Reduced length of hospitalization in primary total knee arthroplasty patients using an updated enhanced recovery after orthopedic surgery (ERAS) pathway. *J Arthroplasty* 2015; **30**: 1705–9
17. Soffin EM, YaDeau JT. Enhanced recovery after surgery for primary hip and knee arthroplasty: a review of the evidence. *Br J Anaesth* 2016; **117**: iii62–72
18. Berry DJ, Bozic KJ. Current practice patterns in primary hip and knee arthroplasty among members of the American Association of Hip and Knee Surgeons. *J Arthroplasty* 2010; **25**: 2–4
19. Juliusson R, Arve J, Ryd L. Cementation pressure in arthroplasty. In vitro study of cement penetration into femoral heads. *Acta Orthop Scand* 1994; **65**: 131–4
20. Tai TW, Chang CW, Lai KA, Lin CJ, Yang CY. Effects of tourniquet use on blood loss and soft-tissue damage in total knee arthroplasty: a randomized controlled trial. *J Bone Jt Surg Am* 2012; **94**: 2209–15
21. Goel R, Rondon AJ, Sydnor K, et al. Tourniquet use does not affect functional outcomes or pain after total knee arthroplasty: a prospective, double-blinded, randomized controlled trial. *J Bone Jt Surg Am* 2019; **101**: 1821–8
22. Alcelik I, Pollock RD, Sukeik M, Bettany-Saltikov J, Armstrong PM, Fismer P. A comparison of outcomes with and without a tourniquet in total knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials. *J Arthroplasty* 2012; **27**: 331–40
23. Ejaz A, Laursen AC, Kappel A, et al. Faster recovery without the use of a tourniquet in total knee arthroplasty. *Acta Orthop* 2014; **85**: 422–6
24. Chen S, Li J, Peng H, Zhou J, Fang H, Zheng H. The influence of a half-course tourniquet strategy on perioperative blood loss and early functional recovery in primary total knee arthroplasty. *Int Orthop* 2014; **38**: 355–9
25. Zhang W, Li N, Chen S, Tan Y, Al-Aidaros M, Chen L. The effects of a tourniquet used in total knee arthroplasty: a meta-analysis. *J Orthop Surg Res* 2014; **9**: 13
26. Olivecrona C, Ponzer S, Hamberg P, Blomfeldt R. Lower tourniquet cuff pressure reduces postoperative wound

complications after total knee arthroplasty: a randomized controlled study of 164 patients. *J Bone Jt Surg Am* 2012; **94**: 2216–21

27. McCarthy Deering E, Hu SY, Abdulkarim A. Does tourniquet use in TKA increase postoperative pain? A systematic review and meta-analysis. *Clin Orthop Relat Res* 2019; **477**: 547–58
28. Ledin H, Aspenberg P, Good L. Tourniquet use in total knee replacement does not improve fixation, but appears to reduce final range of motion. *Acta Orthop* 2012; **83**: 499–503
29. Rantasalo MT, Palanne R, Juutilainen K, et al. Randomised controlled study comparing general and spinal anaesthesia with and without a tourniquet on the outcomes of total knee arthroplasty: study protocol. *BMJ Open* 2018; **8**, e025546
30. Gilron I, Kehlet H, Pogatzki-Zahn E. Current status and future directions of pain-related outcome measures for post-surgical pain trials. *Can J Pain* 2019; **3**: 36–43
31. Olsen MF, Bjerre E, Hansen MD, et al. Pain relief that matters to patients: systematic review of empirical studies assessing the minimum clinically important difference in acute pain. *BMC Med* 2017; **15**: 35
32. Walters SJ, Bonacho Dos Anjos Henriques-Cadby I, Bortolami O, et al. Recruitment and retention of participants in randomised controlled trials: a review of trials funded and published by the United Kingdom Health Technology Assessment Programme. *BMJ Open* 2017; **7**, e015276
33. National Institute of Health and Welfare. Finnish arthroplasty register. Knee arthroplasty. Available from: https://www.thl.fi/far/(accessed 28 Feb 2020).
34. Hill RP, Lubarsky DA, Phillips-Bute B, et al. Cost-effectiveness of prophylactic antiemetic therapy with ondansetron, droperidol, or placebo. *Anesthesiology* 2000; **92**: 958–67
35. Gan TJ, Diemunsch P, Habib AS, et al. Consensus guidelines for the management of postoperative nausea and vomiting. *Anesth Analg* 2014; **118**: 85–113
36. Guay J, Choi P, Suresh S, Albert N, Kopp S, Pace NL. Neuraxial blockade for the prevention of postoperative mortality and major morbidity: an overview of Cochrane systematic reviews. *Cochrane Database Syst Rev* 2014, CD010108
37. Schnettler T, Papillon N, Rees H. Use of a tourniquet in total knee arthroplasty causes a paradoxical increase in total blood loss. *J Bone Jt Surg Am* 2017; **99**: 1331–6
38. Beswick AD, Wylde V, Gooberman-Hill R, Blom A, Dieppe P. What proportion of patients report long-term pain after total hip or knee replacement for osteoarthritis? A systematic review of prospective studies in unselected patients. *BMJ Open* 2012; **2**, e000435
39. Gunaratne R, Pratt DN, Banda J, Fick DP, Khan RJK, Robertson BW. Patient dissatisfaction following total knee arthroplasty: a systematic review of the literature. *J Arthroplasty* 2017; **32**: 3854–60
40. Sadoghi P, Liebensteiner M, Agreiter M, Leithner A, Bohler N, Labek G. Revision surgery after total joint arthroplasty: a complication-based analysis using worldwide arthroplasty registers. *J Arthroplasty* 2013; **28**: 1329–32

Handling editor: Lesley Colvin