

Perioperative Implications of Pneumatic Tourniquets Used During Orthopedic Surgery

Abstract

Objectives: The use of pneumatic tourniquets to prevent major bleeding is well established for orthopedic surgery; however, it is not without complications. The goal of this study was to evaluate the possible perioperative consequences among patients with use of such tourniquets during orthopedic surgery.

Method: This prospective cohort included: patients undergoing arthroscopic knee surgery and were over 18. Patients with diabetes, cardiac disease and those with renal or hepatic insufficiency were excluded. Before beginning the surgery (T1), immediately after surgery (T2) and 12 hours later (T3) after tourniquet de-insufflations, clinical and laboratory data from the patients were collected.

Results: Forty patients were included. The outcome assessment showed that the clinical and laboratory data collected at: T1, T2 and T3 showed statistically significant differences, mainly in T2, for mean arterial pressure, base deficits, PaCO₂, lactate, potassium and CPK. The tourniquet time showed a direct correlation with the length of hospital stay ($R^2 = 0.76$; $P < 0.001$); a longer tourniquet time was correlated with a longer hospital stay.

Conclusion: Careful perioperative monitoring must follow orthopedic surgery that requires the use of pneumatic tourniquets. The results of this study showed important clinical and laboratory alterations that might be associated with increased surgical risk.

Keywords

Orthopedics; Complications; Anesthesia; Pneumatic tourniquet; Correlation

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Abbreviations

ASA: American Society of Anesthesiology; CPK: Creatine-Phosphokinase; ARF: Acute Renal Failure; NO: Nitric Oxide

Introduction

The main role of the circulation is to ensure the perfusion of organs and tissues, promoting the supply of oxygen and nutrients as well the removal of end products from metabolism and carbon dioxide. When interruption of the blood flow to organs and tissues occurs, a state of hypo-perfusion or ischemia can happen. This is followed by impairment of the cellular functions necessary to maintain the viability of tissues, which can culminate in cell and tissue death [1]. Despite the fundamental importance of blood flow for the recovery of tissues, tissue reperfusion can trigger serious consequences that affect the entire body, even distant organs and systems, from the ischemic site [2-5].

In the practice of anesthesia, situations are encountered where the patient has tissue ischemia; this can be caused by the underlying disease and/or the anesthetic used during a surgical procedure or as an inherent part of the technique used during the procedure. An example includes orthopedic surgery that uses pneumatic tourniquets during the operation. The anesthesiologist must identify and manage the consequences of both tissue ischemia and reperfusion intra-operatively. The aim of this study was to evaluate the physiological changes and

effects associated with orthopedic surgery that uses a pneumatic tourniquet during the procedure.

Materials and Methods

A prospective cohort study, over one year, was conducted at the surgical center of a tertiary care hospital, after approval was received from the Ethics Committee of the institution; all participants signed an informed consent.

Only patients undergoing elective arthroscopic knee surgery that were over 18 years of age and required the use of a pneumatic tourniquet for the procedure were included in the study. Patients with diabetes, those with any infectious process, patients with cardiac problems or those with prior renal or hepatic insufficiency were excluded, because their underlying disease could influence the final findings of this study; specifically, their condition could cause acidosis. In order to determine the effects of the tourniquet on patient outcomes, these patients, with medical problems, were not included in this study.

To standardize the collection of data, the ASA (American Society of Anesthesiology) classification was used to determine patient severity as well as prior surgery comorbidities. Ringer lactate solution was used for volemic resuscitation and only the pneumatic tourniquet was used as a limb tourniquet during the procedure.

The patients were evaluated at three different times: before

the beginning of surgery (T1), immediately after pneumatic tourniquet deflation (T2) and 12 hours later (T3), after tourniquet deflation. During these time intervals, clinical and laboratory data (blood gas analysis, biochemical and blood lactate tests) from the patients were collected in order to determine whether the limb tourniquet time had an impact on these variables. All patients were followed until hospital discharge.

