

The optimized tourniquet versus no tourniquet in total knee arthroplasty. Analysis of muscle injury, functional recovery, and knee strength

Douglas Mello Pavão^{a,b,*}, Eduardo Branco de Sousa^a, Fabricio Fogagnolo^b, José Leonardo Rocha de Faria^{a,b}, Victor Elias Titonelli^a, Ubiratã Faleiro Gavilão^a, Conrado Torres Laett^a, Victor Rodrigues Amaral Cosich^a

^a Knee Surgery Center of the National Institute of Traumatology and Orthopedics (INTO), Rio de Janeiro, Brazil

^b University of São Paulo –Ribeirão Preto Medicine School, Brazil

ARTICLE INFO

Keywords:

Clinical outcomes
Knee function
Quadriceps strength
Total knee replacement
Tourniquet

ABSTRACT

Background: Tourniquet is widely used in total knee replacement surgery because it reduces intraoperative hemorrhage and provides a comfortable surgical area for the surgeon. It's possible that its use could lead to impaired postoperative functional and motor recovery, as well as local and systemic complications. Our goal was to compare the outcomes of total knee replacement without ischemia using an optimized protocol, consisting of tourniquet inflation before skin incision and deflation after cementing, with a pressure of one hundred millimeters above systolic blood pressure and without postoperative articular suction drains. We believed that tourniquet effectively would result in no additional muscle damage and no functional or knee strength impairment compared to no tourniquet.

Methods: In a prospective and randomized study, 60 patients with osteoarthritis were evaluated for total knee replacement, divided in two groups: 'without tourniquet' and 'optimized tourniquet'. Outcomes were mean creatine phosphokinase levels, Knee Society Score and knee isokinetic strength. Data were considered significant when $p < 0.05$.

Results: Creatine phosphokinase levels and functional score were similar between groups. There were no differences between groups regarding knee extension strength on the operated limbs, although the knee flexors' peak torque in the operated limb in the optimized tourniquet group was significantly higher at 6 months relative to preoperative and 3 months assessments.

Conclusions: The optimized tourniquet protocol use in total knee replacement combines the benefits of tourniquet use without compromising functional recovery and without additional muscle damage and strength deficits compared to surgery without its use.

1. Introduction

Tourniquet (TNQ) has been widely used during total knee replacement (TKR) surgeries, with more than ninety percent of orthopedic surgeons reporting its use on their patients.^{1,2}

While TNQ use can improve visibility and comfort for the surgeon,^{2–4} there are some adverse effects linked to tissue ischemia that may be considered.⁵ Ischemia caused by TNQ changes the normal tissue physiology, not just locally due to mechanical compression, but also in distal tissues which may be injured by metabolites released during the ischemia and reperfusion period.⁶ This may compromise joint mobility and muscle strength recovery.^{2,3,7,8}

The mean time of TNQ use varies widely between studies, as the moment of use,^{8–14} and the inflation pressures.^{3,8,9,14–16} This variability is an important analytical confounding concern when studying this topic.¹⁷

Our goal was to assess muscle damage, functional outcomes and knee strength after TKR using the optimized TNQ¹⁷ relative to non-use. We believed that TNQ use would effectively result in no additional muscle damage and no functional or knee strength impairment compared to no TNQ.

* Corresponding author. Knee Surgery Center – INTO, Av. Brasil, 500 - Caju, Rio de Janeiro, RJ, CEP: 20940-070, Brazil.

E-mail address: ortoespecializada2018@gmail.com (D.M. Pavão).

<https://doi.org/10.1016/j.jor.2023.11.037>

Received 11 September 2023; Accepted 14 November 2023

Available online 17 November 2023

0972-978X/© 2023 Published by Elsevier B.V. on behalf of Professor P K Surendran Memorial Education Foundation.

2. Materials and methods

2.1. Subjects

Patients of both genders were selected from our institution’s knee surgery care center between August 1st, 2020, and December 1st, 2021. Patients aged 55–85 years old, Kellgren and Lawrence ≥ III knee osteoarthritis (OA) and selected for a primary cemented TKR were included in the study. Patients with contraindications for tranexamic acid or with coagulopathies, or who were regularly using oral anticoagulants were excluded. The study was approved by the Institutional Ethics Board (#21118319.7.0000.5273) and registered on [ClinicalTrials.gov](#) (#RBR-9x99fg8).

