ORIGINAL ARTICLE

Effects of cyclic vs. non-cyclic deflation of pneumatic arterial tourniquet on haemodynamic and arterial blood gases in lower limb surgery: A prospective randomized study

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Abstract

Background: Arterial tourniquet in extremity surgery is an essential tool because it prevents bleeding and improves visualization of the surgical field. Both, tourniquet inflation and deflation are associated with haemodynamic changes. *Aim and Objectives:* To compare the effects of cyclic versus non-cyclic deflation of pneumatic arterial tourniquet on the haemodynamic and systemic parameters. *Material and Methods:* Sixty patients of Society of Anaesthesiologists Physical Status (ASA PS) I and II classification, undergoing lower limb surgery using pneumatic tourniquet under spinal anaesthesia were randomly allocated equally into Group A (non-cyclic deflation) and Group B (cyclic deflation- Deflated thrice with progressive difference in deflation periods). Standard anaesthesia protocol was followed. On completion of surgery or once permissible tourniquet time was reached, tourniquet was deflated as per the method assigned for the patient. The haemodynamic parameters and Arterial Blood Gases (ABG) values were compared just before and after deflation in both the groups. *Results:* In Group A, there was a significant fall in Mean Arterial Pressure (MAP) after 3 minutes, requiring vasopressor ($p < 0.01$, highly significant). After tourniquet deflation, the ABG sample 2 had significant variation with respect to bicarbonate and lactate values. In Group A, mean bicarbonate value was statistically lower than that of Group B (22.76 ± 2.05 v/s 24.06 ± 1.22) ($p = 0.004$). The lactate value in Group A was statistically higher than in Group B (1.73 ± 0.43 v/s 1.35 ± 0.42) ($p = 0.001$). Also, lactate in sample 2 was significantly high compared to sample 1 (1.76 ± 0.40 v/s 1.49 ± 0.6) ($p < 0.05$). *Conclusion:* Cyclic deflation is better than non-cyclic deflation with respect to hemodynamic stability and release of metabolites into blood stream.

Keywords*:* Tourniquet, Spinal Anaesthesia, Orthopaedic Surgery, Deflation, Haemodynamics

Introduction

Tourniquet use is a common practice in orthopaedic and plastic surgeries. They are compressive devices that occlude blood flow to the limbs to create bloodless surgical field and decrease the peri-operative blood loss, allow easy dissection and expedite surgery. Tourniquet usage is associated with several complications. Its use has been associated with several physiological alterations that can affect patient outcome following surgery. The complications may include both local and systemic [1].

The localised complications may result from either direct pressure to the underlying tissues or ischemia in tissues distal to the tourniquet and include nerve injury, vascular injury, skin/tissue necrosis, tourniquet pain etc. On the other hand, the systemic complications are related to tourniquet inflation and deflation and their duration. These include cardiovascular effects leading to haemodynamic alterations, tissue ischaemia, pulmonary embolism and metabolic effects. Among these, the haemodynamic changes that occur, though transient, may lead to devastating complications [2]. Tourniquet deflation is a critical stage as it causes a sudden drop in central venous pressure, Mean Arterial Pressure (MAP) and Heart Rate (HR) variability. Cardiac arrests have been reported following cuff deflation. This significant decrease in blood pressure causes an increase of the heart rate. In a worst-case scenario, a dramatic drop of the mean arterial pressure can lead to a distributive shock [3]. These hemodynamic changes are due to the combination of back shifting of blood volume into the limb and washout of metabolites from the ischemic limb into the systemic circulation causing hypotension, metabolic acidosis, hyperkalaemia, myoglobulinemia, myoglobinuria, and possible renal failure. Delayed deflation can also lead to compartment syndrome in acute trauma cases [4-6]. Numerous research studies have indicated that postoperative pain and swelling can be diminished by decreasing either the duration of tourniquet application or the pressure applied by the tourniquet. However, this remains a topic of debate and disagreement [7].

There are no specific and binding strict guidelines for inflation pressure, duration time, and way of deflation in tourniquet use. Decreasing the duration of tourniquet application or decreasing the pressure could potentially disrupt the surgeon's visibility, extend the surgical procedure duration, or compromise the precision of the surgery [8-9].

In general, this paper probably showcases results concerning the impact of varying deflation techniques for a pneumatic arterial tourniquet on factors related to circulatory dynamics and arterial blood gas levels in individuals having surgery on their lower limbs. We designed our study to evaluate the primary objectives of hemodynamic and Arterial Blood Gas (ABG) changes after cyclic and noncyclic deflation of tourniquet. Secondary objectives like oxygen saturation, respiratory rate and tourniquet pain were also assessed.

