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The Reduced Cuff Inflation Protocol does not improve the Tissue Oxygen Recovery after Tourniquet Ischemia

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Abstract

The study prospectively compared the kinetics of post-deflation tissue oxygen recovery between tourniquets with distinct inflation pressures. Forty knee arthroscopy patients were randomized into standard (350 mmHg) or reduced inflation pressure groups. In the latter group, arterial occlusion pressure was calculated according to a formula [(SBP+10)/K_{TP}], where SBP is the systolic blood pressure and K_{TP} is the tissue padding coefficient based on limb circumference; a safety margin of 40-80 mmHg was added based on occlusion pressure. Pulse oximeter probes were applied to operative and nonoperative second toes and connected to a vital signs monitor. After tourniquet inflation, arthroscopy, and cuff deflation, arterial oxygen saturation was measured and recorded by the monitor every minute for 15 minutes. Standard inflation pressure group tourniquet time averaged 50 minutes at 350 mmHg; the respective values in the reduced pressure group were 51 minutes and 256 mmHg. Oxygen saturation recovery in the studied extremity was immediate after cuff deflation, with a transient drop at 5 minutes and recovery at 13 minutes. The drop was later and lesser in the reduced pressure group. In the control extremity, a transient decrease occurred at 3 minutes, with recovery at 12 minutes. The dip was again less pronounced in the reduced pressure group. In the reduced pressure group bleeding into the arthroscopic field was noted in multiple procedures. Enrollment was stopped early, as the impaired visualization was a safety concern. Unlike in the standard inflation pressure group, a bloodless arthroscopy field was not maintained in the reduced pressure group. The kinetics of post-deflation oxygen saturation recovery was not significantly different between the two groups; however, a transient decrease occurred in post-deflation oxygen saturation in both the operative and nonoperative limbs. This suggests that elective tourniquet use can have systemic effects post-cuff deflation, which warrants further investigation.

Level of Evidence: Level II

Keywords: Intraoperative tourniquet; Oxygen saturation; Bloodless operative field; Knee arthroscopy

Introduction

Tourniquets are used daily in an estimated 15,000 extremity surgeries worldwide [1]. The risk for tourniquet-related complications appears to be directly related to the duration of cuff inflation as well as the inflation pressure [1-7]. Although research has suggested that unreasonably high tourniquet pressures are associated with increased postoperative pain and damage to underlying muscles and nerves, [1] high inflation pressures, typically defined as a pressure greater than 300 mmHg, are frequently used in an effort to maintain a bloodless operative field [8]. Several articles reported different methods for determining optimal inflation pressures, providing evidence that lower inflation pressures can provide a bloodless field with less risk for the patient [2,5,8]. Despite these findings, a recent survey has demonstrated that tourniquet pressures in a range of 300 to 350 mmHg are routinely used for the lower extremity, [8] and less than 20% of respondents routinely use tourniquet pressures of less than 250 mmHg in lower extremity surgery [2].

The current "gold standard" for determining limb occlusion pressure is to inflate the tourniquet cuff slowly until distal pulse cessation is achieved. This can be confirmed with distal limb diagnostic equipment such as a Doppler stethoscope or pulse oximetry [3]; however, these methods are time-consuming and generally outside the scope of what can reasonably be performed prior to a surgical procedure. Because of this limitation, Tuncali et al. [3] developed a formula to more accurately determine a specific patient's limb occlusion pressure based on their limb circumference and systolic blood pressure [AOP=(SBP+10)/K_{TP}], where AOP represents the arterial occlusion pressure, SBP-the systolic blood pressure, and K_{TP} is the tissue padding coefficient is based on the limb circumference as described in Table 1. Because systolic blood pressure normally fluctuates during the surgical procedure, and to account for this physiologic fluctuation of blood pressure, it has been proposed that a cuff inflation pressure safety margin be used to maintain a bloodless field [7]. The recommended safety margin is 40 mmHg for AOP less than 130, 60 mmHg for AOP 130-190, and 80 mmHg for AOP greater than 190 mmHg.

Most of the existing tourniquet clinical studies, to date, solely examine the optimum tourniquet inflation pressures used and bloodless quality of the operative field as a subjective measure of tourniquet effectiveness, but do not monitor limb tissue oxygen recovery after tourniquet deflation [6,7,9]. The objective of this study was to compare the effectiveness of the Tuncali's reduced tourniquet inflation pressure formula versus a standard tourniquet inflation pressure on achieving a bloodless operative field, and the pattern of limb tissue oxygen recovery following tourniquet deflation. The study hypothesis was that these outcomes would be similar for both tourniquet inflation methods.