We used the optimized TNQ protocol, proposed by Pavão et al. (2022),¹⁷ in which TNQ is inflated before skin incision and deflated after cementing, maintaining a 100 mmHg pressure above systolic blood pressure and without postoperative articular suction drains. Theoretically, the optimized TNQ protocol decreases ischemia duration and local tissue damage, which in turn reduces postoperative ischemia-reperfusion response and consequently reduces the negative effects related to its use.^{12–14,18}

2.2. Experimental protocol

This was a prospective and randomized clinical trial. Participants were recruited during normal outpatient care by the same surgeon, and randomly assigned in two groups, “without tourniquet” or “optimized tourniquet” group before the anesthetic procedure. The main surgeon drew an envelope out of four – the total of surgeries running per day – to allocate the patient.

Using the same institutional protocol, four surgeons with 5–10 years of experience performed all surgeries. The patients and researchers involved in the muscle strength evaluation and statistical processing were blinded about the group’s allocation during the study’s data acquisition.

Sample size was determined as 30 patients per group to determine significant differences with a power of 80 %. Fig. 1 presents a flow diagram of patients accessed for eligibility, randomization, allocation into groups, and analysis.

2.3. Surgical procedure and rehabilitation process

All patients had TKR through medial parapatellar approach with the

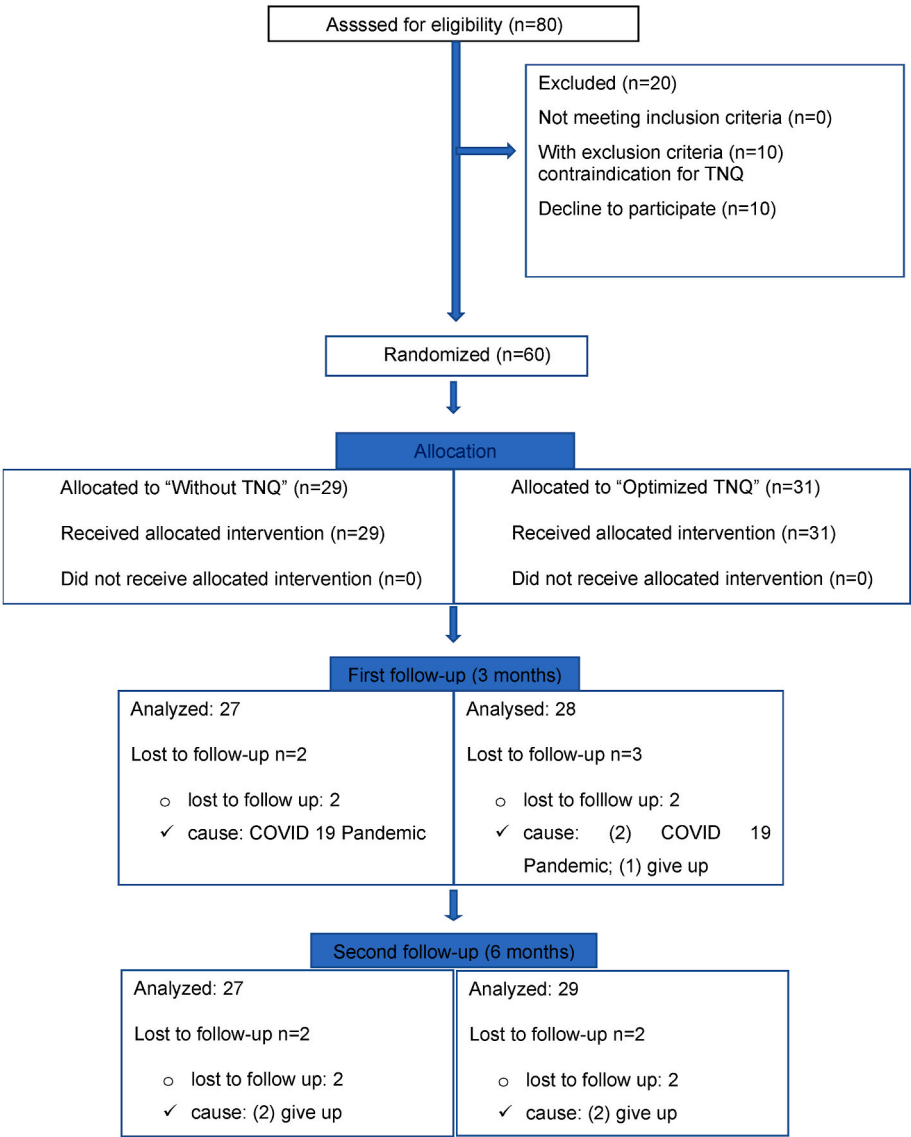


Fig. 1. Patient assessment flowchart for eligibility and group allocation. TKA = total knee arthroplasty; TNQ = tourniquet. CONSORT (Consolidated standard of reporting trials) diagram.

