ORIGINAL ARTICLE

A comparative study of the hemodynamic and clinical effects of using or not tourniquet in total knee arthroplasty

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Abstract

Background: Pneumatic tourniquet is widely used in lower limb surgery to provide a bloodless operating field. Previous studies on total knee arthroplasty (TKA) in which tourniquets have been applied during surgery have reported some vascular and soft-tissue complications. Nevertheless, it is still not well known exactly how use of tourniquets contributes to hemodynamics of the lower limb and its clinical relevance following TKA. In this prospective study, we wished to determine whether tourniquet affects the hemodynamics and postoperative healing of the lower limb in the first few weeks and its clinical relevancies following TKA.

Methods: We prospectively collected consecutive 110 patients with advanced osteoarthritis of the knee. All the subjects were randomly assigned to one of two TKA procedures: TKA with (Group T) or without (Group O) tourniquets. The hemodynamics of each operated leg was assessed by Doppler, first before the operation, then postoperatively on days 2, 6, 14, and 28. The operative and postoperative managements were done the same as those described in the papers done by the author. Parameters during the operative and postoperative course, including, demography, pre- or postoperative knee score, tourniquet time, operation time, estimated blood loss, perioperative blood transfusion, hospital course, and complications will all be recorded and compared in detail. All patients were measured for all response variables, which included demographic variables, results of Doppler, and important surgical outcomes. Fisher's exact test was used to compare differences between the two groups for each discrete variable, and a Mann-Whitney Rank Sum Test was used to analyze each continuous variable. The p value was set for each test at 0.05 before analysis took place. In accordance with the repeated measures, the venous hemodynamic parameters were checked. If any significant differences appeared in the overall test, values were then compared in pairs using two sample t-tests for all statistical tests. The level of significance was set at $p < 0.05$.

Results: In our 110 patients (55 with tourniquet, 55 without), all checked clinical parameter were without significant difference except postoperative quadriceps muscle recovery. This implied tourniquet use influenced postoperative rehabilitation program. Blood loss amount were similar in both groups. There was only one DVT found.

Conclusion: Tourniquet use in TKA must be managed very carefully. Not only because of immediate complication resulted from tourniquet but also influence on post-operational functional recovery, especially in quadriceps muscle function. According to this study, TKA without tourniquet use preserves better quadriceps muscle function to provide faster recovery and less transfusion need. It avoids complications from tourniquets as well.

Keywords: Hemodynamics; Plethysmography; Total knee arthroplasty; Tourniquets

1. INTRODUCTION

The total knee arthroplasty (TKA) is one of most important and successful operations in orthopedics since it was developed. The operative methods and design of implants were getting better and better. Cemented fixation is the mainstay of TKA fixation.[1,2] Tourniquet application is used to reduce blood loss, provide a bloodless surgical field and facilitate the cementation technique by providing a clean blood-poor surface.[3,4] However, application of tourniquet during TKA is still debated.[5] Tourniquet use in TKA may induce wound complication, thigh pain, soft-tissue inflammation and misalign patella-femoral tracking.[6–9] On the other hand, some orthopedic surgeons believed that use of tourniquet would enhance better fixation, less intra-operation blood loss and need for intraoperative transfusion.[4] Up to present, research about tourniquet in TKA were mainly focused on soft-tissue complications, blood loss and formation of thrombus.[10,11] However, the key point of a successful TKA depends on good postoperative function and minimal complications.

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The relationship between postoperative function and tourniquet was rarely studied, especially in quadriceps muscle function. Impairment of quadriceps muscle function after TKA with tourniquet use was often observed in our clinical practice. Besides, thrombus after TKA were most revealed in Multidetector-row computed tomography (MDCT).[12] Color Doppler ultrasonography may provide another point of view since its applicability and dynamic examination. Hemodynamic study is another key point we want to clarify if use of tourniquet interferes hemodynamics which contribute to clinical outcome. It was purposed that tourniquet use is related to clinical difference in TKA, especially in quadriceps muscle function and hemodynamics.