Materials and Methods

The study was a prospective, randomized trial comparing the rate of

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tissue oxygen recovery by using pulse oximetry after tourniquet deflation in patients with reduced versus standard cuff inflation pressures in the operative limb, with the contralateral, non-operative limb used as a control. The study was in compliance with all policies and regulations regarding research involving human subjects, following a review and approval by our Institutional Review Board. The study inclusion criteria mandated that the eligible patients are identified as medically cleared for an elective, unilateral knee arthroscopy to be performed by a single surgeon at a single outpatient surgery center. These as eligible study subjects were subsequently enrolled between July 2013 and March 2014 following reviewing and discussing the study participation, and signing informed consent. The exclusion criteria, in addition to those patients who refused study participation, included patients undergoing anterior cruciate ligament repair, patients with lower extremity circumference of greater than 75 cm, and patients with an initial systolic blood pressure (SBP) greater than 160 mmHg. The enrolled study participants were randomized into a standard inflation pressure group (Group I) or a Tuncali reduced inflation pressure group (Group II) upon arrival to the surgery center. In Group II (reduced pressure) patients, the thigh circumference was measured 5 cm distal to the anterior superior iliac spine just prior to tourniquet application, and the initial SBP was recorded immediately after anesthesia induction. The arterial occlusion pressure formula [AOP=(SBP+10)/K_{TP}] was used to estimate individual patient arterial occlusion pressure. A safety margin was then added to this arterial occlusion pressure calculation: 40 mmHg for AOP less than 130, 60 mmHg for AOP 130-190, and 80 mmHg for AOP greater than 190 mmHg. In Group I (standard inflation) patients the tourniquet pressure was set at 350 mmHg. The tourniquets (Zimmer; Warsaw, IN, USA) employed were all of uniform width, but their length varied to best fit the patient's thigh circumference. Each tourniquet was applied over 3 layers of synthetic cast padding (3M Immobilization Products; St Paul, MN, USA) and secured with foam tape (Figure 1).

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

Table 1: Tissue padding coefficient based on limb circumference. Adopted from Tuncali et al. [3].

The operative extremity was cleaned with alcohol and prepped using ChloraPrep solution (CareFusion, San Diego, CA). After preparation of the limb for surgery, a sterile Nellcor pulse oximeter probe (Covidien; Mansfield, MA, USA) was applied to the second toe of the operative extremity, and another was applied to the second toe of the non-operative, control limb. The pulse oximetry probes were attached to a Phillips SureSigns VM3 vital sign monitor (Phillips Healthcare; Andover, MA, USA). The operative limbs were exsanguinated with an Esmarch bandage just prior to initiation of the surgical procedure, tourniquets were inflated to their appropriate pressure in accordance with the patient group, and all tourniquets remained inflated at the pre-

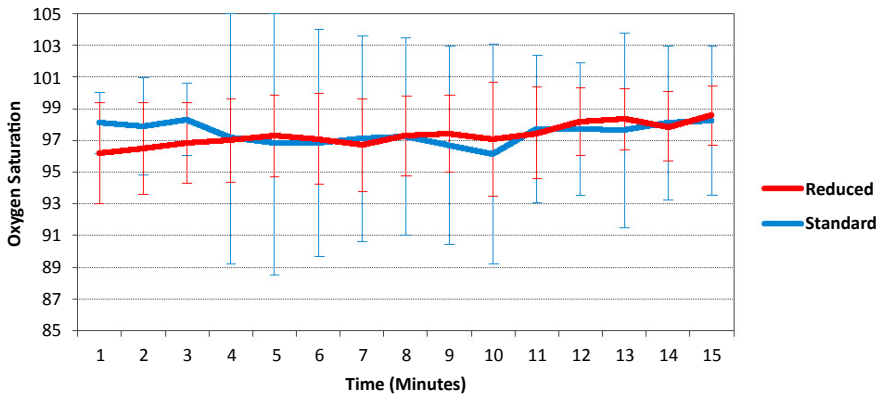

Figure 1: The oxygen saturation of the study extremity as a function of time.This graph compares the reduced pressure Group II (blue) to the standard pressure Group I (red).The oxygen saturation of the extremity appeared to recover immediately after tourniquet cuff deflation.There was a decrease in oxygen saturation observed at about 5 minutes which recovered at about 13 minutes.This decrease in saturation occurred an average of 3 minutes earlier and was more pronounced in the standard inflation pressure group compared to the reduced pressure group, although it did not reach statistical significance.

