Blood Loss in Primary Unilateral Total Knee Arthroplasty with Limited Tourniquet Application

A Randomized Controlled Trial

Doried Diri, MD, Hakam Alasaad, MD, Sedra Abou Ali Mhana, MD, Hussain Muhammed, MD, and
Jaber Ibrahim, MD, PhD

Investigation performed at Damascus University, Damascus, Syria

Background: Tourniquet application in total knee arthroplasty (TKA) has many benefits and may have a role in the incidence of perioperative complications. Our aims were to examine the safety of applying a tourniquet for a limited amount of time during primary unilateral TKA (specifically, during cementation and final component fixation only) and to compare perioperative complications between the limited-application group and the full-application group.

Methods: We conducted a randomized controlled study of 62 patients undergoing primary unilateral TKA. Patients were randomly allocated to either the limited or full tourniquet application. The follow-up period was 6 months. We evaluated intraoperative, postoperative, total, and hidden blood loss as the primary outcome measures and clearance of the surgical field, operative duration, and perioperative complications as the secondary outcome measures.

Results: We found a significant difference in surgical field clearance between the groups. There was no significant difference in total, hidden, or postoperative blood loss between the groups. Mean intraoperative blood loss was significantly lower in the full-application group than in the limited-application group (171.742 ± 19.710 versus 226.258 ± 50.290 mL; $p = 0.001$). Perioperative complications, including allogeneic blood transfusion rates, did not significantly differ between the groups.

Conclusions: Limited tourniquet application is safe to use in primary unilateral TKA and does not increase the incidence of perioperative complications or total blood loss when compared with a standard, full-time tourniquet application.

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

T otal knee arthroplasty (TKA) is considered one of the most successful procedures in orthopaedic surgery. It is mainly indicated for end-stage knee arthritis following the failure of conservative treatment modalities[1]. The rates of TKA have increased in the last few decades, partly as a result of developments in prosthesis manufacturing, patient preparation for surgery, surgeon expertise, postoperative care, and rehabilitation[2].

TKA aims to relieve pain and to restore function. It is an elective procedure that requires the collective efforts of surgeons, anesthesiologists, and physiotherapists for successful outcomes. However, it is still considered a major surgery that can have several complications[3].

Despite the uniform description in the literature of successful results for TKA, many surgeons differ in some of the technical aspects of TKA, whether in terms of the surgical approach, the type of prosthesis used, or the variable regimens for tourniquet application, if a tourniquet is used at all. Tourniquet application has been a regular choice for most orthopaedic surgeons worldwide. The main benefits are reduced intraoperative blood loss, better clearance of the surgical field, and an improved cementation technique provided by blood-free cancellous bone. In contrast, the possible drawbacks are thigh pain, skin burns, neurovascular complications, and an increased risk of venous thromboembolism. Studies have suggested reducing the time of tourniquet application or even forgoing it entirely in order to avoid the associated risks[4,5].

Our primary hypothesis when conducting this double-blinded randomized trial was that full-time application of the tourniquet would reduce total blood loss but might increase the number of complications.

Materials and Methods

The institutional review board of the Faculty of Medicine at Damascus University in Syria approved this prospective, randomized, double-blinded controlled study, which was registered in ClinicalTrial.gov (NCT05691751).

A total of 62 patients undergoing primary unilateral TKA were enrolled between mid-2021 and August 2022. Participants provided written informed consent prior to enrollment (Fig. 1). The exclusion criteria are shown in Table I. Patients were scheduled for surgery with a 6-month follow-up period.