2. METHODS

The study conformed to the Declaration of Helsinki and the institution's Good Clinical Practice guidelines and was approved by the institutional review board of Taipei Veteran General Hospital. This study was a prospective randomized trial performed from February 2019 to January 2020. The study protocol was approved by the ethics committee of Taipei Veterans General Hospital (IRB-2012-02-079B). All patients underwent TKA by a single surgeon (FYC) with medial parapatellar approach, bone cement, surgical instruments and implants (NEXGEN, LPS high flex, Zimmer). The patients who underwent TKA because of degenerative osteoarthritis with severe wearing articular surface at least on compartment were included in our research. Those patients met the criteria of (1) intermittent (several times per week) or constant knee pain for at least 3 to 6 months; (2) radiological confirmation of structural knee damage (osteoarthritis, osteonecrosis); (3) inadequate response to conservative treatment, including pharmacological and nonpharmacological treatment for at least 3 to 6 months; (4) adverse impact of knee disease on patient's quality of life for at least 3 to 6 months; and (5) patient-reported suffering/impairment due to knee disease.[13,14]

The patients who had rheumatoid arthritis, septic arthritis, spontaneous osteonecrosis of knee, peripheral vascular disorder, or malignancy were excluded. There was consecutive 110 patients enrolled in this study then randomized to less tourniquet group (T-group) or tourniquet-less group (O-group).

All procedures were performed under spinal anesthesia. The surgery was performed via the medial parapatellar approach. Posterior-stabilized, cemented TKA (NexGen High Flex, Zimmer Inc., Warsaw, IN, USA) was used in all patients. We performed high-pulse lavage; swabs were used to obtained clean dry-cut bone surface for proper cementing for all the patients. In patients with tourniquets, tourniquets were inflated up to 250 mmHg before application of bone cement and deflated after all implants were fixed. Vancomycin, 1 g per pack, was added in bone cement to prevent from infection. Empirical postoperative antibiotics (Cefazolin) were prescribed for 1 day.

For the pain control protocol, all the patients received ultrasound-guided, single-injection adductor canal block with 10 mL of 0.25% bupivacaine injection by an experienced anesthesiologist. After surgery, an intravenous PCA device (Hospira Gemstar PCA Infusion Pump) was applied and initiated right after the nerve block procedure. During the first 72 hours postoperatively, analgesia was provided by using IV PCA with morphine (1 mg/mL). The pump was set at a loading dose of 0.05 to 0.1 mL/kg, an infusion rate of 0.004 to 0.008 mL/kg/h, a bolus dose of 0.01 to 0.02 mL/kg, and a lockout time of 5 to 12 minutes. Following surgery, an anesthesiologist regularly visited the patient and adjusted the infusion rate and bolus dose according to pain intensity and adverse events. PCA was removed 72 hours following surgery. All patients had oral Tramadol 37.5 mg + Acetaminophen 325 mg, 2 times/day and Etoricoxib 60 mg, 2 times/day after surgery for 3 days and adjust to 1 time/day.

All the patients received TKA without drain using. Intraoperative blood loss was calculated as the volume of liquid in the suction bottle minus the volume of irrigation fluid used throughout the surgery. The increase in surgical gauze weight used was also added to intraoperative blood loss. Estimated blood loss was measured by using the formula described by Gross, which uses the maximum postoperative decrease in the level of hemoglobin adjusted for the weight and height of the patient.[15] Hidden blood loss was calculated by subtracting the apparent total blood loss from the estimated blood loss.

The Blood transfusion strategy was that when the preoperative hemoglobin is <10 mg/dL or when substantial blood loss occurs during the operation, blood transfusion with packed red blood cells (RBCs) is performed during the operation. Hemoglobin is routinely checked on the first postoperative day. If the hemoglobin is <10 mg/dL or there is a substantial drop associated with anemic symptoms, blood transfusion is performed.

No preoperative or postoperative medications prescribed in the purpose of prevention from deep vein thromboembolism (DVT). Immediate postoperative weight bearing is encouraged with walker or not. In patients' demographic data, we take age, gender, body mass index (BMI), and sides of operation into consideration.

About the parameters of operations, the American Society of Anesthesia classification (ASA classification), time of tourniquet use, total operation time, blood loss and the number of packed RBC units' transfusion were counted. About the functional recovery, we compared preoperative and postoperative functional scores (Hospital of Special Surgery Knee Score), length of stay in hospital, and quadriceps muscle function.