Statistical analysis

Initially the demographic, clinical and physiological characteristics of the patients included in the study were recorded. The categorical variables are described as frequencies and percentages. The quantitative variables are described using measures of central tendency and dispersion.

Because the sample included the same patients evaluated at different time intervals, the continuous variables were evaluated using the ANOVA test with the Bonferroni correction; the continuous variables with irregular distribution were analyzed using the Friedman method. Values of $p < 0.05$ (two-tailed) were considered significant. The SPSS 20.0 was used for the calculations. In addition, the Spearman test was used to identify correlations between the variables and the value of R^2 was considered acceptable when greater than 0.6.

Results

Forty patients were included in the study. The average age was 47.5 ± 19.1 years; 23 patients were men and 17 were women. The average surgical time was 3.2 ± 1.0 hours; all patients received spinal anesthesia and remained for an average of 2.4 ± 0.8 days in the hospital, with a minimum - maximum time of 1.0-4.0 days of hospitalization. The majority of patients were assessed as ASA 1 physical state (Table 1).

Interestingly, the outcome assessment of clinical and laboratory data for T1, T2 and T3 showed statistically significant differences in the values for the mean arterial pressure, differences in bases, PaCO_2 , lactate, potassium, and creatine-phosphokinase (CPK). Excluding the values of CPK and lactate, which increased 12 hours after tourniquet deflation, all other factors were worse after tourniquet deflation during recovery. Although the creatinine values did not reach statistically significant changes, 5% of the patients had values above 1.5 mg/dL and a maximum value of 2.3 mg/dL was noted 12hrs after surgery, even in patients with normal baseline creatinine (Table 2).

Given that the length of hospital stay was 1.0 to 4.0 days, when dividing this into four periods, it was found that the tourniquet time showed a direct correlation with the length of hospital stay ($R^2 = 0.76$; $p < 0.001$), that is, as the tourniquet time increased so did the hospital stay (Figure 1).

Discussion

The results of this study showed that the tourniquet time, during an orthopedic procedure for arthroscopic knee surgery, was associated with important physiological changes that should be taken into consideration when performing this type of surgery.

Limb reperfusion may increase the surgical risk, because of the associated acid-base changes, increases in serum potassium, hypotension and increased PaCO_2 , noted in this study; these changes can cause significant problems, especially in patients with underlying disease such as those with cardiac and lung problems, in whom they might be fatal.

Moreover, it was observed that late restoration of perfusion, that is, a longer tourniquet time, was followed by a slower rate of recovery. It was observed that a longer hospital stay was needed in these patients. Even in patients with comorbidities that underwent the same surgery, it is unclear whether an increased hospitalization time is justified.

Table 1: Characteristics of patients (N=40).

Variables	Characteristics
Age (years)	47.5±19.1
Male gender (%)	57.5
Weight (kg)	76.7±13.8
Height (cm)	168.8±11.1
Physical state ASA (%)	
ASA 1	55.0
ASA 2	45.0
Comorbidities (%)	
No	55.0
Hypertension	32.5
Mild depression	2.5
Prostatic hyperplasia	2.5
Hypothyroidism	2.5
Mild asthma	2.5
Osteoarthritis	2.5
Surgery time (min)	194.1± 62.4
Limb tourniquet time (min)	117.6± 35.0
Days of hospitalization	2.4± 0.8

Table 2: Assessment of clinical and laboratory data at baseline (T1), immediately after tourniquet deflation (T2) and 12 hours after deflation (T3).