Patients were randomly assigned to 1 of 2 treatments: full tourniquet application (i.e., inflating the tourniquet before incision and releasing it after closure and application of the compression bandage) or limited tourniquet application (i.e., only inflating the tourniquet during cementation and the application of the final components). A research fellow who was uninvolved in patient care performed randomization with use of simple procedures utilizing computer-generated random numbers. The allocation results were then put into concealed envelopes and kept close by in the office until the independent research member opened the envelope just before anesthesia was initiated, at which point the surgery team became unblinded. Patients were blinded to the intervention throughout the entire study period. The team that collected the data postoperatively was uninvolved in the operations and was unaware of the intervention assignments.
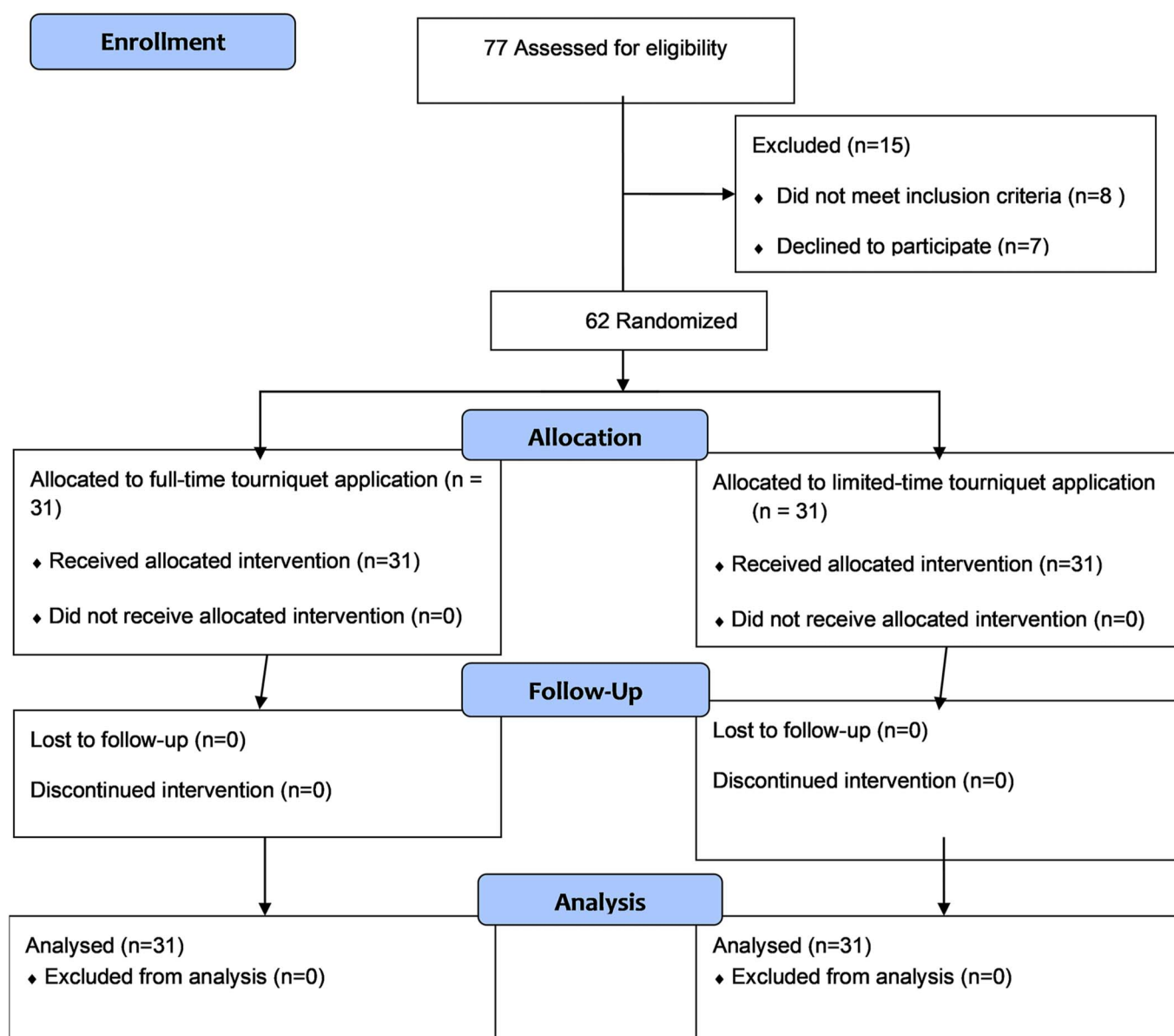

Fig. 1

CONSORT diagram. Of the 77 patients assessed for eligibility, 62 were enrolled and randomized into 1 of 2 intervention groups.

TABLE I Exclusion Criteria*
We included all patients who were undergoing primary unilateral TKA except for:
Patients <50 years old or >85 years old
Patients with a BMI of <20 or >35 kg/m²
Patients with vascular or hematologic disease
Patients who were taking anticoagulant medicine and could not stop it
Patients with acute or chronic renal failure
Patients with an ASA classification of grade 4 or 5
Patients with intraoperative complications such as intraoperative fractures or vascular injuries
Patients with posttraumatic or secondary knee arthritis
Patients undergoing revision or complex primary TKA
Patients with an active infection or a history of lower-limb infection
*BMI = body mass index, ASA = American Society of Anesthesiologists.

