Knee Surg Sports Traumatol Arthrosc (2016) 24:2595–2605
DOI 10.1007/s00167-015-3872-5

KNEE

Comparison of quadriceps muscle volume after unilateral total knee arthroplasty with and without tourniquet use

Olcay Guler[1] · Mahir Mahirogullari[1] · Mehmet Isyar[1] · Ahmet Piskin[2] · Sercan Yalcin[1] · Serhat Mutlu[3] · Bünyamin Sahin[4]

Received: 30 March 2015 / Accepted: 10 November 2015 / Published online: 21 November 2015

Abstract
Purpose Determination of the effect of tourniquet use in total knee arthroplasty (TKA) on thigh and quadriceps muscle volume using magnetic resonance imaging (MRI).
Methods A total of 148 knees of 74 patients (mean age 66.5 ± 4.8 years; female/male, 62/12) with bilateral primary varus gonarthrosis underwent unilateral TKA with a tourniquet (Group A, $n = 35$) or without a tourniquet (Group B, $n = 39$). The total thigh volume and connective, bone, and muscle tissue volumes were stereologically measured on preoperative and postoperative MRI. The Knee Society Score (KSS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score were calculated to evaluate functional outcomes.
Results After TKA, the knees of patients in Group A exhibited a significant decrease in all tissue measurements, except bone tissue volume; however, the knees of patients in Group B exhibited no significant difference in tissue measurements. Although no difference was found between the operated and contralateral non-operated thighs (4076.9 and 4073.4 cm^3, respectively) in Group B postoperatively at 1 month ($p > 0.05$), the operated thighs had lost 20 % of its volume in Group A postoperatively at 1 month ($p < 0.001$). A significant difference was found in all tissue measurements, except the connective and bone tissue volumes of the thigh between the operated and contralateral non-operated knees in Group A. No significant difference was identified between the operated and contralateral non-operated knees in Group B. The total WOMAC score was significantly higher, and the total KSS was significantly lower in Group A than in Group B during the postoperative follow-up period of 1–6 months ($p < 0.001$ for all) but not 12 months (n.s.).
Conclusion Tourniquet use in TKA decreases the thigh and quadriceps muscle volumes and postoperatively delays the recovery of knee function. Therefore, caution should be exercised for tourniquet use during TKA in daily clinical practice and using alternative methods for tourniquet application in preventing intraoperative blood loss.
Level of evidence III.

Keywords Total knee replacement · Total knee arthroplasty · Tourniquet use · Quadriceps muscle · Atrophy · Quantitative analysis · Magnetic resonance imaging

✉ Olcay Guler
olcayguler77@gmail.com

[1] Orthopedics and Traumatology Department, Medical Faculty, Medipol University, Atatürk Bulvarı. No:27 Unkapani, Fatih, 34083 Istanbul, Turkey

[2] Orthopedics and Traumatology Department, Medical Faculty, Ondokuz Mayıs University, Samsun, Turkey

[3] Orthopedics and Traumatology Department, Kanuni Sultan Suleyman Training Hospital, Istanbul, Turkey

[4] Anatomy Department, Medical Faculty, Ondokuz Mayıs University, Samsun, Turkey

Introduction

Intraoperative tourniquet use is a common method to decrease blood loss and obtain a bloodless surgical area during total knee arthroplasty (TKA), an operation associated with significant blood loss because of extensive soft tissue and bone damage [13, 23]. However, the benefits and risks of tourniquet use are contradictory. Although tourniquet use can shorten the operation time, allow a better visualization of the surgical area, control intraoperative blood loss, and increase the tibial cement

Table 1 Basic characteristics of each study group

	TKA with tourniquet (Group A)	TKA without tourniquet (Group B)	Total	*p* value
Number of patients	35	39	74	–
Number of knees	70	78	148	–
Age (years)	67.4 ± 4.3 (55–74)	65.8 ± 5.1 (58–78)	66.5 ± 4.8 (55–78)	n.s.
Sex (female/male)	30/5	32/7	62/12	n.s.
Site of TKA				
Right	16	17		–
Left	19	22		–

TKA total knee arthroplasty, *n.s.* not significant

mantle thickness, recent studies have shown that the overall blood loss does not change with tourniquet use because occult bleeding (also known as hidden blood loss) can continue for several hours after the operation [20, 23]. Furthermore, tourniquet use is a well-known risk factor for thromboembolism after TKA [23, 29, 33]. Other potential complications of tourniquet use include postoperative thigh pain, wound pain because of reactive hyperperfusion after tourniquet deflation [23], vascular injury [28], and nerve palsy [18]; furthermore, in rare cases, tourniquet use includes acute pulmonary oedema, cardiac arrest [6, 17], and thigh fat necrosis [24].

Most of the previous studies on the efficacy and safety of tourniquets have focused on blood loss and thromboembolism, whereas only a few have evaluated the effect of tourniquets on the physical function [14, 15]. Tourniquet use causes electromyographical changes in the quadriceps muscles and increases the plasma myoglobin levels [10, 22], suggesting that tourniquets can induce muscle damage. However, the effect of tourniquets on muscle volume and patients' postoperative functionality has not been studied to date. Further studies on the effect of tourniquets on the physical function are currently being undertaken to clarify the benefits of tourniquet use [15].

In the present study, it was aimed to determine the effect of tourniquet use in TKA on thigh and quadriceps muscle volume using magnetic resonance imaging (MRI), which has not been reported to date. MRI was used to estimate muscle volume, a technique considered to be the gold standard [16]. The functional outcomes of patients who underwent TKA with and without tourniquet use were also compared. Our hypothesis was that tourniquet use during TKA has negative effects on the functional outcomes by decreasing thigh and quadriceps muscle volumes.

Materials and Methods

In total, 174 knees of 87 patients with stage 4 bilateral primary varus gonarthrosis according to the Kellgren–Lawrence radiological classification scale for tibiofemoral joint degeneration [12] underwent unilateral TKA with or without tourniquet use from 2012 to 2014 and were included in this retrospective case–control study. Thirteen patients were excluded from this study because of the following reasons: muscle strength of less than 5/5 (1 patient), body mass index of >35 kg/m^2 (1 patient), history of hip surgery (1 patient), contralateral control knee surgery in the previous year (9 patients), and contraindication for MRI (1 patient). Therefore, 148 knees of 74 patients were analysed.