Variables	T1	T2	T3	P
Sodium (mEq/L)	140.6±2.5	140.3±2.7	140.0±3.4	0.58
Potassium (mEq/L)	3.6±0.3	4.1±0.5	3.8±0.4	0.001
Chlorine (mEq/L)	106.6±2.9	110.3±3.1	106.5±3.4	<0.001
Ionized calcium (mEq/L)	1.1±0.2	1.0±0.1	1.0±0.2	0.38
Lactate (mmol/L)	1.3±0.5	1.8±0.6	2.3±1.1	<0.001
pH	7.42±0.03	7.33±0.05	7.38±0.05	<0.001
HCO ₃ (mmol/L)	24.3±1.9	22.8±2.1	24.4±1.9	0.001
Difference bases (mmol/L)	0.11±0.9	-3.4±2.0	-0.63±2.5	<0.001
PaCO_2 (mmHg)	37.8±4.1	45.2±6.6	42.0±5.0	<0.001
Creatinephosphokinase (U/L)	115.2±107.1	138.7±106.7	301.2±250.8	<0.001
CPK (U/L)				
Creatinine (mg/dL)	0.93±0.2	0.88±0.2	1.1±0.4	0.14
Heart rate (hr/min)	73.5±12.7	73.2±14.5	68.0±8.9	0.09
Mean arterial pressure (mmHg)	96.2±14.4	82.7±14.4	90.8±11.9	<0.001

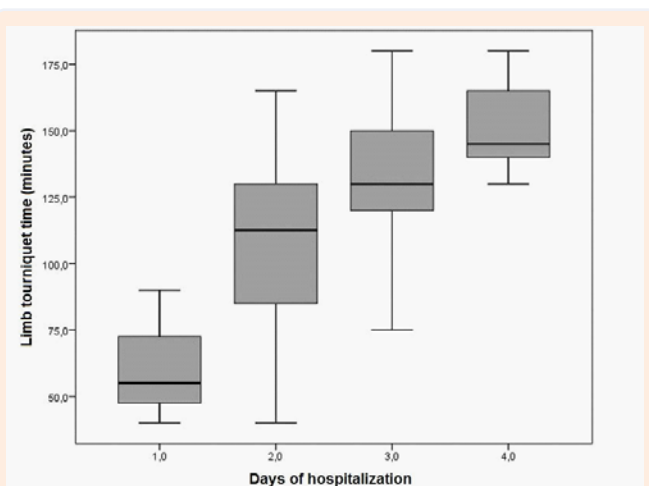


Figure 1: Relationship between limb tourniquet time and hospital stay; Friedman test, $p < 0.001$.

The consequences of oxygen deprivation of tissues are well known. During the Second World War, hemodynamically stable victims progressed rapidly to shock, tachycardia and death after the release of crushed limbs. During the Korean War, rapid clinical deterioration was observed when the blood flow was restored post-arterial reconstruction. The systemic effects may include the systemic inflammatory response syndrome and multiple organ dysfunctions, responsible for 30 to 40% of deaths [1].

The supply of oxygen and nutrients to the cells ensures the production of ATP, which is essential for all living cells; this proceeds by oxidative phosphorylation in the mitochondria. In cases of hypoxia, ATP is produced by the lactate-pyruvate cycle, which produces smaller amounts of ATP and excessive amounts of lactic acid. In this study, acidosis and hyperlactataemia were observed after tourniquet deflation. The metabolic acidosis was usually well tolerated; however severe acidemia may result in decreased cardiac contractility and peripheral vascular resistance [1,2,6].

The insufficient production of ATP is responsible for energy-dependent failure mechanisms associated with pump Na/K ATPase functioning, which promotes intracellular sodium influx, changes the polarity and function of the cell membrane and triggers cellular edema. There is a change in the balance of intracellular calcium with activation of enzymes that promote a genuine process of self-digestion of cells. The calcium itself promotes the activation of caspases that signal the initiation of apoptosis. Buffer substances, such as nitric oxide, cannot neutralize the oxygen free radicals, highly reactive and produced during cellular metabolism; they are impaired due to altered metabolism caused by ischemia. These radicals stay free in the cell reacting with cell membrane lipids and DNA. These reactions damage the cell structures and contribute to cell death [7].