For each patient, a tourniquet was applied around the proximal part of the thigh and inflated to 100 mm Hg above the systolic blood pressure. The use of general, spinal, or regional anesthesia for the procedure was determined on the basis of consultation with the anesthesia team. However, spinal anesthesia was chosen for all patients, and no patients needed conversion to general anesthesia. A dose of tranexamic acid, based on weight, was given intravenously before the incision[6]. All procedures were performed by the same surgery team with use of the medial parapatellar approach. The prosthesis utilized for all patients was the cruciate-substituting cemented DePuy Synthes P.F.C. SIGMA. Resurfacing of the patella was not performed in any of the patients. Intramedullary guides were utilized for the femoral and tibial cuts. Complete clinical and radiographic assessments were conducted at 2-week intervals after the surgery. Routine Doppler ultrasonography was performed on the first visit for all patients and then performed as needed on the basis of the clinical examination and the symptoms of the patient.

The primary outcomes were intraoperative, postoperative, total, and hidden blood loss. Intraoperative blood loss was measured by calculating the increased weight of the utilized wet towels plus the volume of the suction bottle after subtracting the amount of lavage used. Postoperative blood loss was measured as the output of the drain, which was applied routinely for all patients and withdrawn on the third day after surgery. Total blood loss was calculated with use of the Gross formula[7], for which the hematocrit value at 48 hours postoperatively was utilized. Hidden blood loss was calculated as the difference between total blood loss and intraoperative plus postoperative blood loss. The volume of the transfused blood was considered in cases in which the patient needed a blood transfusion. The secondary outcomes were surgical field clearance (as assessed by the surgeon), operative duration (i.e., the number of minutes from skin incision to bandage application), and perioperative complications (i.e., complications that occurred during hospitalization or the follow-up period).

A pre-hoc power analysis was performed for the primary outcome measure of total blood loss. Using a medium effect size of 0.5, a power of 0.8, and an alpha error of 0.05, we determined that 52 patients were required to be enrolled in the study. With an assumed dropout rate of 20%, a total of 62 patients were enrolled.

The Fisher exact test and chi-square analysis were utilized for categorical variables, and the Student t test was utilized for continuous variables. Significance was set at 0.05.

All analyses were performed with use of SPSS Statistics 26.0 (IBM).

Results

A total of 62 patients completed the study. No patients were lost to follow-up and all patients attended their follow-up visits. No significant differences in patient demographics and characteristics were found between treatment groups (Table II).

Surgical field clearance, as evaluated by the surgeon, was significantly different between the groups. There were 11 cases

| TABLE II Patient Demographics and Characteristics*				
		Treatment Group		
	Overall (N = 62)	Limited Application (N = 31)	Full Application (N = 31)	P Value†
Age *(yr)*	66.44 ± 6.355	65.45 ± 7.004	67.42 ± 5.572	0.226
Sex *(no. of patients)*				0.648
Male	21 (33.9%)	12 (38.7%)	9 (29.0%)	
Female	41 (66.1%)	19 (61.3%)	22 (71.0%)	
BMI *(kg/m²)*	28.50 ± 3.425	28.93 ± 3.675	28.07 ± 3.183	0.408
*Values are given as the mean ± standard deviation or as the count with the percentage in parentheses. BMI = body mass index. †P values are given for the difference between treatment groups.				
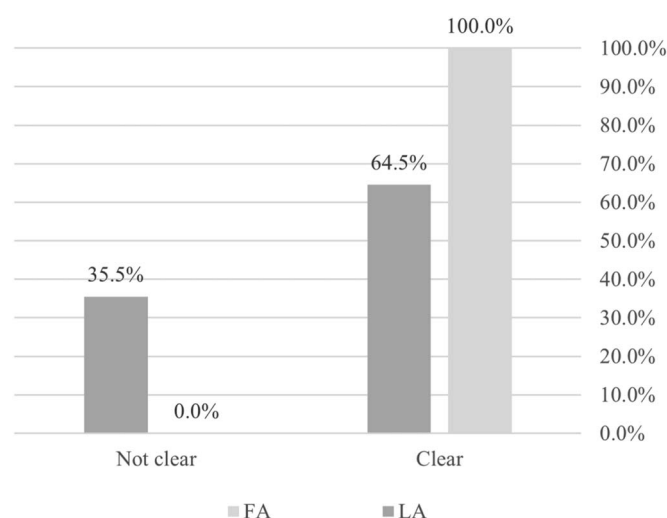
Fig. 2

Bar graph showing the percentage of patients with a surgical field evaluated as clear or not clear in each treatment group. LA = limited-application group, FA = full-application group.

of a nonclear surgical field in the limited-application group but 0 cases in the full-application group (Fig. 2, Table III).