The patients were divided into two groups: Group A comprised 35 patients who underwent TKA with tourniquet use, and Group B comprised 39 patients who underwent TKA without tourniquet use (Table 1). The decision of tourniquet use was taken by the surgeon.

The study was approved by the institutional ethics committee of Medipol University, which operates under the national and international standards (no, 68; date, 12/02/2015), and conducted in accordance with the latest version of the Declaration of Helsinki.

Surgical technique

All operations were performed by two surgeons (O.G. and S.M.) with a 7-year experience each. The decision of tourniquet use during TKA was solely based on each surgeon's clinical and personal experiences. In practice, one of the two surgeons (O.G.) always used a tourniquet during arthroplasty surgery, whereas the other (S.M.) never used. Their decision was not affected by any patient-related factor. The standard TKA to retain the posterior cruciate ligament was performed through parapatellar entrance with a fixed-bearing prosthesis using cement (Vanguard; Biomet, Warsaw, IN, USA) under spinal–epidural plus general anaesthesia. In Group A, after the leg had been exsanguinated, a tourniquet was kept inflated throughout the operation at twice the arterial blood pressure and released after suture application.

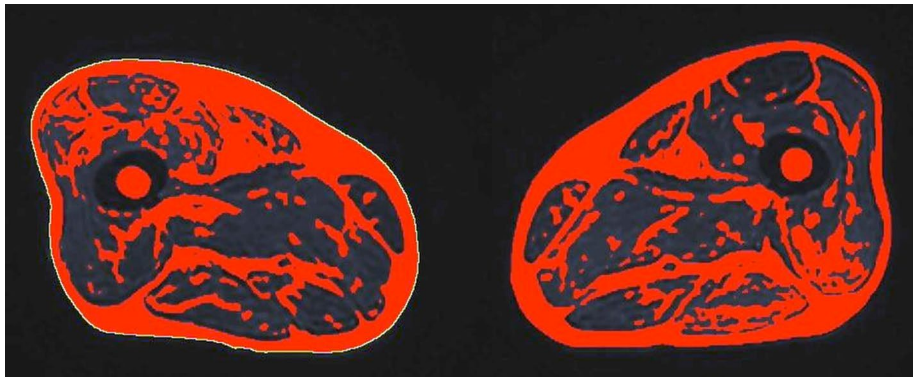

Fig. 1 Calculation of the total volume of the right thigh on single axial T2-weighted MRI. The *yellow line* shows the thigh circumference

From the first day after surgery, the patients were allowed to walk using two walking sticks for a period of 1 month and using one stick thereafter. The standard postoperative rehabilitation program was applied to all patients. Continuous passive motion was performed in flexion postoperatively for 15 days, depending on the patients' tolerance level. Isometric quadriceps exercises were continued postoperatively for 3 months. The patients were evaluated postoperatively at 1, 3, 6, and 12 months.

MRI and evaluation

MRI was performed preoperatively and postoperatively at 1, 3, 6, and 12 months by two surgeons who performed the operations (O.G. and S.M.). To ensure the accuracy of image fusion, both surgeons performed the measurements on all axial MR images between the hip joint and femur supracondylar region. All imaging studies were conducted on a 1.5-Tesla MRI device (Sigma HDXT; General Electric, Chicago, IL, USA). T2-weighted MRI scans were obtained in the axial and sagittal planes covering the hip joint and supracondylar region of the femur, and the hip and knee joints were fully extended. The area was continuously scanned at an axial slice thickness of 8 mm with 2-mm spaces, a matrix of 320×224, and Nex $= 2$. Images were stored in a picture archiving and communication system (PACS; General Electric, Chicago, IL, US) and viewed on a RadiAnt DICOM Viewer for Windows (Medixant, Poznan, Poland). Serial images of the thigh were exported for volume analysis. For each thigh, another software package (ImageJ 1.45 s; NIH, Bethesda, MD, USA) was used to measure the sectional areas of the examined structures on MRI. Cavalieri's principle of the stereological technique was used for this process. The sectional areas of total thigh, bone, soft tissue, and quadriceps muscles were individually measured. The tissue to be measured was marked leaving no space in the outer surface margin. In accordance with the shape of tissue in the sectional area, the volume within the outer surface was measured by combining the marked points. The structures were multiplied by the section thickness, and the final volume was obtained in cm^3 with one decimal point of accuracy. All volume calculations were performed on MS Excel worksheets (2007; Microsoft, Redmond, WA, USA), where the results were automatically obtained by entering the section thickness and area of the structure into the worksheet.

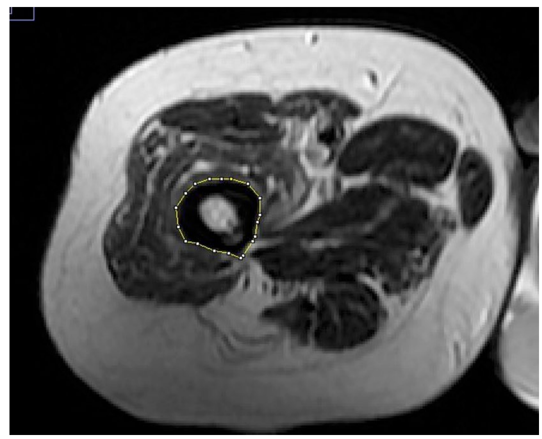

Fig. 2 Calculation of right femoral bone and muscle tissue volumes on single axial T2-weighted MRI

Regions of interest were delineated in ImageJ to assess the total section surface areas of the thigh (Fig. 1), bone (Fig. 2), and soft tissue (fat, muscle, and connective tissue) (Fig. 3). The section surface area of the region of interest was automatically calculated using the software. These values were then used for the estimation of the volume for all structures in cm^3. For standardization, the volume of the region between the trochanter minor in the proximal femur and supracondylar aspect of the distal femur was calculated. Furthermore, the muscle volumes of the vastus lateralis, vastus medialis, rectus femoris, and vastus intermedius (Fig. 4) were stereologically estimated in cm^3.