same cemented posterior stabilized prostheses (Legion Total Knee System®, Smith and Nephew®, Memphis, Tennessee), without patella resurfacing.

The anesthetic protocol was the same for all patients, consisting of spinal, femoral, and sciatic nerve block. In the group without TNQ, joint replacements were carried out without ischemia, although a cuff was attached to the proximal thigh. In contrast, in the optimized TNQ group, joint replacements were performed under ischemia by a standard 10 × 110 cm pneumatic cuff (Striker®, Color Cuff Dual Port cuff Kalamazoo Michigan). The cuff was inflated with continuous pressure of 100 mmHg above the patient's systolic blood pressure (measured immediately before spinal anesthesia), after limb exsanguination with a crepe bandage, just before the skin incision. The cuff was deflated shortly after the prosthesis's fixation cement had dried. All patients received 1g intravenous tranexamic acid (TXA - Transamin®, Zydus Nikkho Farmacéutica Ltd São Paulo, São Paulo) before anesthetic induction and 750 mg topic TXA, diluted in 15 mL saline solution soon after cement drying in both groups. After 5 min of TXA action, hemostasis was carried out by coagulating the bleeding vessels with electrocautery. We do not use joint aspiration drains. Prophylaxis for deep vein thrombosis started 12 h after the procedure with 40 mg subcutaneous enoxaparin (Clexane®, Sanofi-Aventis Farmacêutica Ltd Sao Paulo, Sao Paulo) for 14 days. Postoperative analgesia with analgesics and weak opioids was used for seven days; patients followed the same rehabilitation guidelines as outlined in a standard institute workbook immediately after surgery and were referred to physiotherapy for assessment three weeks after surgery. Ischemia time (elapsed time between the cuff inflation and total deflation) and cuff pressure were collected.

2.4. Serum creatine phosphokinase analysis

Serum creatine phosphokinase (CPK) levels, a good marker of muscle injury,¹³ were evaluated over time in 5 mL blood samples collected from the antecubital veins preoperatively, one and three days after surgery.

2.5. Knee functional score analysis

Knee Society Score (KSS),¹⁹ was used for clinical assessment regarding pain intensity, range of motion, stability in the anteroposterior and mediolateral plane, presence of flexion deformities, contractures, poor alignment, in addition to the ability to walk, ascend and descend stairs, with or without assistance.

2.6. Muscle strength analysis

Knee muscle strength was assessed using an isokinetic dynamometer (HUMAC NORM II, CSMI, Stoughton Massachusetts). The participants were positioned seated with hips flexed ~90° with trunk and thighs stabilized with non-elastic straps, and the knee joint was aligned with the device axis of rotation. Participants performed a warm-up/familiarization set comprising five progressive intensity repetitions (20, 40, 60, 80, and 100 % of subjective effort), followed by five maximum exertions at 60°/s to obtain the knee extensors and flexors' peak torque. The highest instantaneous torque observed was recorded as the peak torque value.

2.7. Statistical analysis

Numerical data were presented as mean ± standard deviation and categorical data as percentages. Data distribution was tested with the Henze-Zirkler multivariate normality test. Only the KSS function score was considered normal (p > 0.05). The Friedman ANOVA and the Wilcoxon post-hoc test were used to compare the non-normal variables for pairwise comparison at different moments (operating and contralateral limbs were analyzed).

Comparisons between groups were performed using the Mann-

Whitney test. Otherwise, a mixed two-way ANOVA was used (group x moment) followed by the Bonferroni post-hoc. All the procedures were performed using the package Pingouin version 0.5.1 developed for Python version 3 Berkeley, California.

3. Results

Optimized and without groups had similar essential characteristics, such as gender, age, weight, height, and body mass index. (Table 1).