Quadriceps muscle function was checked every 8 hours immediately after TKA till the patient could make hip flexion with straight leg raising up to 60° in bed without aid. Quadriceps function was graded according to the angle of elevation measured postoperatively. If the quadriceps muscle cannot exert force, it is 0 points; if it can be straightened with force, it is 1 point; if it can be slightly lifted against gravity, it is 2 points; if it can successfully lift 60°, it is 3 points.

Sonograms (SIEMENS ACUSON S2000 Ultrasound System) were performed before and after operation to evaluate if there is possibility of deep vein thrombosis. All patients were followed at 2 weeks, 4 weeks, 8 weeks, 6 months, and 12 months postoperatively. The diagnosis of deep vein thrombosis was based on clinical condition and positive sonogram findings. Clinical condition included progressive pain, swelling, and calf tenderness 30 days postoperatively. Sonograms were interpreted for DVT by two independent orthopedic radiologists who were blinded to the clinical condition of the patients. The sonographic criteria for the diagnosis of DVT included direct signs (direct visualization of a filling defect within the venous system) and indirect signs (eg, nonfilling or varicosity changes).

All patients were measured for all response variables, which included demographic variables, results of sonograms, and significant surgical outcomes or complications. Fisher's exact test was used to compare differences between the two groups for each discrete variable, and a Mann-Whitney Rank Sum Test was used to analyze each continuous variable. The p value was set for each test at 0.05 before analysis took place. In accordance with the repeated measures, the venous hemodynamic values obtained for averaged arterial flow index (AFI), venous capacitance (Vc), venous outflow (Vo) and half-emptying time (T1/2) were analyzed with generalized linear mixed models and two-way analysis of variance was used to compare numerical values within and between groups.

Table 1

Demographic data of the patients

	Group O	Group T	Total patients
Patient no. (M/F)	55 (22/33)	55 (22/33)	110 (44/66)
Age (mean ± standard deviation) (range)	71.4 ± 4.4 (54–89)	73.1 ± 5.8 (55–88)	72.3 ± 5.0 (54–89)
BMI (mean ± standard deviation) (range)	23.94 ± 3.0 (16.1–25.9)	24.74 ± 2.7 (16.4–25.8)	20.8 ± 2.9
Side of operation (L/R)	26/29	28/27	54/56
ASA classification (I, II, III, IV, V)	12, 26, 17, 0, 0	13, 23, 19, 0, 0	25, 49, 36, 0, 0

ASA = American Society of Anesthesia; O = without tourniquet; T = tourniquet-less.

If any significant differences appeared in the overall test, values were then compared in pairs using two sample t-tests for all statistical tests. The level of significance was set at $p < 0.05$.

3. RESULTS

In our studies, the enrolled patients were classified to 2 groups randomly, as tourniquet-less group (O-group) and less-tourniquet group (T-group). Grouping is based on the mantissa of the medical record number, the group with an odd number is O-group; the one with an even number is T-group.

There were 55 patients in O-group with 22 males and 33 females. Mean age of O-group was 71 years old (range: 54–89). Mean BMI in O-group was 23.94 and most anesthesia classification was ASA 3. Mean length of operation time in O-group was 53.8 minutes (range: 45–62) and mean intraoperative estimated blood loss amount was 165ml (range: 110–220). Postoperative packed RBC transfusion due to blood loss in O-group was 0.36 units. Average length of stay in hospital was 7.03 days. Mean preoperative and postoperative functional scores were 49.50 and 93.07. Quadriceps muscle function recovery achieved our endpoint in mean time of 23.84 hours postoperatively. One patient was found to have deep vein thrombosis 2 weeks after operation and resolved in 4 weeks.

There were 55 patients in T-group with 22 males and 33 females. Mean age of T-group was 73 years old (range: 55-88). BMI in T-group was 24.74 and most ASA classification was 3. Mean length of operation time in T-group was 53.3 minutes (range: 48–62). Mean tourniquet using time was 9 minutes (range: 7–12) and mean intraoperative estimated blood loss amount was 166 ml (range: 110-210). Postoperative packed-RBC transfusion due to blood loss in T-group was 0.89 units. The average length of stay in hospital was 7.02 days. Mean preoperative and postoperative functional scores were 48.90 and 93.31. Quadriceps muscle function recovery achieved our endpoint in mean time of 45.92 hours postoperatively. No patient was found to have DVT postoperatively.