One of the consequences, observed in clinical practice, is rhabdomyolysis evidenced by the increase in CPK. Despite being

a less precise marker to identify problems in the muscle cells, its increase may be linked to renal failure [8,9]; in this study an increase in CPK and serum creatinine occurred, but this did not appear to have significant effects, although a maximum value of creatinine of 2.3 mg/dl was found in 5% of patients that had values above 1.5 mg/dL after surgery, even though their basal creatinine was normal before tourniquet inflation. With acute renal failure (ARF) it is very difficult to manage patients' electrolyte changes during the acute reperfusion phase. Retrospective studies have shown that the development of ARF is a risk factor with an initial creatinine greater than 1.5 mg/dL and a baseline deficit of -4.0 or more negative. Patients without any of these factors almost never develop ARF. The presence of acidosis without prior abnormalities of renal function suggests an intermediate risk. CPK levels that were extremely high were associated with an increased likelihood of developing ARF that would require hemodialysis and possible permanent renal dysfunction [4, 9].

However, in the arterioles, the main change observed is a decrease in smooth muscle-dependent nitric oxide (NO) relaxation [10]. This was noted in this study when the blood pressure showed a significant decrease, although in the population studied this decrease was not considered severe. However, in other patients, such as those with cardiac dysfunction it can be fatal. The first consequence of flow release is an acute increase in the vascular content. The blood pressure may drop considerably and compromise global tissue perfusion. The hypotension should be corrected with the infusion of fluids and/or vasoactive drugs [11,12].

However, in the capillaries there is an increase in the capillary barrier permeability and extravasations into the interstitial space with edema. This edema causes compression and distortion of the capillary architecture, which contributes to the barrier structures formed by activated leukocytes and results in obstructing the circulation and worsening of the poor tissue perfusion [13]. For this reason the metabolic acidosis and the hyperlactataemia were noted as important factors in this study.

The lungs have been most extensively studied in the context of organ ischemia and reperfusion; some patients may have a catastrophic evolution [14]. In this study, the patients did not experience a direct worsening of oxygenation; perhaps because these patients did not have serious underlying health concerns and the surgery was elective. However, increased CO_2 was observed. In some patients with pulmonary pathology, as with CO_2 retainers, this may aggravate the situation. Some risk factors associated with cardiovascular disease appear to promote an increase in reperfusion injury. For example, hypercholesterolemia and diabetes mellitus appear to increase the expression of adhesion molecules in endothelium and leukocyte activation during reperfusion of ischemic areas [1,15]. For these reasons, patients with such pathologies were excluded from this study.

The revascularization phase changes with the blood flow of the vascular environment; leading to an impact on substances of the entire body as well as the cells present in the ischemic region.

The earliest change to appear or worsen is the acidosis caused by anaerobic metabolism [4,16,17]. There is also hyperkalemia caused by the release of intracellular potassium [8]. This may indicate a poor prognosis; the increase in potassium can lead to serious cardiac arrhythmias such as pulse less ventricular tachycardia or ventricular fibrillation with immediate death. Therefore, there is a need to monitor potassium levels, which is often ignored during these surgical procedures. The current study identified this problem, but only one patient had electrocardiographic abnormalities with mild symptoms. It is important to remember that only healthy individuals were included in this study. This might explain the absence of serious consequences; however, patients with serious underlying disease might have very different outcomes. Patients that experience tissue ischemia, such as for example acute arterial occlusions and those with various comorbidities may have a more complicated course pre, intra and post surgery. In such patients, the consequences of blood flow release to ischemic areas can be severe.

Despite the potential for severe consequences during reperfusion of ischemic areas, the re-establishment of tissue perfusion, as soon as possible, with blood flow recovery is essential [1,7]. However, the results of this study showed that the patients with a longer limb tourniquet time also had a longer hospital stay. The limitations of this study include the small sample size; however, this did not invalidate the study and the statistical significance of the findings. In addition, the problems associated with a cohort design.

Conclusion

Patients undergoing orthopedic surgery that require tourniquet use should be monitored carefully; there were important clinical and laboratory changes observed that could increase the surgical risk for some patients.

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