Study parameters

The total thigh volume; volumes of the connective, bone, and muscle tissues of both thighs; and muscle volumes of the vastus medialis, vastus lateralis, rectus femoris, and

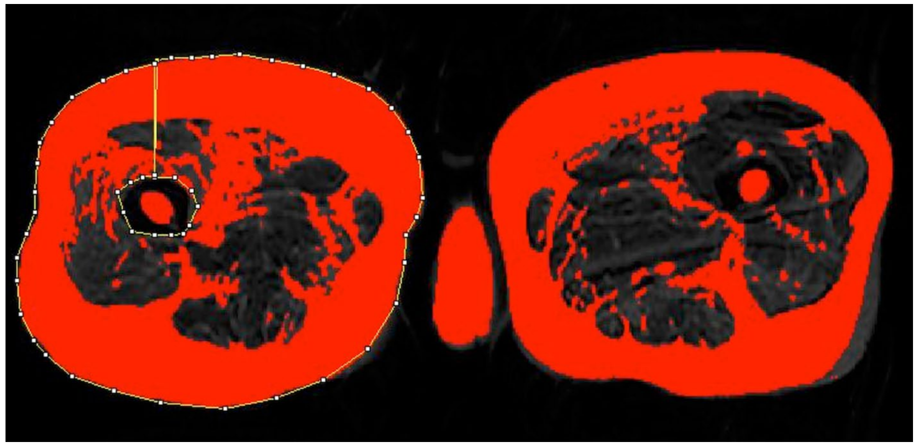

Fig. 3 Calculation of right thigh soft tissue (fat and connective tissue) volume on single axial T2-weighted MRI. The outer *yellow line* indicates the thigh circumference. The area between the two *yellow lines* indicates the non-bone soft tissue

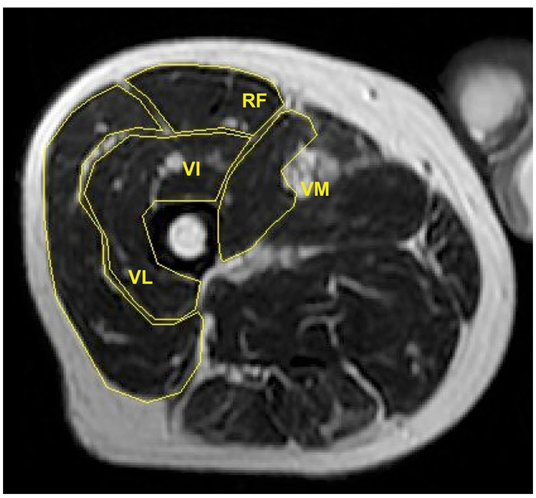

Fig. 4 Calculation of the muscle volume of the right vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), and vastus intermedius on single axial T2-weighted MRI

vastus intermedius were stereologically measured on preoperative and postoperative MRI. Moreover, the preoperative and postoperative Knee Society Score (KSS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score [2], which are the routine scoring systems used preoperatively and postoperatively in all patients who underwent TKA in our clinic, were used to evaluate the patients' functional outcomes.

Statistical analysis

Study data were summarized using descriptive statistics, i.e. mean, standard deviation, and range for continuous variables and frequency and percentage for categorical variables. The change over time and the difference between the operated and contralateral knees were analysed using the preoperative and follow-up tissue volume and KSS/WOMAC scores of both groups.

Repeated-measures analysis of variance was used to test the difference between more than two dependent and normally distributed variables. A paired-samples *t* test was applied for the post hoc analysis of significant results.

The difference between two and more than two dependent and non-normally distributed variables was analysed using the Wilcoxon signed-rank test and the Friedman test, respectively. The Wilcoxon signed-rank test was used as a post hoc test following the Friedman test. The interobserver variability for interpreting the MR images was determined by comparing the 95 % confidence intervals of every parameter calculated by each of the two surgeons. The power of the study was calculated by post hoc power analysis on the total WOMAC score results at postoperative first month and found to be 98.3 % through an online power calculator program (http://clincal.com/).

The statistical level of significance was set as $p \leq 0.05$. Analysis was performed using the MedCalc Statistical Software (version 12.7.7; MedCalc Software bvba, Ostend, Belgium).

Results

The study groups were considered to be similar in terms of age and sex (Table 1). The operated site was the left thigh in 19 of 35 patients from Group A and in 22 of 39 patients from Group B.

Tissue measurements

MRI tissue volume measurements for thighs on the operated and contralateral non-operated sides are summarized in Tables 2 and 3 and Fig. 5. Although no difference was found between the operated and contralateral non-operated thigh volumes in Group B postoperatively at 1 month, the operated side lost 20 % of its volume ($p < 0.001$) in Group A postoperatively at 1 month. However, the muscle tissue

Table 2 Descriptive statistics of preoperative and postoperative tissue measurements in operated and contralateral non-operated knees of each study group

	Preoperative	Postoperative 1st month	Postoperative 3rd month	Postoperative 6th month	Postoperative 12th month
Thigh					
Group A					
Operated knee	***4012.8 ± 319.3***	***3230.3 ± 269.1***	***3756.5 ± 291.0***	***3930.4 ± 327.1***	***4031.5 ± 319.9***[a]
Contralateral non-operated knee	4021.3 ± 334.4	4019.0 ± 334.4	4021.1 ± 333.6	4022.6 ± 337.1	4023.5 ± 336.4[b]
Group B					
Operated knee	4077.4 ± 343.0	4076.9 ± 339.9	4074.8 ± 337.7	4074.8 ± 356.9	4079.7 ± 341.6
Contralateral non-operated knee	4073.4 ± 347.1	4073.4 ± 348.2	4070.8 ± 347.7	4072.3 ± 347.7	4074.7 ± 349.4
Connective tissue					
Group A					
Operated knee	***2369.0 ± 195.3***	***2075.9 ± 181.8***	***2344.4 ± 187.6***	***2353.8 ± 194.1***	***2379.1 ± 194.9***[a]
Contralateral non-operated knee	2379.2 ± 203.1	2378.4 ± 203.9	2377.9 ± 202.7	2379.0 ± 203.3	2380.3 ± 203.2
Group B					
Operated knee	2382.0 ± 243.0	2384.8 ± 243.5	2383.0 ± 242.5	2379.5 ± 258.7	2386.8 ± 241.9
Contralateral non-operated knee	2379.0 ± 246.2	2380.6 ± 246.7	2378.5 ± 245.9	2378.7 ± 244.8	2379.9 ± 246.1
Bone tissue					
Group A					
Operated knee	104.9 ± 5.7	105.0 ± 5.7	105.0 ± 5.7	104.9 ± 5.8	104.9 ± 5.6
Contralateral non-operated knee	104.9 ± 5.7	105.1 ± 5.8	104.7 ± 5.8	105.0 ± 5.8	104.9 ± 5.7
Group B					
Operated knee	102.3 ± 7.8	102.6 ± 7.4	102.5 ± 7.7	102.6 ± 7.7	102.6 ± 7.6
Contralateral non-operated knee	102.5 ± 7.0	102.6 ± 6.5	102.9 ± 6.8	102.5 ± 6.6	102.8 ± 6.8
Muscle tissue					
Group A					
Operated knee	***1538.9 ± 153.2***	***1049.3 ± 129.5***	***1307.1 ± 135.6***	***1471.7 ± 165.8***	***1547.5 ± 152.3***[a]
Contralateral non-operated knee	1537.2 ± 157.9	1535.5 ± 157.6	1538.5 ± 158.0	1538.6 ± 160.2	1538.3 ± 159.8[c]
Group B					
Operated knee	1593.4 ± 148.9	1589.5 ± 146.5	1589.3 ± 143.6	1592.8 ± 148.2	1590.3 ± 149.9
Contralateral non-operated knee	1591.9 ± 150.2	1590.2 ± 151.3	1589.4 ± 151.9	1591.2 ± 150.2	1592.2 ± 152.1