Between O-group and T-group, there were no significant differences in patients' age, gender, side of operation, BMI, ASA score, intraoperative estimated blood loss, operation time, and length of hospital stay. Preoperative and postoperative functional scores were regarded as no significant difference (Table 1).

However, longer recovery of quadriceps muscle function was noted in T-group, 45.92 hours versus 23.84 hours in O-group ($p < 0.0001$). More blood transfusion was also noted in T-group, 0.89 unit, versus 0.36 unit in O-group ($p = 0.001$) (Table 2).

The venous hemodynamic values showed in (Table 3)[16], and there was no significant difference between two groups.

4. DISCUSSION

Tourniquets used in orthopedic surgery were mainly regarded as devices for decreasing intraoperative blood loss so that the operation could be performed easily. Some surgeons believed that tourniquet use was beneficial to implant cemented fixation because of less blood interfered with cement impaction.[1,2,17] However, there were more and more research revealed that tourniquet use less likely decrease a significant amount of intraoperative blood loss which needs blood transfusion.[18] Cemented fixation was also reported to be fixed well without tourniquet via radiostereometric study.[1,9,19,20] In our study, there was no significant difference in intraoperative blood loss between O-group and T-group. There were no fixation failures observed during our follow-up period.

A successful total knee TKA depends on good operation and postoperative recovery.[21–23] Ejaz et al showed that TKA without tourniquet use results in better functional and clinical outcomes.[24] Quadriceps muscle function is very important in knee

Table 2

Surgical results for group O and group T

Parameters	Group O (mean ± standard deviation)	Group T (mean ± standard deviation)	*p*
HSS score			
Preoperative	49.50 ± 10.1	48.90 ± 12.3	0.780
Postoperative	93.07 ± 15.6	93.31 ± 17.4	0.934
Quadriceps muscle function recovery (h) (range)	23.84 ± 4.2	45.92 ± 6.3	<0.0001[a]
Length of operative time (min) (range)	53.8 ± 17.3	53.3 ± 16.2	0.876
Intraoperative estimated blood loss (mL) (range)	165.2 ± 23.1	166.4 ± 19.8	0.771
Postoperative packed-RBC transfusion (unit) (range)	0.36 ± 0.2	0.89 ± 1.5	0.001[a]
Hospital days (range)	7.03 ± 2.2	7.02 ± 1.9	0.979

The powers of the performed tests (0.050) were below the desired power of 0.800. Statistical analysis of the radiographic parameters of these two groups was performed using the Mann-Whitney Rank Sum test, and the unpaired *t* test from the SigmaStat software package, version 2.0 (Jandel Corp., San Rafael, CA, USA), and power analysis was also performed with the alpha set at 0.05. A *p* value less than 0.05 was considered significant.

HSS = hospital of Special Surgery Knee; O = without tourniquet; RBC = red blood cell; T = tourniquet-less.

[a]The use of tourniquets during total knee arthroplasty can reduce the amount of blood loss in the surgical field, and it will increase the amount of hidden blood loss (hidden blood loss), resulting in higher transfusion rates. Hidden bleeding refers to the amount of bleeding that is difficult to detect or measure due to local tissue necrosis, leakage from the cutting bone surface, and congestion in the joint capsule during or after surgery.

Table 3

Changes in leg venous hemodynamics (VDI, $T_{1/2}$, and AFI) and leg volumes after surgery

Postoperative second week	Group O	Group T	*p*
VDI, × 10^{-2} mL/100 mL × mmHg	6.4 ± 0.6	6.5 ± 0.4	0.306
$T_{1/2}$, S	5.9	5.8	0.805
AFI, mL/100 mL	1.4 ± 0.3	1.5 ± 0.4	0.141
Leg volume, mL	2587 ± 64	2569 ± 79	0.192
Postoperative fourth week			
VDI, × 10^{-2} mL/100 mL × mmHg	6.3 ± 0.6	6.4 ± 0.3	0.271
$T_{1/2}$, S	5.8	5.7	0.866
AFI, mL/100 mL	1.5 ± 0.1	1.4 ± 0.6	0.225
Leg volume, mL	2495 ± 89	2477 ± 43	0.180
Postoperative eighth week			
VDI, × 10^{-2} mL/100 mL × mmHg	6.2 ± 0.7	6.3 ± 0.1	0.296
$T_{1/2}$, S	5.5	5.6	0.952
AFI, mL/100mL	1.3 ± 0.5	1.4 ± 0.1	0.149
Leg volume, mL	2421 ± 72	2398 ± 87	0.134
Postoperative sixth month			
VDI, × 10^{-2} mL/100 mL × mmHg	5.8 ± 0.4	5.9 ± 0.2	0.101
$T_{1/2}$, S	5.9	5.8	0.978
AFI, mL/100 mL	1.2 ± 0.1	1.3 ± 0.5	0.149
Leg volume, mL	2367 ± 64	2358 ± 83	0.526
Postoperative 12th month			
VDI, × 10^{-2} mL/100 mL × mmHg	5.3 ± 0.6	5.4 ± 0.7	0.422
$T_{1/2}$, S	4.7	4.8	0.975
AFI, mL/100mL	1.1 ± 0.1	1.2 ± 0.6	0.225
Leg volume, mL	2314 ± 61	2307 ± 38	0.471