The ischemia time was 74.02 ± 17.77 min and the pressure used 228.0 ± 19.92 mmHg. The mean time of surgery without a TNQ was 108.2 ± 26.11 and with a TNQ 106.6 ± 23.83 (p > 0.05).

Clinical outcomes of patients undergoing total knee replacement according as CPK levels and peak force analysis are expressed in Table 2.

Mean serum CPK levels were statistically different over time, in both groups, without differences (p > 0,05) between groups at any time.

Both groups improved KSS knee domain comparingpreoperative and postoperative values at three and six months. Both groups consistently improved the KSS function domain across moments without differences between groups.

Regarding peak torque of knee extensors, a significant difference over time was found only in the non-operated limb in the optimized tourniquet group, which was significantly higher at 3 and 6 months compared to the preoperative period. A significant difference in the peak

Table 1
Characteristics of the patients included in the study.

Characteristics	Optimized Tourniquet (mean [range])	Without Tourniquet (mean [range])	P value
Mean age in years	69 (62.4–75.6)	67 (60.6–73.4)	0.07
Mean weight in kg	82.5 (62.9–102.1)	81.2 (65.5–96.9)	0.78
Mean height in m	160.6 (151.1–170.1)	159.5 (150.6–168.4)	0.66
Mean surgery time in min	106 (72–220)	109 (61–170)	0.60
Mean tourniquet time in min	76 (40–127)	NA	NA
Mean tourniquet pressure in mmHg	237 (200–300)	NA	NA

kg = kilograms; m = meters; L = liters; min = minutes; mmHg = millimeters of mercury; NA = not applicable.

Table 2
Clinical outcomes of patients undergoing total knee replacement according to group.

	Time points	Optimized tourniquet	Without Tourniquet	P-value
CPK (U/L)	Preop	208.7 ± 29.3	187.7 ± 11.3	0.33
	POD 1	256.1 ± 20.1	244.0 ± 12.7	0.76
	POD 3	244.0 ± 26.5	186.8 ± 74.4	1.00
KSS Knee	Preop	46.5 ± 15.7	47.8 ± 15.7	0.97
	3 Mo	74.1 ± 17.8	80.7 ± 15.8	0.14
	6 Mo	87.7 ± 14.5	86.1 ± 12.0	0.80
KSS Function	Preop	35.2 ± 15.2	39.9 ± 18.8	0.13
	3 Mo	45.0 ± 19.5	51.6 ± 23.4	0.13
	6 Mo	50.8 ± 22.8	61.2 ± 24.4	0.13
Extension Peak Torque: Operated member	Preop	50.2 ± 30.8	53.5 ± 35.4	0.82
	3 Mo	52.2 ± 32.5	51.2 ± 26.8	0.99
	6 Mo	63.6 ± 32.4	59.1 ± 27.3	0.80
Extension peak torque: contralateral limb	Preop	58.7 ± 32.3	62.2 ± 32.2	0.47
	3 Mo	68.4 ± 32.0	69.7 ± 26.3	0.53
	6 Mo	73.8 ± 34.4	71.6 ± 27.0	0.50
Flexion peak torque: operated limb	Preop	27.9 ± 24.9	21.7 ± 19.2	0.91
	3 Mo	30.1 ± 14.6	23.9 ± 18.1	0.17
	6 Mo	31.6 ± 17.6	33.1 ± 2.3	0.35
Flexion peak torque: contralateral limb	Preop	31.9 ± 20.0	32.0 ± 23.2	0.87
	3 Mo	35.8 ± 20.3	36.4 ± 19.3	0.70
	6 Mo	38.9 ± 22.4	39.0 ± 22.5	0.99

CPK: creatine phosphokinase; KSS: Knee Society Score; Preop = preoperative; POD 1 = postoperative day 1; POD 3 = postoperative day 3; Mo = month.