Data are given as mean ± standard deviation in cm^3. Statistically significant measurements are marked as bold and italic

[a] $p < 0.001$ for the change with time. [b] $p = 0.004$ for the overall difference between operated versus contralateral non-operated knees. [c] $p < 0.001$ for the overall difference between operated versus contralateral non-operated knees

volume of the operated knees increased with time in Group A postoperatively after 3 months ($p < 0.001$), reaching the muscle volume of the contralateral non-operated side at 12 months.

The operated side in patients from Group A exhibited a significant postoperative decrease in all tissue measurements, except bone tissue volume (Tables 2, 3, Fig. 5). On the other hand, the operated or contralateral non-operated side in Group B exhibited no statistically significant difference in all tissue measurements (Tables 2, 3).

A significant difference was noted in all tissue measurements, except connective and bone tissue volumes, of the thigh between the operated and contralateral non-operated knees in Group A (Table 3). However, no significant difference was noted in all tissue measurements between the operated and contralateral non-operated knees in Group B (Table 3).

Table 3 Descriptive statistics of preoperative and postoperative muscle tissue measurements in operated and contralateral non-operated knees in each study group

	Preoperative	Postoperative 1st month	Postoperative 3rd month	Postoperative 6th month	Postoperative 12th month
Total quadriceps					
Group A					
Operated knee	***696.7 ± 88.5***	***415.8 ± 72.1***	***547.8 ± 83.1***	***630.5 ± 91.8***	***690.8 ± 81.6***[a]
Contralateral non-operated knee	697.3 ± 88.5	695.4 ± 86.3	697.0 ± 83.9	697.5 ± 87.1	696.1 ± 89.6[b]
Group B					
Operated knee	696.4 ± 88.1	695.0 ± 88.4	691.9 ± 86.1	696.3 ± 87.6	696.1 ± 87.7
Contralateral non-operated knee	697.1 ± 88.1	695.5 ± 88.3	697.1 ± 87.6	696.9 ± 87.7	696.7 ± 88.1
Vastus lateralis					
Group A					
Operated knee	***245.2 ± 35.5***	***149.5 ± 24.8***	***195.8 ± 28.9***	***225.6 ± 29.4***	***242.4 ± 29.1***[a]
Contralateral non-operated knee	244.1 ± 34.3	243.5 ± 33.5	245.0 ± 32.7	245.1 ± 34.5	244.7 ± 34.7[b]
Group B					
Operated knee	242.9 ± 30.9	242.3 ± 31.2	242.9 ± 30.6	243.0 ± 30.8	243.1 ± 30.9
Contralateral non-operated knee	243.2 ± 31.0	242.3 ± 31.2	243.4 ± 30.6	243.3 ± 30.8	243.2 ± 30.9
Vastus medialis					
Group A					
Operated knee	***136.2 ± 17.7***	***85.6 ± 14.5***	***114.3 ± 18.5***	***130.9 ± 23.8***	***134.7 ± 17.6***[a]
Contralateral non-operated knee	137.5 ± 17.8	137.2 ± 17.6	137.8 ± 17.7	137.7 ± 17.9	137.9 ± 17.6[b]
Group B					
Operated knee	137.6 ± 18.8	137.3 ± 18.9	137.7 ± 18.8	137.8 ± 18.8	137.8 ± 18.8
Contralateral non-operated knee	137.8 ± 18.7	137.5 ± 19.0	137.9 ± 18.8	137.9 ± 18.7	137.9 ± 18.8
Vastus intermedius					
Group A					
Operated knee	***193.8 ± 24.7***	***85.6 ± 14.5***	***147.4 ± 22.9***	***171.1 ± 28.4***	***192.5 ± 24.9***[a]
Contralateral non-operated knee	195.1 ± 25.4	137.2 ± 17.6	194.7 ± 23.8	195.1 ± 23.9	193.8 ± 26.9[b]
Operated knee	195.8 ± 25.7	195.6 ± 25.7	195.5 ± 25.5	195.5 ± 25.6	195.5 ± 25.5
Contralateral non-operated knee	195.9 ± 25.7	195.8 ± 25.6	195.7 ± 25.6	195.7 ± 25.7	195.6 ± 25.6
Rectus femoris					
Group A					
Operated knee	***121.5 ± 12.0***	***67.7 ± 12.9***	***90.3 ± 13.7***	***102.9 ± 11.5***	***121.1 ± 12.6***[a]
Contralateral non-operated knee	120.7 ± 12.3	120.3 ± 11.9	119.5 ± 11.2	119.5 ± 12.2	119.6 ± 12.3[b]
Group B					
Operated knee	120.1 ± 13.8	119.8 ± 13.9	119.9 ± 13.7	119.9 ± 13.8	119.8 ± 13.6
Contralateral non-operated knee	120.2 ± 13.8	119.9 ± 13.8	120.1 ± 13.8	119.9 ± 13.8	119.9 ± 13.9

Data are given as mean ± standard deviation in cm^3. Statistically significant measurements are marked as bold and italic

[a] $p < 0.001$ for the change with time. [b] $p < 0.001$ for the overall difference between operated versus contralateral non-operated knees