Values are means ± SE.
AFI = arterial flow index; $T_{1/2}$ = half-emptying time; VDI = venous distensibility index.

extension and normal gait. Saleh et al reported that functional recovery following TKA is closely associated with the strength of the thigh muscles, particularly the quadriceps femoris muscle.[25] Liu et al compared the patients underwent TKA with or without tourniquet using evaluated by electromyography. The result showed patients in the tourniquet group had less muscle activity than the no tourniquet group at 6 months postoperatively.[26] Our study is in accordance with the previous study, quadriceps muscle function recovered faster in O-group. It implied the use of a tourniquet does have a detrimental effect on the quadriceps muscle function recovered following TKA. Postoperative limb pain may be resulting from local pressure exerted by tourniquet. Transient ischemia caused by tourniquet application in TKA was proved to be a human clinical model of ischemia-reperfusion, and it was also a probable source of inflammatory mediator which evoked pain.[27]

Many surgeons preferred tourniquet use to provide a bloodless operative field to facilitate and reduce intraoperative blood loss. In our study, we found more need for transfusion in T-group although both groups had similar intraoperative blood loss. This implied more postoperative blood loss in T-group. Li et al demonstrated that application of tourniquet would promote hidden blood loss and hinder rehabilitation.[23] Alcelik et al and Harvey et al also reported that tourniquet use would activate local thrombogenic and fibrinolytic activity which may play a role in hemostasis.[5,28] Tourniquet use may not decrease blood, but probably increase uncensored blood loss postoperatively in our study. It was corresponded with previous study, tourniquet using is associated with significantly higher volumes of blood loss.[3,29] This may be because that it's easier to check bleeding in O-group than in T-group, thus more secure hemostasis is performed in O-group. Besides, we did not find any significant difference in operative time among the groups whether tourniquet use or not. It is our opinion that relinquishing the tourniquet allows for controlled and expeditious hemostasis of vessels that are identified throughout the procedure, which may be more effective at limiting perioperative blood loss.

In incidence of DVT after TKA, some studies disclosed more common with tourniquet use. An increased length of tourniquet time may increase the risk of DVT due to increased venous stasis and potential damage to vessels inducing an inflammatory stimulus.[30] Abdel-Salam et al reported an increased incidence of DVT as confirmed by venography with the use of a tourniquet in TKA.[31] Mori et al found that the use of a tourniquet was associated with a significantly increased risk of distal DVT as identified by ultrasound.[8] Many authors have suggested that shortening the tourniquet time will reduce the disadvantages of its use while preserving the advantages. Razak et al reported the incidence of a symptomatic DVT in patients was significantly related to a longer tourniquet time.[32] In our study, there is no significant difference between the groups. There are two possible reasons to explain such a condition. First, we applied less-tourniquet use in the T-group; therefore, thrombosis was less likely to appear. Then, this result may be attributed for lower DVT incidence in Taiwanese and early rehabilitation program performed postoperatively.

In conclusion, tourniquet use in TKA must be managed very carefully. Not only because of immediate complication resulted from tourniquet but also influence on post-operational functional recovery, especially in quadriceps muscle function. Blood loss and transfusion need, which were traditionally thought as pros of tourniquet use, did not differ from ones in TKA without tourniquet.

According to our study, tourniquet will be used less in our clinical practice of TKA. TKA without tourniquet use preserves better quadriceps muscle function to provide faster recovery and less transfusion need. It avoids complications from tourniquets as well.

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