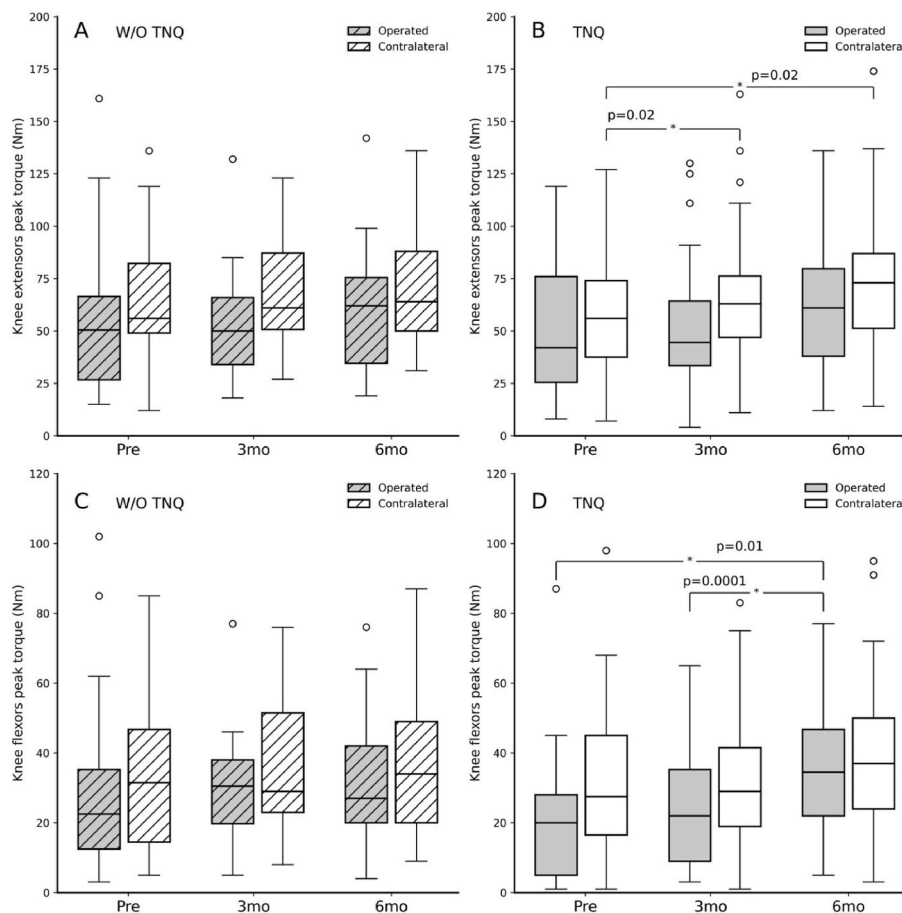


Fig. 2. Knee extensors and flexors peak torques in preoperative and three and six months postoperatively. The graphs show the distribution of peak torques of the knee extensors (A and B) and flexors (C and D) in the operated and contralateral limb in the groups without and with TNQ use over time. W/O TNQ = without optimized tourniquet group. TNQ = optimized tourniquet group. (A) knee extensors peak torque W/O TNQ. Within-group across moment (operated limb $p = 0.25$, contralateral limb $p = 0.10$). (B) knee extensors peak torque TNQ. Within-group across moment (operated limb: $p = 0.08$, contralateral limb: $p = 0.01$). (C) knee flexors peak torque W/O TNQ. Within-group across moment (operated limb: $p = 0.11$, contralateral limb: $p = 0.15$). (D) knee flexors peak torque TNQ. Within-group across moment (operated limb: $p = 0.003$, contralateral limb: $p = 0.73$). *Significant different pairwise comparisons within group. No other significant difference between groups was observed for knee extensors and flexors peak torques.

torque of knee flexors was observed over time only in the operated limb in the TNQ group, which was significantly higher at 6 months compared to preoperative assessments and 3 months. No other comparisons (Fig. 2) were considered significant ($p > 0.05$).

4. Discussion

The optimized TNQ protocol allowed the surgeon to perform TKR without intraoperative bleeding, without any degree of additional muscle damage and any functional or muscle strength impairment, supporting our initial hypothesis.

In the present study, the mean serum CPK levels were similar in both groups, thus corroborating the idea that the tissue damage caused by the TNQ, especially when minimized by means of using low pressures and for a short period, adds little to the tissue damage caused by the arthroplasty procedure itself.¹⁵

Tai et al. (2012)¹³ observed a lower inflammatory response and a lower degree of muscle tissue injury in surgeries using the TNQ relative to its non-use, based on the measurements of C- Reactive Protein (a marker of inflammatory response) and CPK. Tsunoda et al. (2017)¹⁵ found no significant differences between the groups regarding body temperature, C- reactive protein, interleukin 6 and CPK levels.

Contrary to the previous studies, Huang et al. (2017)¹⁰ found CPK levels significantly higher in the TNQ group. We believe that these CPK levels could have been lower if the TNQ had been used for a shorter time.