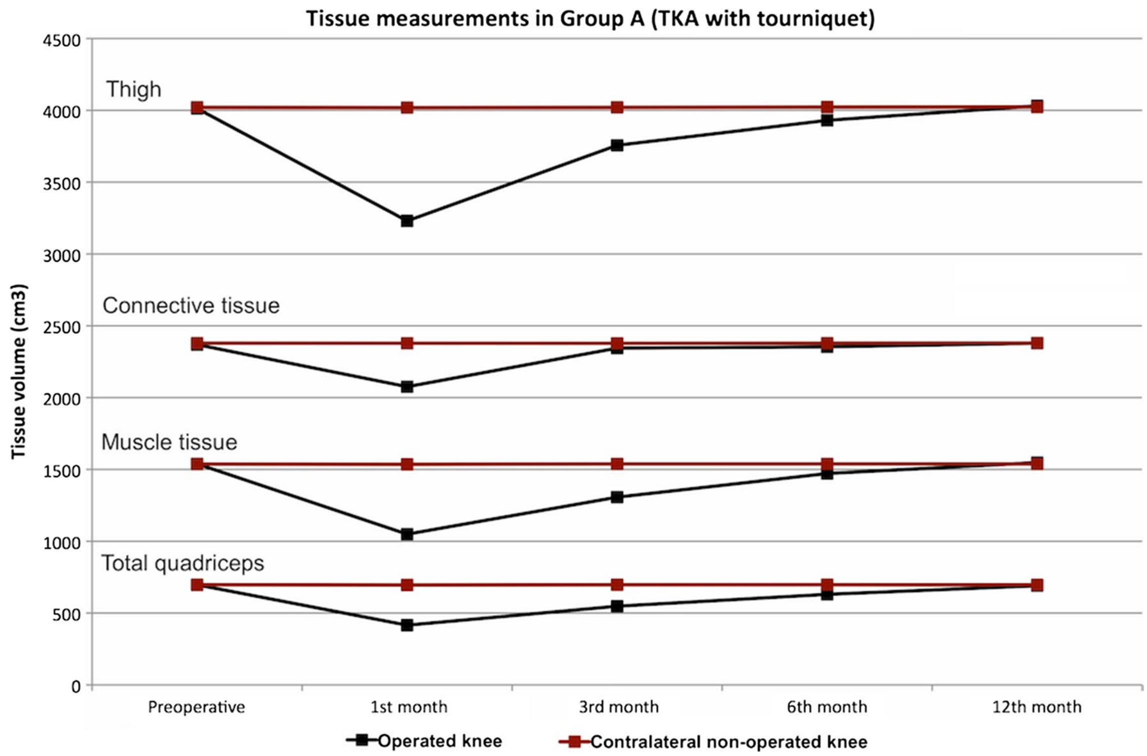

Fig. 5 Preoperative and postoperative tissue measurements in operated and contralateral non-operated knees of patients who underwent TKA with a tourniquet (Group A). On the operated side, $p < 0.001$ for change with time for all tissues

WOMAC score and KSS

The total WOMAC score and subscores for pain, stiffness, and physical function were significantly lower after the operation in both Group A and Group B ($p < 0.001$ for all) (Table 4, Fig. 6). The decrease was significant throughout the 12-month follow-up period (Table 4). The total WOMAC score was significantly higher in Group A than in Group B postoperatively at 1–6 months ($p < 0.001$ for all) but not at 12 months (Table 4). The physical function scores postoperatively at 1–6 months, stiffness scores postoperatively at 3 months, and pain scores postoperatively at 3 to 6 months were also significantly different between the two groups ($p < 0.001$ for all) (Table 4).

The KSS knee and functional scores were significantly higher in the operated knees of both groups during the 12-month postoperative period than the preoperative period ($p < 0.001$ for all) (Table 5, Fig. 7). The KSS for Group A was significantly lower than that for Group B postoperatively at 1–6 months (Table 5). The 95 % confidence intervals for the independent measurements of each parameter were similar among the surgeons, indicating that there was no significant interobserver variability. The measurements derived from the images were also reproducible.

Discussion

The most important finding of the study was that tourniquet use during TKA had a negative impact on the thigh muscles and could postoperatively delay the functional recovery of patients.

Because of the low quality of evidence among the large number of clinical studies on the perioperative tourniquet use in TKA, many meta-analysis studies have recently been published. All these meta-analyses showed that the potential complications of tourniquet use in TKA outweigh its benefits and that the long-term outcome of tourniquet use is uncertain [1, 9, 23, 31, 33, 34]. These studies suggested that although tourniquet use saves time, it increases thromboembolic complications and does not significantly reduce blood loss [1, 9, 23, 31, 33, 34]. Li et al. [13] indicated that tourniquet use may promote postoperative hidden blood loss and prevent patients' participation in early rehabilitation exercises. Ejaz et al. [4] showed that TKA without tourniquet use results in better functional and clinical outcomes, i.e. faster recovery and wider range of motion. Recent studies have also suggested tourniquet use at a lower pressure [19, 27] or for a limited time during the operation, for example, during cementation [5, 25] or wound closure [32, 34], to eliminate the risks associated with prolonged

Table 4 Preoperative and postoperative Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores of operated knee of study groups

WOMAC subscale	Preoperative	Postoperative 1st month	Postoperative 3rd month	Postoperative 6th month	Postoperative 12th month	*p* value (Change with time)
Pain						
Group A ($n = 35$)	16.9 ± 1.9	10.60 ± .9	4.2 ± 0.9	2.3 ± 0.7	1.6 ± 0.5	<0.001[a]
Group B ($n = 39$)	16.1 ± 1.8	9.9 ± 1.3	2.1 ± 0.6	1.6 ± 0.5	1.6 ± 0.5	<0.001[a]
p value (Groups A vs. B)	0.047	0.037	<0.001	<0.001	n.s.	
Stiffness						
Group A ($n = 35$)	6.08 ± 1.09	2.94 ± 0.76	1.68 ± 0.63	0.60 ± 0.55	0.28 ± 0.45	<0.001[a]
Group B ($n = 39$)	5.82 ± 1.04	2.69 ± 0.83	0.69 ± 0.56	0.51 ± 0.55	0.38 ± 0.54	<0.001[a]
p value (Groups A vs. B)	n.s.	n.s.	<0.001	n.s.	n.s.	
Physical function						
Group A ($n = 35$)	50.17 ± 4.99	39.14 ± 4.23	24.02 ± 3.77	11.02 ± 2.50	8.97 ± 1.22	<0.001[a]
Group B ($n = 39$)	48.92 ± 5.21	35.89 ± 2.81	11.92 ± 2.36	8.94 ± 1.23	8.82 ± 1.16	<0.001[a]
p value (Groups A vs. B)	n.s.	<0.001	<0.001	<0.001	n.s.	
Total score						
Group A ($n = 35$)	73.22 ± 7.48	52.68 ± 5.05	29.91 ± 4.52	13.88 ± 3.04	10.88 ± 1.40	<0.001[a]
Group B ($n = 39$)	70.84 ± 7.45	48.48 ± 3.56	14.74 ± 2.61	11.07 ± 1.61	10.74 ± 1.40	<0.001[a]
p value (Groups A vs. B)	n.s.	<0.001	<0.001	<0.001	n.s.	