Among all patients, intraoperative blood loss ranged from 137.500 to 287.500 mL. There was a significant difference in intraoperative blood loss between the 2 groups, with measurements ranging from 137.500 to 287.500 mL in the limited-application group and from 146.000 to 210.000 mL in the full-application group. There was no significant difference in hidden, total, or postoperative blood loss between the groups. Blood loss measurements are shown in Table IV.

The mean (and standard deviation) operative duration was 56.177 ± 6.075 minutes. Operative duration did not differ significantly between the groups (Fig. 3, Table III).

A total of 15 patients had perioperative complications. The most common complication, at a rate of 22.6%, was the need for allogeneic blood transfusion, which was required for 9 patients in the limited-application group and 5 in the full-application group. Two patients in the limited-application group and 3 in the full-application group developed superficial infec-

tion and wound-healing problems. No cases of deep infection were observed during the follow-up period. Perioperative complications are reported in Table V.

Discussion

Theoretically, the use of a tourniquet in TKA has many benefits that facilitate the surgical technique; for example, less intraoperative blood loss leads to a blood-free surgical field and less time spent controlling bleeding. Additionally, a blood-free environment is expected to facilitate better cement integration into the cancellous bone, which affects long-term outcomes and the survival of the prosthesis[8,9]. However, many disadvantages to tourniquet use in TKA have been reported in the literature, such as an increased risk of venous thromboembolism (VTE) and neurovascular injury during the perioperative period[10,11].

Our study found a significant difference in intraoperative blood loss between the 2 groups. It is possible that bleeding from the tissues occurred while the tourniquet was being deflated in the limited-application group but that no such bleeding, or only a limited amount, occurred in the full-application group, thereby causing the limited-application group to have a higher mean intraoperative blood loss. This might have also led to the difference in surgical field clearance between the 2 interventions. However, the evaluation of surgical field clearance is not objective and depends on the experience of the surgeon. For example, in their study of patients who underwent TKA with or without a tourniquet, Ejaz et al. did not find a significant difference in surgical field clearance between the 2 groups[12].

Furthermore, the difference in intraoperative blood loss in our study was not of much clinical importance and its small size may be explained by the administration of tranexamic acid to all patients. Additionally, the tourniquet was inflated to a pressure equal to the systolic blood pressure plus 100 mm Hg, which may not always be effective in eliminating bleeding, particularly in patients who are obese, as inadequate exsanguination of the limb before inflating the tourniquet could cause the veins to be congested with blood. Besides, a TKA performed without use of a tourniquet at all would not cause much bleeding, as bleeding from most sources is reduced when the knee is extremely flexed; instead, the duration of the operation and the expertise of the surgeon play a much larger role in bleeding management.

TABLE III Surgical Field Clearance and Operative Duration*				
		Treatment Group		
	Overall (N = 62)	Limited Application (N = 31)	Full Application (N = 31)	P Value†
Surgical field evaluation (*no. of patients*)				**0.001**
Clear	51 (82.3%)	20 (64.5%)	31 (100.0%)	
Not clear	11 (17.7%)	11 (35.5%)	0 (0.0%)	
Operative duration (*min*)	56.177 ± 6.075	57.45 ± 5.573	54.90 ± 6.373	0.099

*Values are given as the count, with the percentage in parentheses, or as the mean ± standard deviation. †P values are given for the difference between treatment groups. Bold indicates significance (p < 0.05).

TABLE IV Blood Loss Measurements*				
		Treatment Group		
	Overall	Limited Application	Full Application	P Value†
Blood loss *(mL)*				
Intraoperative	199.000 ± 46.798	226.258 ± 50.290	171.742 ± 19.710	**0.001**
Postoperative	341.940 ± 76.952	324.520 ± 59.671	359.350 ± 88.617	0.074
Hidden	501.129 ± 139.941	509.840 ± 161.578	492.420 ± 116.430	0.628
Total	1042.066 ± 222.294	1060.613 ± 252.234	1023.52± 190.115	0.931

*Values are given as the mean ± standard deviation. †P values are given for the difference between treatment groups. Bold indicates significance ($p < 0.05$).