Material and Methods:

It was a prospective, randomized, single-blinded, observational study. This study was conducted at SDM College of Medical Sciences and Hospital, Dharwad. After obtaining approval from the Institutional Ethics Committee and written informed consent in the language best understood by all the patients, a total of 60 patients, of either gender, aged 18-70 years, belonging to American Society of Anaesthesiologists Physical Status (ASA PS) I and II, undergoing lower limb surgery (orthopaedic and plastic surgeries) (using pneumatic arterial tourniquet), were considered for the study. Patients were randomized into two groups of 30 each depending on the tourniquet deflation technique planned using computer-generated random numbers as:

Group A: Non-cyclic deflation: tourniquet deflated only once over 2 min.

Group B: Cyclic deflation with variable post-deflation interval: tourniquet deflated thrice with progressive increases in the periods of deflation: 0, 10 and 30 s respectively, separated by an interval of 1 min of re-inflation.

A thorough pre-operative assessment was done. After arrival of the patient to Operating Room (OR), Intravenous Cannula (IV) was secured and IV fluids started. Standard monitoring with 3- lead Electrocardiogram (ECG), Non-invasive Blood Pressure (NIBP), pulse oximeter (SpO_2) was initiated to record the baseline parameters. Under all aseptic precautions, anaesthesia was provided by subarachnoid block performed in sitting position, using 25G or 26G Quincke's needle introduced at L2-L 3 or L3-L4 interspace, with 13-16 mg of hyperbaric Bupivacaine 0.5% with Clonidine 30 µg used as additive. The patient was made to lie supine. The sensory level of anaesthesia was assessed by pin-prick method after 15 min. A level of T10 was achieved in all the patients. Before skin incision, the lower limb to be operated was exsanguinated by limb elevation for 2 min, an elastic bandage was used when indicated, beginning at the distal end up to 2 inch distal to tourniquet. A single-cuff pneumatic tourniquet was applied to the ipsilateral thigh and inflated to a pressure 100 mmHg above the Systolic Blood Pressure (SBP). The tourniquet was deflated once the permissible tourniquet time was reached. Depending on the deflation method followed, patients under study were categorised into 2 groups as mentioned.

The haemodynamic parameters were recorded just after induction of anaesthesia, intraoperatively, just before tourniquet deflation and after deflation i.e., every minute for first 5 min, and every 5 min for the next 15 min. Any drop in MAP >20% from baseline was managed by 0.1 mg/kg of Ephedrine. At the end of the procedure, two samples of arterial blood were taken from radial artery for ABG analysis, one 5 min before the tourniquet deflation and the second after deflation wherein the parameters such as PO_2, serum bicarbonate, and lactate were assessed.

Sample size was calculated using the formula;

$$\boxed{\text{Sample size } =} \left(\frac{r+1}{r}\right) \times \left(\frac{Sd^2 \; (Z_\beta + Z\alpha)^2}{d^2}\right)$$

Where,

r = Ratio

Z_β = Std normal variate for power 80% power = 0.84

$Z\alpha$ = 1.96

d = mean difference between groups

Sd = 1.4 (From previous studies)

d = 0.8

Therefore, the sample required was 48 cases. To strengthen the power of the study, the required sample size was rounded off and accordingly, 60 cases were selected & were randomly divided into two groups (30 in Group A: Non-cyclic deflation and 30 in Group B: Cyclic deflation) by computer generated random numbers.

Statistical analysis

The following data pertaining to each patient were recorded: demographic details, anaesthesia level attained, tourniquet inflation time and pressure, HR, SBP, Diastolic Blood Pressure (DBP), MAP, SpO_2, tourniquet deflation time and duration of tourniquet application. Two samples of arterial blood were taken for ABG analysis. All the data were collected, tabulated and expressed as Mean and Standard Deviation (SD). Categorical data were represented in the form of frequency and percentage. Chi-square test was applied to know the association between variables. Mean ± SD values were calculated for continuous variables.

Comparison of mean between two groups was done using unpaired student's *t*-test. Assessment within the group was done with paired t-test. Value of $p < 0.05$ was considered statistically significant and $p < 0.001$ was considered highly significant. IBM Statistical Package for Social Sciences (SPSS) version 22 for Windows was used for analyzing the data.

