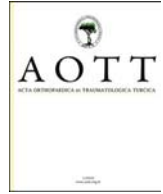


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Tourniquet pressure settings based on limb occlusion pressure determination or arterial occlusion pressure estimation in total knee arthroplasty? A prospective, randomized, double blind trial

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ABSTRACT

Objective: The aim of this study was to compare the limb occlusion pressure (LOP) determination and arterial occlusion pressure (AOP) estimation methods for tourniquet setting in adult patients undergoing knee arthroplasty under combined spinal-epidural anesthesia.

Methods: Ninety-three patients were randomized into two groups. Pneumatic tourniquet inflation pressures were adjusted based either on LOP determination or AOP estimation in Group 1 (46 patients, 38 female and 8 male; mean age: 67.71 ± 9.17) and Group 2 (47 patients, 40 female and 7 male; mean age: 70.31 ± 8.27), respectively. Initial and maximal systolic blood pressures, LOP/AOP levels, required time to estimate AOP/determinate LOP and set the cuff pressure, initial and maximal tourniquet pressures and tourniquet time were recorded. The effectiveness of the tourniquet was assessed by the orthopedic surgeons using a Likert scale.

Results: Initial and maximal systolic blood pressures, determined LOP, estimated AOP, duration of tourniquet and the performance of the tourniquet were not different between groups. However, the initial (182.44 ± 14.59 mm Hg vs. 200.69 ± 15.55 mm Hg) and maximal tourniquet pressures (186.91 ± 12.91 mm Hg vs. 200.69 ± 15.55 mm Hg) were significantly lower, the time required to estimate AOP and set the tourniquet cuff pressure was significantly less (23.91 ± 4.77 s vs. 178.81 ± 25.46 s) in Group II ($p = 0.000$). No complications that could be related to the tourniquet were observed during or after surgery.

Conclusion: Tourniquet inflation pressure setting based on AOP estimation method provides a bloodless surgical field that is comparable to that of LOP determination method with lower pneumatic inflation pressure and less required time for cuff pressure adjustment in adult patients undergoing total knee arthroplasty under combined spinal epidural anesthesia.

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Introduction

Pneumatic tourniquets which are widely used in extremity surgery may lead to soft tissue damage including the skin, vessels, muscles, and nerves due to unnecessarily excessive inflation pressure.^{1–4} Therefore, the use of the lowest effective tourniquet inflation pressure which provides a bloodless surgical field is recommended.^{5–15} However, there is still a lack of standard practice regarding optimal inflation pressures.^{16–19}

Limb occlusion pressure (LOP) and arterial occlusion pressure (AOP) are the terms that mean the lowest tourniquet pressure required to cease the arterial blood flow into the extremity distal to

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the cuff. LOP can be determined manually or automatically by slow cuff inflation to pulse cessation with a diagnostic equipment such as Doppler flowmeter or pulse oximeter.^{20–24} AOP can be estimated by a formula using patient's systolic blood pressure (SBP) and tissue padding coefficient (K_{TP}) values ($AOP = [SBP + 10]/K_{TP}$).^{25–27} In both methods, addition of a safety margin to LOP or AOP is recommended for potential hemodynamic fluctuations during surgery. Setting the tourniquet pressure on the basis of LOP or AOP allows to use a personalized tourniquet pressure in each individual patient and has been shown to be useful in optimizing tourniquet cuff pressures.^{20–27} However, we were unable to find a study which compared the LOP determination and AOP estimation based tourniquet pressure settings in extremity surgery.

The aim of the present study was to compare the practices of individualized tourniquet pressure settings based on LOP determination and AOP estimation methods in terms of LOP and AOP levels, required time to set the tourniquet pressures, tourniquet pressures and their effectiveness in adult patients scheduled for total knee arthroplasty (TKA) under combined spinal epidural anesthesia (CSEA).