In the present study, we did not find a significant difference between the groups with respect to postoperative or total blood loss, both of which were calculated with use of the Gross formula. Our findings are similar to those reported by Tai et al., who conducted a meta-analysis of studies comparing TKA with and without the use of a tourniquet (none of the included studies assessed limited tourniquet application)[13]. Tai et al. found that the groups with and without tourniquet use did not significantly differ with respect to total blood loss calculated with use of the Gross formula. One possible explanation for why the application regimens have not been shown to differ in total blood loss despite differing in intraoperative blood loss is that hemostasis performed during surgery may decrease postoperative blood loss following limited tourniquet application, whereas the combination of leaving bleeding sources to primary hemostasis and the increased blood flow to the limb following tourniquet deflation likely increases postoperative blood loss following full tourniquet application.

We preferred the Gross formula for estimating total blood loss because it allowed us to estimate hidden blood loss, which might reach higher levels than blood lost in the drain. Hidden blood loss is the amount of blood lost into tissues during and after surgery[14]. The Gross formula estimates total blood loss by multiplying patient blood volume by the difference between the pre- and postoperative hematocrit values divided by the initial hematocrit value. Thus we can calculate hidden blood loss by subtracting the intraoperative and postoperative blood loss values from the estimated total blood loss value, which is a more precise method of calculating total blood loss than calculating only intraoperative blood loss plus drain and bandage output as the total blood loss[15].

In this regard, we encountered controversy in the literature. Wang et al. found in their meta-analysis that limited tourniquet application significantly increased intraoperative and total blood loss but did not increase blood transfusion requirements[16]. A meta-analysis by Zhang et al. demonstrated no significant difference in total blood loss between TKA with and without tourniquet application, but demonstrated that complications increased when the tourniquet was utilized[17]. Ahmed et al. had similar findings but included revision and secondary arthritis cases. Specifically, they found no significant

difference in total blood loss between TKA with and without tourniquet use but reported an increased incidence of major complications when the tourniquet was utilized[18]. In contrast, in a comparison of 6 tourniquet application regimens, Cao et al. found that full-time application decreased total blood loss but increased complication rates[19].

Although intraoperative blood loss differed significantly between the groups in the present study, this difference may not have much clinical importance. Still, complex primary and revision cases are more technically difficult, require more surgical dissection, and have a longer operative duration, which could lead to a more clinically relevant volume of blood loss. Also, the prolonged tourniquet application time in such surgeries may lead to an increased risk of complications.

In our study, we included only primary cases and excluded high-risk patients and patients with many comorbidities. All procedures were performed by an expert surgeon with approximately 30 years of experience in this field, and all operations lasted ≤69 minutes. These factors may explain why we did not find a significant difference in any of the perioperative
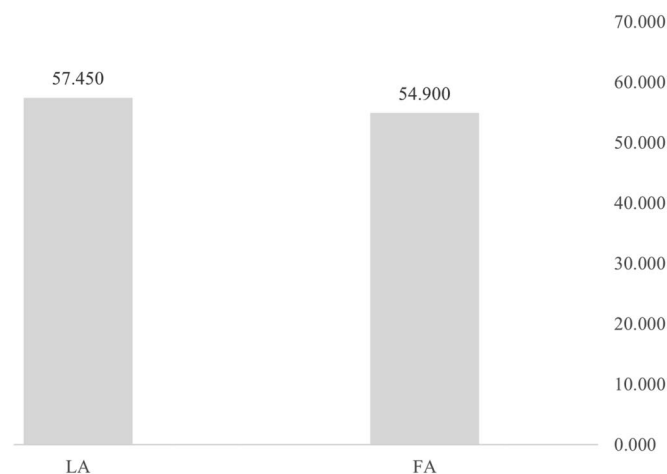

Fig. 3
Bar graph showing the mean operative duration and standard deviation, in minutes, for each treatment group. LA = limited-application group, FA = full-application group.