Results

In the present study, sixty patients belonging to ASA-PS I and II, scheduled to undergo elective lower limb surgeries (orthopaedic and plastic surgeries) under subarachnoid block were randomized into two groups i.e., Group A- non-cyclic deflation and Group B- cyclic deflation of tourniquet. None of the patients were excluded after recruitment and all patients completed the study. These groups were compared for haemodynamic changes and ABG analysis following tourniquet deflation. Demographic data (age and gender) was comparable in both the groups. The dosage of spinal anaesthetic (ml) used was 3.08 ± 0.31 in Group A and 3.11 ± 0.24 in Group B ($p = 0.608$, insignificant) and dosages were comparable among the groups. Both group patients received 30 μg of Clonidine as an additive along with the local anaesthetic according to protocol. The level of sensory blockade achieved was T10 to T6 among the group members. The baseline haemodynamic parameters with respect to heart rate, systolic and diastolic blood pressure, mean arterial pressure, SPO_2, respiratory rate ($p > 0.05$) were comparable among the two groups as shown in Table 1. The duration of tourniquet in minutes was 85.5 ± 33.57 in Group-A and 92.57 ± 27.82 in Group-B, ($p = 0.38$) and was not statistically significant (Table 2).

Haemodynamic parameters after tourniquet deflation

There was no significant variation in the heart rate before or after tourniquet deflation in both the groups ($p > 0.05$) (Table 3). Following tourniquet deflation, in Group A, there was a significant fall in SBP after 3 minutes (73.5 ± 13.76 at 3 min and 72.90 ± 11.98 at 4 min), requiring vasopressor.

However, in Group B, there was no significant variation with SBP after deflation ($p < 0.01$) (Figure 1). Following deflation, DBP in Group A had a significant fall after 3 min (53.1 ± 11.92 at 3 min, 50.4 ± 11.46 at 4 min and 51.3 ± 11.24 at 5 min). There was no significant variation in Group B ($p < 0.05$, significant) (Figure 2). There was a significant drop in the MAP among patients in Group A following tourniquet deflation (70.1 ± 9.94; 71.40 ± 9.81; 70.5 ± 9.39 at 3, 4 and 5 min respectively), which was not significant in Group B patients ($p < 0.05$) (Figure 3). There was no significant variation with respect to SPO_2 following tourniquet deflation in both groups ($p > 0.05$) (Figure 4). Respiratory rate did not show significant variation following tourniquet deflation, ($p > 0.05$) (Figure 5).

Requirement of vasopressor

Among the two groups, the requirement of vasopressor (Ephedrine) was significantly higher in Group A (30% v/s 10%) and also, few patients in Group A required an additional dose of vasopressor suggesting a significant hypotension in patients of Group A (10%) when compared to Group B ($p < 0.01$) (Figure 6).

ABG changes after tourniquet deflation

After tourniquet deflation, the ABG sample 2 had significant variation with respect to bicarbonate and lactate values. In Group A, mean bicarbonate value was statistically lower than that of Group B (22.76 v/s 24.06) ($p = 0.004$, $p < 0.05$). The lactate value in Group A was statistically higher than in Group B (1.35v/s 1.73) ($p = 0.001$).

In Group A, the post deflation PO_2 value (sample 2) was statistically lower than that of sample 1 (135.93 v/s 160.60) ($p < 0.000$). Also, lactate in sample 2 was significantly high compared to sample 1 (1.76 v/s 1.49) ($p < 0.05$) (Tables 4 and 5).

Table 1: Baseline parameters between Groups A and B

Baseline Parameters	Group A	Group B	*p*
HR (bpm)	79.90 ± 12.91	79.13 ± 12.77	0.818 NS
SBP (mmHg)	130.77 ± 17.67	130.97 ± 15.26	0.963 NS
DBP (mmHg)	77.93 ± 10.95	74.37 ± 11.37	0.221 NS
MAP (mmHg)	96.30 ± 11.53	94.40 ± 10.99	0.516 NS
SpO_2 (%)	98.07 ± 1.46	97.47 ± 1.61	0.136 NS
RR (cpm)	16.47 ± 2.57	17.43 ± 2.73	0.163 NS

Values expressed in Mean ± SD, NS=Not Significant
HR: Heart Rate, SBP: Systolic Blood Pressure,DBP: Diastolic Blood Pressure,MAP: Mean Arterial Pressure, SpO_2:Oxygen Saturation, RR: Respiratory Rate

Table 2: Comparison of duration of tourniquet inflation (min) between Groups A and B

Duration of tourniquet inflation (min)	Group A	Group B	*P*
	85.50 ± 33.57	92.57 ± 27.82	0.38 NS