Methods

After, ethical approval (Ethical Committee Number: KA13/96), informed consent was obtained from 100 patients scheduled for total knee arthroplasty with the pneumatic tourniquet under CSEA. Exclusion criteria were age outside the range of 18–85 years, American Society of Anesthesiology (ASA) physical status ≥ 3 , peripheral claudication, severe anemia, any contraindication to regional anesthesia, previous adverse reactions to medications used in the study, and inability to provide informed consent. The gender, age, ASA status, weight and height of the patients, circumference of the lower extremity were recorded.

In the operating room, an 18-gauge intravenous catheter was inserted in the arm; and 0.9% NaCl solution was administered. Supplemental oxygen (3 L/min) via a face mask was administered during the procedure. All patients were continuously monitored for heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), oxygen saturation (SpO_2), and respiratory rate (RR) during the surgical procedure. CSEA was performed in the sitting position via L3-4 interspace with 0.5% hyperbaric bupivacaine, followed by placement of an epidural catheter. The patients were turned to supine position and it was confirmed that the sensory block level reached at least T₁₀. Then, the patients were randomly assigned to one of two study groups. Randomization was provided using a computer-generated randomization list including 100 patients. Surgical procedure and anesthetic management were performed by the same surgical and anesthesia teams respectively. The attending anesthesiologist was aware of the allocated group, but the data analyst, surgeon and the patients were blinded to group allocation.

In Group I, the tourniquet cuff was placed around the thigh with the distal edge 15 cm proximal to the proximal pole of the patella. To determine the LOP, a pulse oximetry probe was applied to the toe at the side of the operation and the tourniquet was inflated slowly until the arterial pulsations disappeared on the monitor. This pressure was recorded as LOP and the tourniquet was deflated. The time required for the determination process was recorded. Following exsanguination of the limb with an Esmarch bandage, the tourniquet cuff was inflated to the pressure according to the guidelines of the Association of Perioperative Registered Nurses (AORN) which recommends that a safety margin of 40 mmHg should be added for AOP below 130 mmHg, 60 mmHg for AOP between 131 mmHg and 190 mmHg, and 80 mmHg for AOP above 190 mmHg for adult patients.²⁴

In Group II, the thigh circumference was measured 20 cm proximal to the superior pole of the patella with the knee in extension using a tape measure. Then the tourniquet cuff was placed around the thigh with the distal edge 15 cm proximal to the proximal pole of the patella. To determine the appropriate tourniquet inflation pressure, AOP estimation formula was used. The calculation ($AOP = [SBP+10]/K_{TP}$) was made using initial SBP and tissue padding coefficient (K_{TP}) values from a list, according to limb circumferences of the patient (Table 1).²⁵ After calculation of AOP, tourniquet pressure (TP) was determined by adding a safety margin of 20 mmHg to AOP ($TP = AOP + 20$ mm Hg). The time required for the measurement of extremity circumference and calculation process was recorded. Following exsanguination of the limb with an Esmarch bandage, the tourniquet cuff was inflated to the pre-determined setting in all patients. During the tourniquet period, TP was manually raised 10 mmHg in response to each 10 mmHg increment in SBP.

Primary outcome measures were initial and maximal SBP, LOP and AOP levels, initial and maximal tourniquet pressures, required time to estimate AOP and determine LOP and set the cuff pressure and tourniquet time. Secondary outcome measure was tourniquet performance determined by the quality of bloodless operative field. The orthopedic surgeon who was blinded to group allocation rated the performance of the tourniquet using a 4-point scale [1 (Excellent) = No blood in the surgical field, 2 (Good) = Some blood in the surgical field but no interference with surgery, 3 (Fair) = Blood in the surgical field but no significant interference with surgery, 4 (Poor) = Blood in the surgical field obscures the view] at the beginning, in the middle, and at the end of the surgical procedure. All patients were examined on the day after surgery for signs of any complications, such as skin damage, nerve palsies, or vascular occlusion that could be associated with the use of a tourniquet. The patients were also asked whether or not they felt pain, burning, coldness, numbness, or paresthesia on their feet by a blind investigator.