TABLE V Perioperative Complications*				
		Treatment Group		
	Overall	Limited Application	Full Application	P Value†
Deep vein thrombosis	3	1	2	0.546
Pulmonary embolism	0	0	0	–
Superficial infection and wound-healing problems	5	2	3	0.546
Deep infection	0	0	0	–
Allogeneic blood transfusion	14	9	5	0.195
Other complications	0	0	0	–

*Values are given as the number of patients in whom the complication occurred. †P values are given for the difference between treatment groups.

complications between the 2 groups. We observed 2 cases of superficial infection in the limited-application group and 3 in the full-application group; all affected patients responded to antibiotics and local treatment. One patient in the limited-application group and 2 patients in the full-application group had findings of deep vein thrombosis on ultrasonography with no clinical symptoms and were treated, on the recommendation of the vascular surgeon, with apixaban (two 5-mg tablets twice per day for 1 week followed by one 5-mg tablet twice per day for 3 months, with regular checkups with a vascular consultant at 2-week intervals) with no consequences. We also needed to transfuse allogeneic blood in 9 patients in the limited-application group and in 5 patients in the full-application group. Although 8 g/dL was our threshold for blood transfusion, clinical symptoms of anemia also influenced our decisions. There was no need for transfusion of >2 units of blood in any patient, and allergic reactions were managed accordingly with no consequences. Nonetheless, allogeneic blood transfusion is still considered a complication that carries many risks, especially in arthroplasty; these may include an increased risk of infection and allergic reaction, which can potentially prove fatal[20,21].

The most important finding of our study was that limited tourniquet application is safe for use in primary unilateral TKA. The absence of a significant difference in total blood loss or perioperative complications between the treatment groups in our study indicates that tourniquet application should not be considered an absolute necessity in TKA, especially given the recent emergence of many methods of blood loss reduction, such as tranexamic acid usage and low-pressure anesthesia[22,23].

We acknowledge that our study had many limitations. First, the exclusion criteria were numerous. We excluded patients with a higher risk of perioperative complications, and we only included patients who were undergoing primary unilateral TKA. Furthermore, all procedures were performed by an experienced surgeon. We do not know if we would have had the same results with less experienced surgeons or with revision or complex primary cases, as the incidence of complications in patients undergoing such procedures is expected to be

higher. Therefore, our findings may not be generalizable to those populations.

Additionally, we did not include prosthesis survival or long-term complications among the outcomes studied. Also, although functional outcomes following TKA may be affected by different tourniquet application regimens, we did not assess such outcomes in our study. A more extended follow-up period might reveal more complications.

One of the reasons that we chose the Gross formula to assess blood loss was to decrease the risk of bias. Although blood loss measurements were collected by the authors' assistant, who was blinded for the entire study period, the risk of bias is still present because the surgeon was unblinded when making a decision related to blood transfusion, especially when the decision was based on clinical manifestations of anemia.

Our method of evaluating total blood loss by the hematocrit value might have underestimated the amount of hidden blood loss. Blood loss may continue for several days after surgery, but we evaluated it at only 2 days postoperatively.

Conclusions
The use of limited tourniquet application is safe for low-risk patients undergoing primary unilateral TKA performed by an expert surgeon. When compared with the full application regimen, the limited application regimen showed no increased rates of perioperative complications or total blood loss. ■

Doried Diri, MD[1]
Hakam Alasaad, MD[1]
Sedra Abou Ali Mhana, MD[1]
Hussain Muhammed, MD[1]
Jaber Ibrahim, MD, PhD[1]

[1]Damascus University, Damascus, Syria

Email for corresponding author: Doried.diri@gmail.com

References

1. Adie S, Harris I, Chuan A, Lewis P, Naylor JM. Selecting and optimising patients for total knee arthroplasty. Med J Aust. 2019 Feb;210(3):135-41.

2. Singh JA. Epidemiology of knee and hip arthroplasty: a systematic review. Open Orthop J. 2011 Mar 16;5(1):80-5.

3. Whittaker JL, Truong LK, Dhiman K, Beck C. Osteoarthritis year in review 2020: rehabilitation and outcomes. Osteoarthritis Cartilage. 2021 Feb;29(2):190-207.

4. Xu H, Yang J, Xie J, Huang Z, Huang Q, Cao G, Pei F. Tourniquet use in routine primary total knee arthroplasty is associated with a higher transfusion rate and longer postoperative length of stay: a real-world study. BMC Musculoskelet Disord. 2020 Sep 18;21(1):620.