However, it was used until the wound was closed.

Goel et al. (2019)¹² found no differences in their groups regarding the Knee Injury and Osteoarthritis Outcome Score and 12-item Short Form Survey (SF-12) functional scores and in the “Timed Up & Go” and “stairs-climbing” tests. Jawhar et al. (2020)²⁰ found no differences regarding the functional scores “Oxford knee score”, “WOMAC score”, “Mancuso score”, “EQ-5D index”, “EQ-VAS” in pre-and postoperative follow-up (6 weeks and 6 months). Ayik et al. (2020)¹⁶ also evidenced no differences between their groups regarding the KSS functional domain. As in those recent studies, we also did not observe differences in the functional score between our groups.

Liu et al. (2014)⁹ analyzed the effect of TNQ on quadriceps motor function in TKR using surface electromyography during active knee extension. Motor function was compromised in the TNQ group for six months compared to the control group. They mentioned that an individualized strategy of TNQ use would be necessary, optimizing its use by decreasing ischemia time and TNQ pressure.

Ayik et al. (2020)¹⁶ prospectively evaluated 65 patients undergoing TKR with and without TNQ use and found no differences in pre-and postoperative (1 and 3 months) levels of isokinetic muscle strength between groups (extension and flexion torque peaks; $p < 0.05$). Likewise, Jawhar et al. (2020)²⁰ evaluated 100 patients and they also found no differences between their groups in the pre-and postoperative extension and flexion strength (6 weeks and 6 months).

We did not observe deficits in extension strength with TNQ relative

to surgery without its use, with superiority in the peak flexion torques in the operated limb, corroborating the idea that the optimized TNQ use does not compromise the knee muscle contraction capacity, similarly to the publications previously mentioned.

Unfortunately, we lost the follow-up of some patients due to the limitations imposed by the COVID-19 pandemic and we also had some dropouts. In addition, the relatively short period of postoperative follow-up may be considered a limitation of the study. However, we believe that it would not be necessary to maintain it after the sixth month, since the possible deleterious effects of TNQ on muscle function and peak forces only occur in the first weeks.

On the other hand, we highlight our strengths: this was a prospective and randomized study with objective functional analysis through isokinetic muscle function evaluation with relevant clinical implications in our practice, considering that adequate visualization of the surgical field not only gives comfort to the attending surgeon but may also facilitate anatomical references identification in difficult cases.

5. Conclusions

The optimized TNQ use in TKR combines the benefits of using the TNQ without compromising functional recovery and without additional muscle damage and strength deficits compared to surgery without its use.

Funding/sponsorship

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Informed consent (patient/guardian)

Informed consent was obtained from all individual participants included in the study.

Institutional ethical committee approval

This trial was approved by the ethical standards of Ethics Committee (Institutional Ethics Board #21118319.7.0000.5273) in accordance with the 1964 Helsinki Declaration and its later amendments and was registered on [ClinicalTrials.gov](https://clinicaltrials.gov) (#RBR-9x99fg8).

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by Douglas Pavão and all authors commented on previous versions of the manuscript.

Consent to publish

All authors have read and approved to publish the final manuscript.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgments

None.