Data are given as mean ± standard deviation

n.s. not significant

[a] $p < 0.001$ for preop versus postop 1st, 3rd, 6th, and 12th months

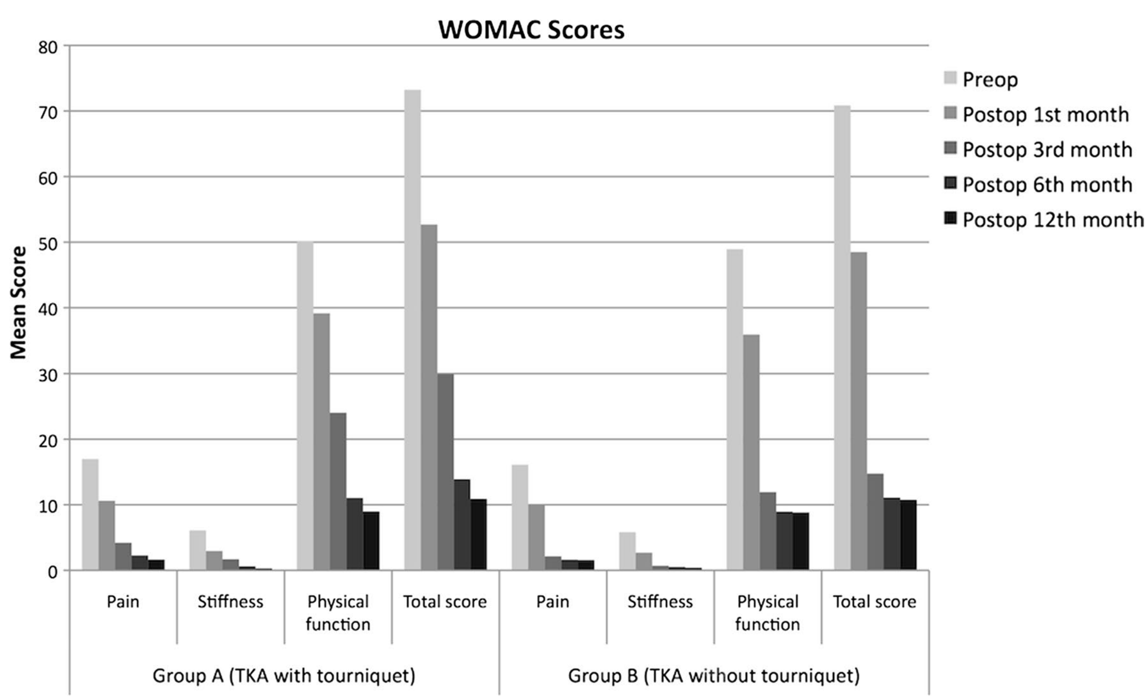

Fig. 6 Preoperative and postoperative Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores for the operated knees of patients who underwent TKA with (Group A) and without (Group B) a tourniquet

Table 5 Preoperative and postoperative Knee Society Score (KSS) of operated knee of study groups

KSS subscore	Preoperative	Postoperative 1st month	Postoperative 3rd month	Postoperative 6th month	Postoperative 12th month	*p* value (Change with time)
Knee score						
Group A ($n = 35$)	34.48 ± 2.91	57.45 ± 5.53	68.68 ± 5.31	77.62 ± 5.00	83.80 ± 5.23	<0.001[a]
Group B ($n = 39$)	34.35 ± 2.76	61.00 ± 4.84	80.12 ± 5.46	81.74 ± 4.58	82.15 ± 4.04	<0.001[a]
p value (Groups A vs. B)	n.s.	0.017	<0.001	<0.001	n.s.	
Functional score						
Group A ($n = 35$)	29.85 ± 10.60	47.14 ± 8.68	61.71 ± 7.27	73.71 ± 5.98	82.85 ± 7.10	<0.001[a]
Group B ($n = 39$)	31.92 ± 8.55	64.35 ± 8.59	80.89 ± 5.48	83.07 ± 5.45	82.82 ± 5.10	<0.001[a]
p value (Groups A vs. B)	n.s.	<0.001	<0.001	<0.001	n.s.	