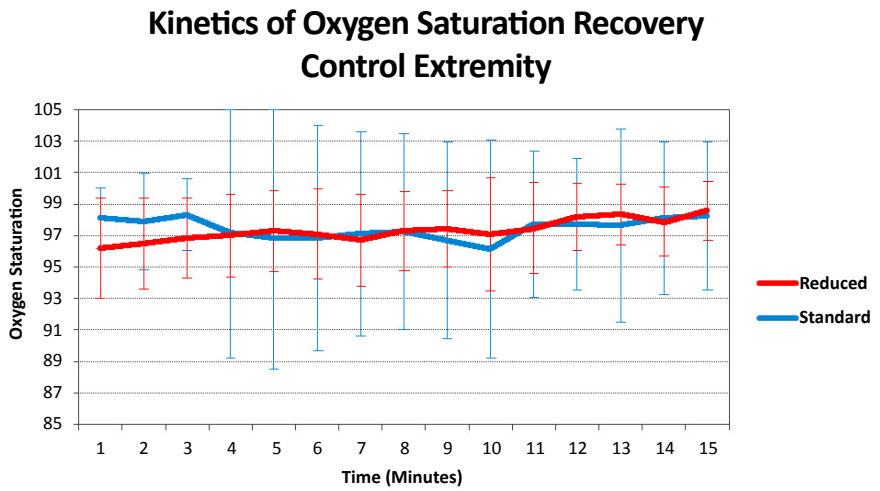

Figure 2:The recovery of the oxygen saturation of the control extremity as a function of time.A small decrease in oxygen saturation similar to that seen in the operative extremity is demonstrated, but it is less pronounced and occurs slightly later at about 8 minutes and recovered at approximately 12 minutes.This decrease in oxygen saturation was dampened in the reduced pressure group (group II), as the saturation dropped an average of 2 minutes later and by only 1-2 mmHg.This difference did not reach statistical significance.

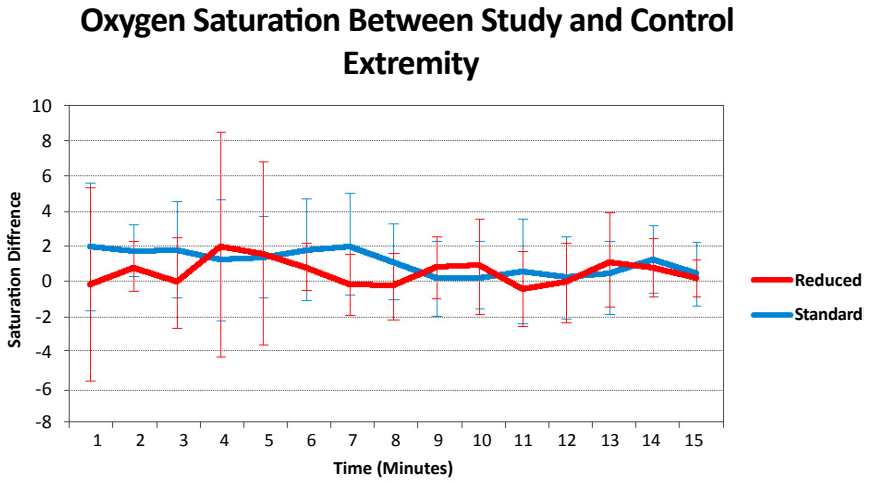

Figure 3: The difference in oxygen saturation between the study and control extremity as function of time.The reduced pressure group is represented by the blue line, and standard the red line.The operative and control saturations were slightly variable at the time of tourniquet deflation, became considerably more variable between 4 and 8 minutes, and were less divergent after the 8 minutes time point.Overall, there was no statistical significance between the oxygen saturation of the study and control extremity at any time point.

determined pressure until the sterile dressings had been applied at the conclusion of the procedure. The tourniquets were then deflated and immediately removed from the thigh. Pulse oximetry measurements were recorded every minute during the surgical procedure, and every minute for 15 minutes after tourniquet deflation.

Statistical Methodology

Post-deflation pulse oximeter levels were normalized as the difference in level between the operative and non-operative leg. A null hypothesis of no difference between the reduced pressure group and standard pressure group in normalized oximeter levels was assumed. Assessment of the differences within and between the reduced and standard cuff inflation pressure groups was performed using analysis of variance (ANOVA) with repeated measures, with confidence level set at 95%.

Results

Forty patients were enrolled in the study. There were 19 patients in the standard inflation pressure group (Group I) and 21 patients in the reduced inflation pressure group (Group II). In Group I, tourniquet inflation pressure was 350 mmHg in all subjects, and the average tourniquet inflation time was 50 minutes (range 30 to 72 minutes). In Group II, the average tourniquet inflation pressure was 256 mmHg (range 190 to 317 mmHg) and the average tourniquet inflation time was 52 minutes (range 30 to 70 minutes) (Figure 2).

Significant bleeding through the tourniquet during the arthroscopic procedure was encountered in the reduced pressure group. To maintain visualization during the procedure, the arthroscopic fluid pump pressure was increased when this bleeding was encountered. This allowed the surgeon to maintain the study protocol by not increasing the tourniquet

inflation pressure. Although this permitted the safe completion of the surgical procedures, enrollment of patients was stopped early because of the high incidence of impaired visualization in the reduced pressure group (Figure 3).