The t test was used for continuous data. The χ^2 test was used for comparison of categorical data. A P value of less than 0.05 was

Table 1
Tissue padding coefficients based on limb circumferences.²⁸

Extremity Circumferences (cm)	Estimated K_{TP}
20	0.91
21	0.90
22	0.89
23	0.88
24	0.87
25	0.86
26 to 27	0.85
28	0.84
29	0.83
30 to 31	0.82
32 to 33	0.81
34	0.80
35 to 36	0.79
37 to 38	0.78
39 to 40	0.77
41 to 43	0.76
44 to 45	0.75
46 to 48	0.74
49 to 51	0.73
52 to 54	0.72
55 to 57	0.71
58 to 60	0.70
61 to 64	0.69
65 to 68	0.68
69 to 73	0.67
74 to 75	0.66

K_{TP} = Tissue padding coefficient.

considered to be statistically significant. All data were analyzed by using SPSS 20.0 for Windows. Calculation of sample size was based on the primary end point of the study, the initial and maximal tourniquet pressures of 2 groups. We assumed that the difference of the initial and maximal tourniquet pressures was around 20% between the groups. Assuming a 10% decrease, 33 patients were needed in each group with α value of 0.05, effect size of 90%, and a power of 95%. Because we assessed multiple parameters, we planned to include 50 patients in each group.

Results

A total of 93 patients were included in the study and all patients received CSEA anesthesia for the operation. Seven patients were excluded because of missing data. The demographic characteristics (age, gender, ASA status, weight, height, circumference of the lower extremity) were not statistically different among groups (Table 2).

Initial systolic and diastolic blood pressures, determined LOP and estimated AOP values were not different between groups. In Group II, the time required to estimate AOP and set the tourniquet cuff pressure was significantly less (23.91 ± 4.77 s vs. 178.81 ± 25.46 s) than Group I ($p = 0.000$). Initial pneumatic tourniquet pressure was also significantly lower (182.44 ± 14.59 mm Hg vs. 200.69 ± 15.55 mm Hg) in Group II ($p = 0.000$). Additionally, maximal tourniquet pressures were significantly lower (186.91 ± 12.91 mm Hg vs. 200.69 ± 15.55 mm Hg) in Group II ($p = 0.000$) although maximal systolic arterial blood pressures were not different between groups during the tourniquet period, The mean tourniquet application times were comparable in both groups (Table 3).

The performance of the tourniquets was assessed as excellent or good in all stages of the procedure in all patients in both groups. No complications such as damage to skin, vessels, nerves, or compartment syndrome that could be associated with the use of a tourniquet was observed during or after surgery (Table 4).

Discussion

This study showed that both LOP determination and AOP estimation methods based tourniquet inflation pressure setting ensures equally effective bloodless surgical field without pressure related tourniquet complications in total knee arthroplasty under combined spinal epidural anesthesia. However, AOP estimation method based tourniquet pressure setting provided significant advantages in terms of reduced required time for cuff pressure adjustment and lower cuff inflation pressures when compared with LOP determination method based tourniquet inflation pressure setting.

Evidence from the literature shows that higher tourniquet pressures are associated with higher complications including skin, muscle, vessel, nerve injuries and wound infections.^{1–4} Thus, the use of a minimal effective tourniquet inflation pressure which provides a bloodless surgical field is desired.^{5–15} Although, clinical efforts and advances in tourniquet technology have resulted in the use of lower inflation pressures, there is still a lack of standard

practice and consensus regarding minimal effective tourniquet inflation pressures.^{16–18} Most of the orthopedic surgeons even routinely apply fixed tourniquet pressure of 250–300 mmHg or add fixed amount of pressure above SAP ($SAP + 100–150$ mm Hg) in lower extremity surgery based on individual experiences and accept these pressures as safe, in spite of reported adverse effects due to unnecessarily high tourniquet pressures.^{7,19}