Data are given as mean ± standard deviation

n.s. not significant

[a] $p < 0.001$ for preop versus postop 1st, 3rd, 6th, and 12th months

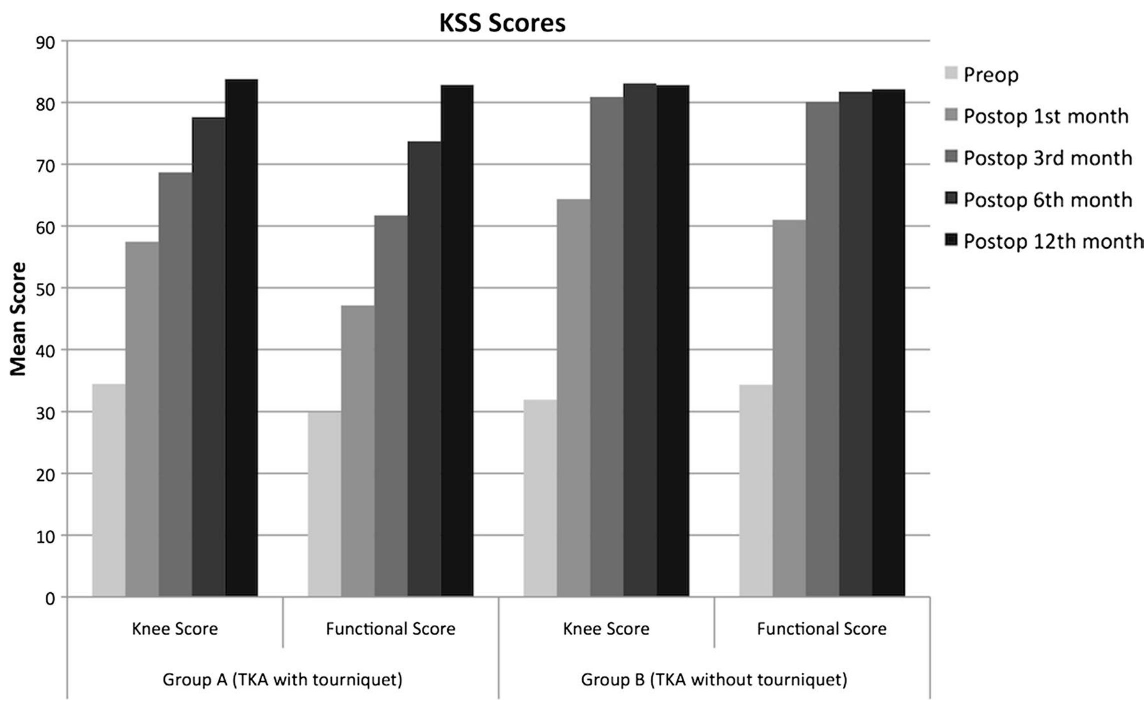

Fig. 7 Preoperative and postoperative Knee Society Score (KSS) of the operated knee in patients who underwent TKA with (Group A) and without (Group B) a tourniquet

tourniquet use. In addition, instead of tourniquet use, other measures that have been shown to be effective and safe in reducing blood loss have been proposed, including the use of tranexamic acid [3, 11]. However, all aspects of tourniquet use should be extensively evaluated to reach a final conclusion on the benefits and risks of perioperative tourniquet use in TKA.

Tourniquets can cause tissue ischaemia and reperfusion, but the outcome of ischaemia/reperfusion on the muscles and soft tissues of the thigh remains incompletely understood. Therefore, in this study, the effect of tourniquet use on the volume of the entire thigh, the quadriceps femoris, and other thigh muscles was investigated.

Hocker et al. [8] obtained biopsies from the vastus lateralis during TKA and found increased endoplasmic reticulum stress in muscle tissue with tourniquet use. The biopsies from the quadriceps femoris muscle in TKA with tourniquet use indicated that tourniquet-induced ischaemia/

reperfusion induces changes in glutathione metabolism, signifying oxidative stress [30]. Liu et al. [14] compared quadriceps function using electromyography following TKA with and without tourniquet use in 20 patients with osteoarthritis. They found that the tourniquet group had significantly more pain and limited quadriceps function than the non-tourniquet group postoperatively at 6 months. Consistent with the previous studies, it was found that the quadriceps and other thigh muscles were negatively affected by the perioperative tourniquet use. In the group with tourniquet use, in comparison with the non-operated knees, the operated knees exhibited significantly lower thigh and all-muscle volumes for the total quadriceps, vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris. However, in patients who underwent TKA without tourniquet use, no significant difference was observed in tissue measurements between the operated and non-operated knees. It was considered that the negative effect of a tourniquet on thigh muscle volume is caused by tourniquet-induced tissue ischaemia and reperfusion, which initiates a cascade of tissue reactions leading to oxidative stress, as previously shown [8, 14, 21].

A tourniquet-induced decrease in thigh muscle volume is not without clinical effects. The patients' postoperative WOMAC score and KSS were evaluated because these are common indicators of pain and physical functionality in operated knees. Our results indicated that regardless of tourniquet use, the functionality of operated knees increased significantly with TKA from the first month after the operation. However, the improvement in functionality, which was evaluated by both the WOMAC score and KSS, was greater in patients who underwent TKA without tourniquet use than in those who underwent TKA with tourniquet postoperatively up to 12 months. However, both groups were found to have a similar level of functionality at the 12-month follow-up. Our findings regarding late functional recovery following TKA with tourniquet use are in line with those of previous studies, which reported that functional recovery following TKA is closely associated with the strength of the thigh muscles, particularly the quadriceps femoris muscle [21]. In a meta-analysis of 13 randomized clinical trials involving 689 patients, the postoperative knee range of motion in the tourniquet group was less than that in the non-tourniquet group during the early stages after surgery; therefore, tourniquet use may hinder patients' early postoperative rehabilitation exercises [33].

The present study primarily showed that tourniquet use during TKA had negative effects on the knee functions and patients' quality of life, as shown by WOMAC score and KSS; therefore, caution should be exercised for tourniquet use during TKA in daily clinical practice.

The retrospective design and small sample size were the main limitations of this study. Furthermore, the decision of tourniquet use was solely based on each surgeon's clinical and personal experiences, which represented a selection bias. Furthermore, all surgeries were performed by two surgeons, which was another source of bias. Because the decision of tourniquet use was based on each surgeon's preference, not defined by any randomization, and sample size would be small if only one surgeon's patients were included, two surgeons performed all surgeries. Another limitation was that intraobserver reliability could not be assessed. Despite these limitations, which prevented us from reaching a definitive conclusion, this was the first study to show an association between a decrease in thigh muscle volume and tourniquets use in TKA. Our results were significantly important because it is well known that the surgical factors such as approach and tourniquet use affecting the function and strength of the quadriceps femoris muscle should be understood and eliminated by surgeons to obtain the best TKA outcome [7, 26]. Further prospective studies with a larger sample size are needed to reach a final conclusion on the effect of tourniquet use in TKA on patients' thigh muscles and functionality and to suggest alternative clinical measures to prevent intraoperative blood loss.

Conclusion

In conclusion, the thigh and quadriceps muscle volumes are decreased, and recovery of knee functions is delayed postoperatively by tourniquet use in TKA. Therefore, the use of alternative methods for tourniquet use to prevent intraoperative blood loss is recommended.

Acknowledgments The authors would like to thank Enago (www.enago.com) for the English language review.

Compliance with ethical standard

Conflict of interest The authors declare no conflicts of interest.