Discussion

A minimum tourniquet inflation pressure based on SBP has been proposed, where the cuff is inflated to the SBP plus 100 mmHg [2,8]. It has been suggested that this method of establishing tourniquet inflation pressure on the basis of SBP alone tends to be inaccurate. The relationship between limb occlusion pressure and SBP is variable, and depends on vessel wall compliance, the circumference of the limb, tourniquet cuff design, and limb tissue characteristics [1,7]. There are several methods for estimating the limb occlusion pressure, and our aim was to compare the rate of tissue reperfusion between one such estimation technique and a "standard" 350 mmHg inflation pressure. We used pulse oximetry to monitor the reperfusion of the limb after cuff deflation.

Pulse oximetry is a commonly employed, non-invasive way to measure the oxygen saturation of distal tissues, such as the finger, toe, or ear lobe [10]. In the present study pulse oximetry served as a reliable indicator of reperfusion of a limb that has been ischemic during an operative procedure performed with an inflated tourniquet. Because the pulse oximeter relies on pulsed arterial flow to measure oxygen saturation, it cannot be used during the surgical procedure to monitor the perfusion of the limb. It can, however, be used to monitor the kinetics of oxygen saturation recovery after deflation of the tourniquet, which was evaluated in our study.

Previous investigations have suggested that lower tourniquet inflation pressures may result in incomplete capillary occlusion, and therefore lead to decreased overall tissue hypoxia [11-15]. Based on these findings, it could be inferred that the recovery of tissue oxygenation after tourniquet deflation should be more rapid when the tourniquet is inflated to a lower pressure. The added benefits would also include improved wound healing, [12] possibly fewer free radicals formed and released into circulation, [16] and a reduction in the rebound hyperemia associated with tourniquet deflation [17].

By applying the Tuncali et al. formula [3] to patients undergoing knee arthroscopy, the average tourniquet inflation pressure was reduced by about 100 mmHg. We found no statistical significance in the kinetics of oxygen saturation recovery between the two groups. Although there are numerous established benefits to a decreased tourniquet inflation pressure, there does not appear to be an effect on tissue oxygen recovery. In addition, applying the reduced limb occlusion formula did not provide sufficient arterial occlusion to prevent bleeding in the arthroscopic field during surgery. Bleeding into the field in reduced inflation pressure patients made visualization difficult, and required an increase in the arthroscopic fluid pressure to counteract the bleeding and complete the surgical procedure. This is, obviously, a deleterious effect of a reduced tourniquet inflation pressure and, in our opinion, outweighs the advantages previously described.

When we examined the kinetics of oxygen saturation recovery, oxygen saturation of operative limbs recovered to near-normal levels almost instantly in both reduced and standard cuff inflation pressure groups. There was, however, a slight decrease in oxygen saturation between 4 and 12 minutes in the standard pressure group, and a smaller decrease from 6-12 minutes in the reduced pressure group. The precise etiology of this transient decrease in perfusion cannot be elucidated by our study design. This effect may, however, be related to the release of metabolic waste products into the circulation, or by the reperfusion injury incited by free radical formation [16]. Another possible explanation could be a compensatory vasoconstriction as a result of reactive hyperemia observed after tourniquet deflation [17]. The study protocol included a full, immediate release of the tourniquet at the end of the procedure, and it is unknown whether this rapid method of tourniquet deflation may have potentiated this observed effect. This transient decrease in post-deflation recovery oxygen saturation at the second toe was not only observed in the operative extremity in both reduced and standard tourniquet pressure groups, but it also occurred in the contralateral extremity of both groups as well. This suggests that tourniquet release may have widespread effects on the entire circulatory system, and not just the circulation of the operative extremity.

Our study had several limitations. First, we used the contralateral extremity as a control as opposed to the oxygen saturation of the limb prior to tourniquet inflation. Because the effects of tourniquet deflation were appreciated in both the operative and non-operative limbs, monitoring oxygen saturation before the procedure could have provided an additional level of control. Also, we did not correlate individual patient's blood pressure fluctuations during surgery with the presence or severity of bleeding into the arthroscopic field.

Conclusions

By monitoring the kinetics of tissue oxygen recovery after tourniquet ischemia during knee arthroscopic procedures, we were able to demonstrate that no significant difference in limb oxygen recovery exists between a standard cuff inflation protocol and a reduced inflation protocol using a previously described method of estimating arterial occlusion pressure. We also determined that the use of the limb occlusion formula [$AOP=(SBP+10)/K_{TP}$] with an added safety margin was ineffective in maintaining a blood-free arthroscopic field. Enrollment in our study was discontinued prematurely because of decreased visualization during surgery in the reduced inflation pressure group. The observed transient decrease in limb perfusion in both the operative and control extremities warrants further investigation into the local effects of tourniquet deflation, as well as further study of the systemic effect of tourniquet deflation, which is not fully understood.

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