Experimental and clinical studies showed that tissue pressures under a tourniquet cuff are lower than cuff pressures, which are inversely correlated with the circumference of the limb and the most important factors affecting minimal tourniquet pressures include the girth of the limb and SBP of the patient in tourniquet pressure adjustment.^{9–12,20–27} LOP and AOP are the terms which represent the minimal pneumatic tourniquet inflation pressure required to stop the arterial flow into the limb. LOP can be determined by inflating the cuff and observing at which pressure the distal pulse is ceased. In this method, addition of a safety margin to LOP for potential hemodynamic fluctuations during surgery is recommended.^{20–24} Reid et al reported that a bloodless field was provided at pressures of 231.0 ± 26.5 mmHg for lower extremity surgery by adding a safety margin of 75 mmHg to LOP.²⁰ The guidelines of the Association of Perioperative Registered Nurses recommend that a safety margin of 40 mmHg should be added for AOP below 130 mmHg, 60 mmHg for AOP between 131 mmHg and 190 mmHg, and 80 mmHg for AOP above 190 mmHg for adults.²² Since the LOP determination method requires additional monitoring and time, an automated tourniquet system was developed to measure LOP and set tourniquet pressure. Using this system, Younger et al found that 87.5% of patients had “excellent” or “good” operative field with a mean tourniquet pressure of 198.5 ± 20.2 mmHg in lower limb surgery.²³ They also reported that the time required to determine LOP was 20 ± 6 s.²³ On the other hand, these systems also have limitations such as the need for skilled personnel, special equipment with additional cost and perioperative workload on the team.²⁴ The AOP estimation method was developed based on a formula including systolic blood pressure (SBP) and tissue padding coefficient (KTP) values ($AOP = [SBP + 10]/KTP$) according to extremity circumference of patients.²⁵ Previous studies which used this method, revealed that the bloodless field was achieved at tourniquet pressures of 169.7 ± 7.9 mmHg and 173.3 ± 15.6 mm Hg in adult patients who underwent knee arthroplasty under hypotensive general and regional anesthesia respectively.^{26,27}

In this study, the mean estimated AOP and determined LOP levels were similar (160.04 ± 14.17 vs. 161.85 ± 15.75) in both groups, suggesting that the both methods are equally effective, because the extremity circumference and the initial SBP of patients were similar in both groups. Additionally, the surgical team rated the performance of tourniquet as “excellent” and “good” in all patients in both groups, showing that both methods provided equally effective bloodless surgical field. On the other hand, the mean initial tourniquet pressures applied with AOP estimation based tourniquet setting were approximately 9% lower when compared with LOP determination based tourniquet setting although the mean estimated AOP and determined LOP levels were similar in both groups. The difference in initial tourniquet pressures between groups can be explained by the amount of safety margin added to LOP and AOP. In Group I, a safety margin of 40–80 mmHg added to LOP, in accordance with the Association of Perioperative Registered Nurses’ recommendations.²² However, a safety margin of 20 mmHg which was lower than Group I was added to AOP in Group II, according to a previous study which successfully used AOP estimation method in lower limb procedures.²⁷ Moreover, the mean maximal tourniquet inflation pressures were also significantly lower (186.91 ± 12.91 vs. 200.69 ± 15.55) in AOP estimation based tourniquet setting. The possible explanation for this difference is the

Table 2
Demographic characteristics of the patients.

	Group I (n: 46)	Group II (n: 47)	p
Age (year)	67.71 ± 9.17	70.31 ± 8.27	0.154
Gender (Female/Male)	38/8	40/7	0.785
ASA status (I/II)	11/35	7/40	0.304
Weight (kg)	83.30 ± 14.91	82.55 ± 16.03	0.816
Height (cm)	160.67 ± 7.09	160.00 ± 6.31	0.629
Limb circumference (cm)	53.91 ± 8.11	55.40 ± 8.94	0.402

Variables are mean \pm Standard deviation (SD) or number.

Table 3
Blood pressures, tourniquet pressures and tourniquet times.