5. Horlocker TT, Hebl JR, Gali B, Jankowski CJ, Burkle CM, Berry DJ, Zepeda FA, Stevens SR, Schroeder DR. Anesthetic, patient, and surgical risk factors for neurologic complications after prolonged total tourniquet time during total knee arthroplasty. Anesth Analg. 2006 Mar;102(3):950-5.

6. Dunn CJ, Goa KL. Tranexamic acid: a review of its use in surgery and other indications. Drugs. 1999 Jun;57(6):1005-32.

7. Gross JB. Estimating allowable blood loss: corrected for dilution. Anesthesiology. 1983 Mar;58(3):277-80.

8. Vaishya R, Chauhan M, Vaish A. Bone cement. J Clin Orthop Trauma. 2013 Dec; 4(4):157-63.

9. Schroer WC, Berend KR, Lombardi AV, Barnes CL, Bolognesi MP, Berend ME, Ritter MA, Nunley RM. Why are total knees failing today? Etiology of total knee revision in 2010 and 2011. J Arthroplasty. 2013 Sep;28(8)(Suppl):116-9.

10. Park JH, Restrepo C, Norton R, Mandel S, Sharkey PF, Parvizi J. Common peroneal nerve palsy following total knee arthroplasty: prognostic factors and course of recovery. J Arthroplasty. 2013 Oct;28(9):1538-42.

11. Sundaram K, Udo-Inyang I, Mont MA, Molloy R, Higuera-Rueda C, Piuzzi NS. Vascular Injuries in Total Knee Arthroplasty: A Systematic Review and Meta-Analysis. JBJS Rev. 2020 Jan;8(1):e0051-0051.

12. Ejaz A, Laursen AC, Kappel A, Laursen MB, Jakobsen T, Rasmussen S, Nielsen PT. Faster recovery without the use of a tourniquet in total knee arthroplasty. Acta Orthop. 2014 Aug;85(4):422-6.

13. Tai TW, Lin CJ, Jou IM, Chang CW, Lai KA, Yang CY. Tourniquet use in total knee arthroplasty: a meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2011 Jul;19(7): 1121-30.

14. Sehat KR, Evans RL, Newman JH. Hidden blood loss following hip and knee arthroplasty. Correct management of blood loss should take hidden loss into account. J Bone Joint Surg Br. 2004 May;86(4):561-5.

15. Gao FQ, Li ZJ, Zhang K, Sun W, Zhang H. Four Methods for Calculating Blood-loss after Total Knee Arthroplasty. Chin Med J (Engl). 2015 Nov 5;128(21): 2856-60.

16. Wang C, Zhou C, Qu H, Yan S, Pan Z. Comparison of tourniquet application only during cementation and long-duration tourniquet application in total knee arthroplasty: a meta-analysis. J Orthop Surg Res. 2018 Aug 30;13(1):216.

17. 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 Mar 6; 9(1):13.

18. Ahmed I, Chawla A, Underwood M, Price AJ, Metcalfe A, Hutchinson CE, Warwick J, Seers K, Parsons H, Wall PDH. Time to reconsider the routine use of tourniquets in total knee arthroplasty surgery. Bone Joint J. 2021 May;103-B(5):830-9.

19. Cao Z, Guo J, Li Q, Wu J, Li Y. Comparison of efficacy and safety of different tourniquet applications in total knee arthroplasty: a network meta-analysis of randomized controlled trials. Ann Med. 2021 Dec;53(1):1816-26.

20. Ferraris VA, Hochstetler M, Martin JT, Mahan A, Saha SP. Blood transfusion and adverse surgical outcomes: The good and the bad. Surgery. 2015 Sep; 158(3):608-17.

21. Everhart JS, Sojka JH, Mayerson JL, Glassman AH, Scharschmidt TJ. Perioperative Allogeneic Red Blood-Cell Transfusion Associated with Surgical Site Infection After Total Hip and Knee Arthroplasty. J Bone Joint Surg Am. 2018 Feb 21;100(4):288-94.

22. Kim C, Park SS, Davey JR. Tranexamic acid for the prevention and management of orthopedic surgical hemorrhage: current evidence. J Blood Med. 2015 Aug 25;6:239-44.

23. Lu Q, Peng H, Zhou GJ, Yin D. Perioperative Blood Management Strategies for Total Knee Arthroplasty. Orthop Surg. 2018 Feb;10(1):8-16.