References

- 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(6 Suppl):2–4. <https://doi.org/10.1016/j.arth.2010.04.033>.
- Hasanain MS, Apostu D, Alrefae A, Tarabichi S. Comparing the effect of tourniquet vs tourniquet-less in simultaneous bilateral total knee arthroplasties. *J Arthroplasty*. 2018;33(7):2119–2124. <https://doi.org/10.1016/j.arth.2018.02.013>.
- Zhou K, Ling T, Wang H, et al. Influence of tourniquet use in primary total knee arthroplasty with drainage: a prospective randomised controlled trial. *J Orthop Surg Res*. 2017;12(1):172. <https://doi.org/10.1186/s13018-017-0683-z>. Published 2017 Nov 14.
- Mayer C, Franz A, Harmsen JF, et al. Soft-tissue damage during total knee arthroplasty: focus on tourniquet-induced metabolic and ionic muscle impairment. *J Orthop*. 2017;14(3):347–353. <https://doi.org/10.1016/j.jor.2017.06.015>. Published 2017 Jun 24.
- Mangum LC, Garcia GR, Akers KS, Wenke JC. Duration of extremity tourniquet application profoundly impacts soft-tissue antibiotic exposure in a rat model of ischemia-reperfusion injury. *Injury*. 2019;50(12):2203–2214. <https://doi.org/10.1016/j.injury.2019.09.025>.
- Leurcharusmee P, Sawaddiruk P, Punjasawadwong Y, Chattipakorn N, Chattipakorn SC. The possible pathophysiological outcomes and mechanisms of tourniquet-induced ischemia-reperfusion injury during total knee arthroplasty. *Oxid Med Cell Longev*. 2018;8087598. <https://doi.org/10.1155/2018/8087598>. Published 2018 Nov 5.
- Ejaz A, Laursen AC, Kappel A, et al. Faster recovery without the use of a tourniquet in total knee arthroplasty. *Acta Orthop*. 2014;85(4):422–426. <https://doi.org/10.3109/17453674.2014.931197>.
- Wang K, Ni S, Li Z, et al. The effects of tourniquet use in total knee arthroplasty: a randomized, controlled trial. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(9):2849–2857. <https://doi.org/10.1007/s00167-015-3964-2>.
- Wang K, Ni S, Li Z, et al. The effects of tourniquet use in total knee arthroplasty: a randomized, controlled trial. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(9):2849–2857. <https://doi.org/10.1007/s00167-015-3964-2>.
- Huang Z, Xie X, Li L, et al. Intravenous and topical tranexamic acid alone are superior to tourniquet use for primary total knee arthroplasty: a prospective, randomized controlled trial. *J Bone Joint Surg Am*. 2017;99(24):2053–2061. <https://doi.org/10.2106/JBJS.16.01525>.
- Khair MM, Ziembra-Davis M, Dilley JE, Hood Jr MJ, Meneghini RM. Tourniquetless total knee arthroplasty with modern perioperative protocols decreases pain and opioid consumption in women. *J Arthroplasty*. 2018;33(11):3455–3459. <https://doi.org/10.1016/j.arth.2018.06.038>.
- 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 Joint Surg Am*. 2019;101(20):1821–1828. <https://doi.org/10.2106/JBJS.19.00146>.
- 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 Joint Surg Am*. 2012;94(24):2209–2215. <https://doi.org/10.2106/JBJS.K.00813>.
- Dennis DA, Kittelson AJ, Yang CC, Miner TM, Kim RH, Stevens-Lapsley JE. Does tourniquet use in TKA affect recovery of lower extremity strength and function? A randomized trial. *Clin Orthop Relat Res*. 2016;474(1):69–77. <https://doi.org/10.1007/s11999-015-4393-8>.
- Tsunoda K, Sonohata M, Kugisaki H, et al. The effect of air tourniquet on interleukin-6 levels in total knee arthroplasty. *Open Orthop J*. 2017;11:20–28. <https://doi.org/10.2174/1874325001711010020>. Published 2017 Jan 30.
- Ayik O, Demirel M, Birisik F, et al. The effects of tourniquet application in total knee arthroplasty on the recovery of thigh muscle strength and clinical outcomes. *J Knee Surg*. 2021;34(10):1057–1063. <https://doi.org/10.1055/s-0040-1701454>.
- Pavão DM, Pires e Albuquerque RS, de Faria JLR, Sampaio YD, de Sousa EB, Fogagnolo F. Optimized tourniquet use in primary total knee arthroplasty: a comparative, prospective, and randomized study. *J Arthroplasty*. 2023;38(4):685–690. <https://doi.org/10.1016/j.arth.2022.10.026>.
- 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 Joint Surg Am*. 2012;94(24):2216–2221. <https://doi.org/10.2106/JBJS.K.01492>.
- Silva ALPE, Croci AT, Gobbi RG, Hinckel BB, Pecora JR, Demange MK. Translation and validation of the new version of the knee society score - the 2011 KS score - into Brazilian Portuguese. *Rev Bras Ortop*. 2017;52(4):506–510. <https://doi.org/10.1016/j.rboe.2016.08.020>. Published 2017 Jul 6.
- Jawhar A, Skeirek D, Stetzelberger V, Kollowa K, Obertacke U. No effect of tourniquet in primary total knee arthroplasty on muscle strength, functional outcome, patient satisfaction and health status: a randomized clinical trial. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(4):1045–1054. <https://doi.org/10.1007/s00167-019-05646-5>.