	Group I (n: 46)	Group II (n: 47)	p
Initial systolic blood pressure (mm Hg)	105.67 ± 9.81	105.27 ± 9.79	0.846
Initial diastolic blood pressure (mm Hg)	57.56 ± 6.60	58.23 ± 7.30	0.644
Time to estimate/determinate AOP and set the cuff pressure (second)	178.81 ± 25.46	23.91 ± 4.77	0.000
LOP in Group I and AOP in Group II (mm Hg)	160.04 ± 14.17	161.85 ± 15.75	0.562
Initial tourniquet pressure (mm Hg)	200.69 ± 15.55	182.44 ± 14.59	0.000
Maximal systolic blood pressure (mm Hg)	111.76 ± 7.45	109.74 ± 7.66	0.202
Maximal tourniquet pressure (mm Hg)	200.69 ± 15.55	186.91 ± 12.91	0.000
Tourniquet time (minute)	69.63 ± 15.96	66.19 ± 15.95	0.302

Variables are mean ± Standard deviation (SD) or number. AOP = Arterial occlusion pressure.

Table 4
Surgeon's opinion about the performance of the tourniquets at various stages of surgery.

Surgeon's Opinion	Stage of surgery					
	Group I (n: 46)			Group II (n: 47)		
	Initial n (%)	Middle n (%)	End n (%)	Initial n (%)	Middle n (%)	End n (%)
1 = Excellent	45 (97.82)	46 (100)	46 (100)	45 (95.74)	47 (100)	47 (100)
2 = Good	1 (2.17)	0	0	2 (4.25)	0	0
3 = Fair	0	0	0	0	0	0
4 = Poor	0	0	0	0	0	0
Complications	0			0		

anesthetic management of patients which provided stable hemodynamic profile during tourniquet period. As the only manageable factor SBP of the patients should be kept as low as possible and maintained throughout surgery. Previous studies, which used controlled hypotension in tourniquet pressure optimization, reported adequate bloodless field in all patients, with a mean tourniquet pressure of 169.7 ± 7.9 – 173.3 ± 15.6 mmHg for lower extremity surgeries and 118.2 ± 7.2 mmHg for upper extremity surgeries, values significantly lower than those previously reported and recommended in the literature.^{26–28} These findings show that anesthetic management is of critical importance in preventing intraoperative hemodynamic fluctuations to allow the use of minimal inflation pressures during the tourniquet period.

In our study, the mean time required to estimate AOP and set the tourniquet pressure in Group II was 23.91 ± 4.77 s which is significantly less than 178.81 ± 25.46 s for LOP determination method in Group I. This finding is consistent with the previous study which reported the required time of 19.0 ± 2.6 s for AOP estimation and tourniquet pressure setting.²⁷ Additionally, the time period of 23.91 ± 4.77 s for AOP estimation based tourniquet pressure setting is comparable to that reported (20 ± 6 s) using LOP determination method with automated tourniquet systems.²³

Several studies have suggested using wider tourniquet cuffs, as they allow arterial closure at lower pressures.^{21,29} Although wider cuffs stop the arterial flow with lower inflation pressures, Mittal et al found that wider cuffs impair nerve conduction more severely than narrower cuffs.³⁰ Moreover, in a prospective randomized study with 14 healthy volunteers, Kovar et al found no differences between narrow and wide tourniquets.³¹ We applied the same size cuff (11 cm) to all our patients in this study, because the tissue padding coefficients were determined using 11-cm wide tourniquet cuffs in the AOP estimation formula.²⁵

In conclusion, tourniquet inflation pressure setting based on AOP estimation method provides a bloodless surgical field that is comparable to that of LOP determination method with less required time for cuff pressure adjustment and lower pneumatic inflation pressure in adult patients underwent total knee arthroplasty under CSEA. The reduction of tourniquet pressure with this method may reduce the frequency and severity of pressure related tourniquet

complications. The simplicity, speed and effectiveness of AOP estimation method, with broader clinical usage, may make it a feasible method with safer, personalized cuff pressures in tourniquet applications in limb surgery.

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