References

1. Alcelik I, Pollock RD, Sukeik M, Bettany-Saltikov J, Armstrong PM, Fismer P (2012) 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 27:331–340
2. Bellamy N (1989) Pain assessment in osteoarthritis: experience with the WOMAC osteoarthritis index. Semin Arthritis Rheum 18:14–17
3. Bidolegui F, Arce G, Lugones A, Pereira S, Vindver G (2014) Tranexamic acid reduces blood loss and transfusion in patients undergoing total knee arthroplasty without tourniquet: a prospective randomized controlled trial. Open Orthop J 8:250–254
4. Ejaz A, Laursen AC, Kappel A, Laursen MB, Jakobsen T, Rasmussen S, Nielsen PT (2014) Faster recovery without the use of a tourniquet in total knee arthroplasty. Acta Orthop 85:422–426

5. Fan Y, Jin J, Sun Z, Li W, Lin J, Weng X, Qiu G (2014) The limited use of a tourniquet during total knee arthroplasty: a randomized controlled trial. Knee 21:1263–1268
6. Gielen M (1991) Cardiac arrest after tourniquet release. Can J Anaesth 38:541
7. Greene KA, Schurman JR 2nd (2008) Quadriceps muscle function in primary total knee arthroplasty. J Arthroplasty 23(7 Suppl):15–19
8. Hocker AD, Boileau RM, Lantz BA, Jewett BA, Gilbert JS, Dreyer HC (2013) Endoplasmic reticulum stress activation during total knee arthroplasty. Physiol Rep 1:e00052
9. Jiang FZ, Zhong HM, Hong YC, Zhao GF (2015) Use of a tourniquet in total knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials. J Orthop Sci 20:110–123
10. Jorgensen HR (1987) Myoglobin release after tourniquet ischemia. Acta Orthop Scand 58:554–556
11. Kelley TC, Tucker KK, Adams MJ, Dalury DF (2014) Use of tranexamic acid results in decreased blood loss and decreased transfusions in patients undergoing staged bilateral total knee arthroplasty. Transfusion 54:26–30
12. Kellgren JH, Lawrence JS (1957) Radiological assessment of osteo-arthrosis. Ann Rheum Dis 16:494–502
13. Li B, Wen Y, Wu H, Qian Q, Lin X, Zhao H (2009) The effect of tourniquet use on hidden blood loss in total knee arthroplasty. Int Orthop 33:1263–1268
14. Liu D, Graham D, Gillies K, Gillies RM (2014) Effects of tourniquet use on quadriceps function and pain in total knee arthroplasty. Knee Surg Relat Res 26:207–213
15. Lohmann-Jensen R, Holsgaard-Larsen A, Emmeluth C, Overgaard S, Jensen C (2014) The efficacy of tourniquet assisted total knee arthroplasty on patient-reported and performance-based physical function: a randomized controlled trial protocol. BMC Musculoskelet Disord 15:110
16. Maden-Wilkinson TM, Degens H, Jones DA, McPhee JS (2013) Comparison of MRI and DXA to measure muscle size and age-related atrophy in thigh muscles. J Musculoskelet Neuronal Interact 13:320–328
17. McGrath BJ, Hsia J, Epstein B (1991) Massive pulmonary embolism following tourniquet deflation. Anesthesiology 74:618–620
18. Olivecrona C, Blomfeldt R, Ponzer S, Stanford BR, Nilsson BY (2013) Tourniquet cuff pressure and nerve injury in knee arthroplasty in a bloodless field: a neurophysiological study. Acta Orthop 84:159–164
19. Olivecrona C, Ponzer S, Hamberg P, Blomfeldt R (2012) Lower tourniquet cuff pressure reduces postoperative wound complications after total knee arthroplasty: a randomized controlled study of 164 patients. J Bone Joint Surg Am 94:2216–2221
20. Pfitzner T, von Roth P, Voerkelius N, Mayr H, Perka C, Hube R (2014) Influence of the tourniquet on tibial cement mantle thickness in primary total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-014-3341-6
21. Saleh KJ, Lee LW, Gandhi R, Ingersoll CD, Mahomed NN, Sheibani-Rad S, Novicoff WM, Mihalko WM (2010) Quadriceps strength in relation to total knee arthroplasty outcomes. Instr Course Lect 59:119–130
22. Saunders KC, Louis DL, Weingarden SI, Waylonis GW (1979) Effect of tourniquet time on postoperative quadriceps function. Clin Orthop Relat Res 143:194–199
23. Tai TW, Lin CJ, Jou IM, Chang CW, Lai KA, Yang CY (2011) Tourniquet use in total knee arthroplasty: a meta-analysis. Knee Surg Sports Traumatol Arthrosc 19:1121–1130
24. Tamvakopoulos GS, Toms AP, Glasgow M (2005) Subcutaneous thigh fat necrosis as a result of tourniquet control during total knee arthroplasty. Ann R Coll Surg Engl 87:W11–W13
25. Tarwala R, Dorr LD, Gilbert PK, Wan Z, Long WT (2014) Tourniquet use during cementation only during total knee arthroplasty: a randomized trial. Clin Orthop Relat Res 472:169–174
26. Thienpont E (2013) Faster quadriceps recovery with the far medial subvastus approach in minimally invasive total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 21:2370–2374
27. Unver B, Karatosun V, Tuncali B (2013) Effects of tourniquet pressure on rehabilitation outcomes in patients undergoing total knee arthroplasty. Orthop Nurs 32:217–222
28. Wakankar HM, Nicholl JE, Koka R, D'Arcy JC (1999) The tourniquet in total knee arthroplasty. A prospective, randomised study. J Bone Joint Surg (Br) 81:30–33
29. Wauke K, Nagashima M, Kato N, Ogawa R, Yoshino S (2002) Comparative study between thromboembolism and total knee arthroplasty with or without tourniquet in rheumatoid arthritis patients. Arch Orthop Trauma Surg 122:442–446
30. Westman B, Weidenhielm L, Rooyackers O, Fredriksson K, Wernerman J, Hammarqvist F (2007) Knee replacement surgery as a human clinical model of the effects of ischaemia/reperfusion upon skeletal muscle. Clin Sci (Lond) 113:313–318
31. Yi S, Tan J, Chen C, Chen H, Huang W (2014) The use of pneumatic tourniquet in total knee arthroplasty: a meta-analysis. Arch Orthop Trauma Surg 134:1469–1476
32. Zan PF, Yang Y, Fu D, Yu X, Li GD (2015) Releasing of tourniquet before wound closure or not in total knee arthroplasty: a meta-analysis of randomized controlled trials. J Arthroplasty 30:31–37
33. Zhang W, Li N, Chen S, Tan Y, Al-Aidaros M, Chen L (2014) The effects of a tourniquet used in total knee arthroplasty: a meta-analysis. J Orthop Surg Res 9:13
34. Zhang W, Liu A, Hu D, Tan Y, Al-Aidaros M, Pan Z (2014) Effects of the timing of tourniquet release in cemented total knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials. J Orthop Surg Res 9:125