Values expressed in Mean ± SD, NS=Not Significant

Table 3: Comparison of heart rate variation between Groups A and B

Heart Rate (bpm)	Group-A	Group-B	*p*
After inflation	78.33 ± 12.14	75.17 ± 14.46	0.362 NS
Just before deflation	77.33 ± 12.22	72.63 ± 12.15	0.141 NS
After deflation			
1 min	77.33 ± 11.72	75.33 ± 12.83	0.531 NS
2 min	77.43 ± 10.89	76.57 ± 14.46	0.794 NS
3 min	77.87 ± 10.75	77.73 ± 13.82	0.967 NS
4 min	78.97 ± 9.75	77.03 ± 14.07	0.538 NS
5 min	78.67 ± 11.37	76.23 ± 13.04	0.444 NS
10 min	77.90 ± 11.04	75.07 ± 11.97	0.345 NS
15 min	78.33 ± 11.27	76.03 ± 12.45	0.456 NS
20 min	78.37 ± 10.39	76.03 ± 11.80	0.420 NS

Values expressed in Mean ± SD, NS=Not Significant

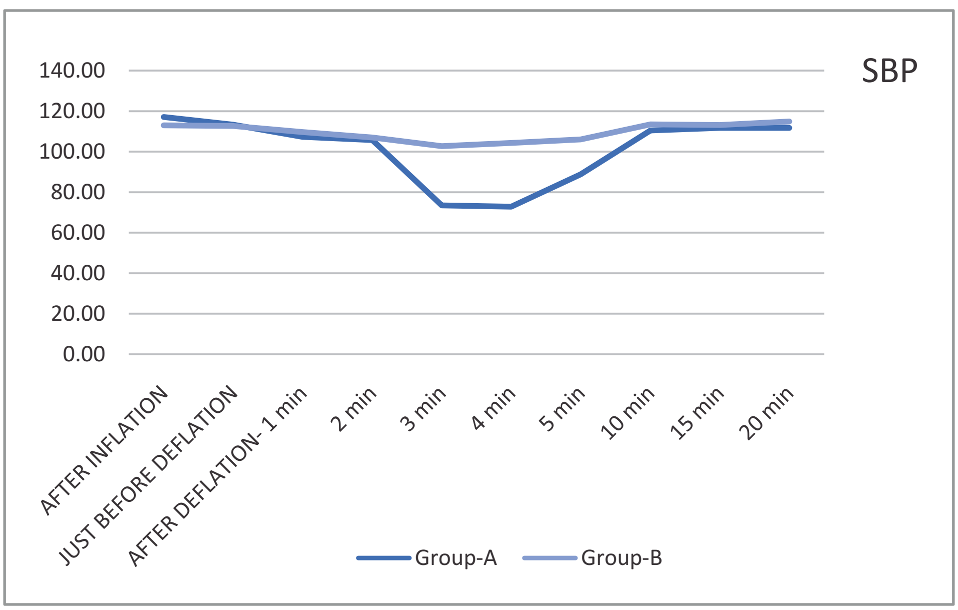

Figure 1: Comparison of variation of SBP between Groups A and B

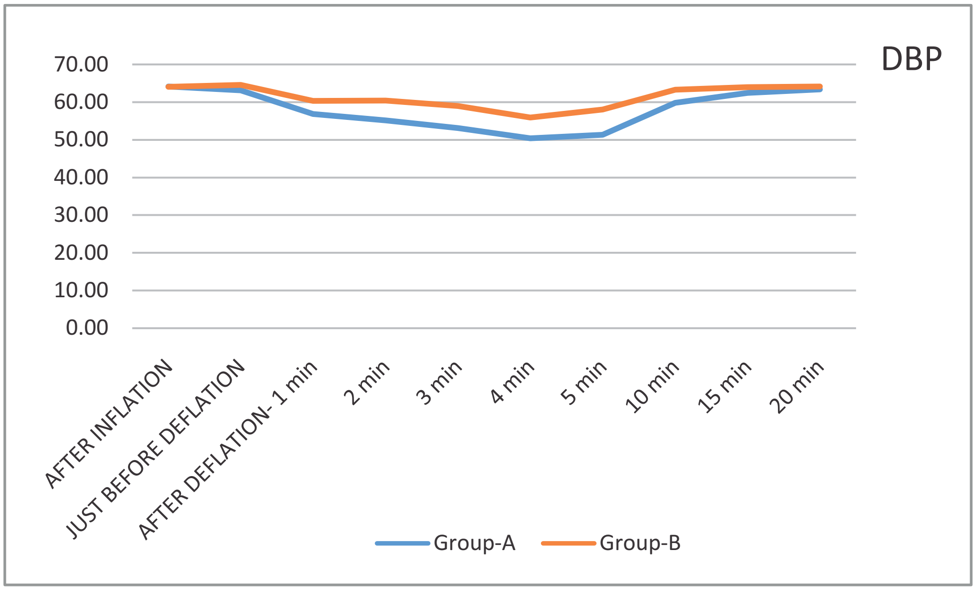

Figure 2: Comparison of variation in DBP between Groups A and B

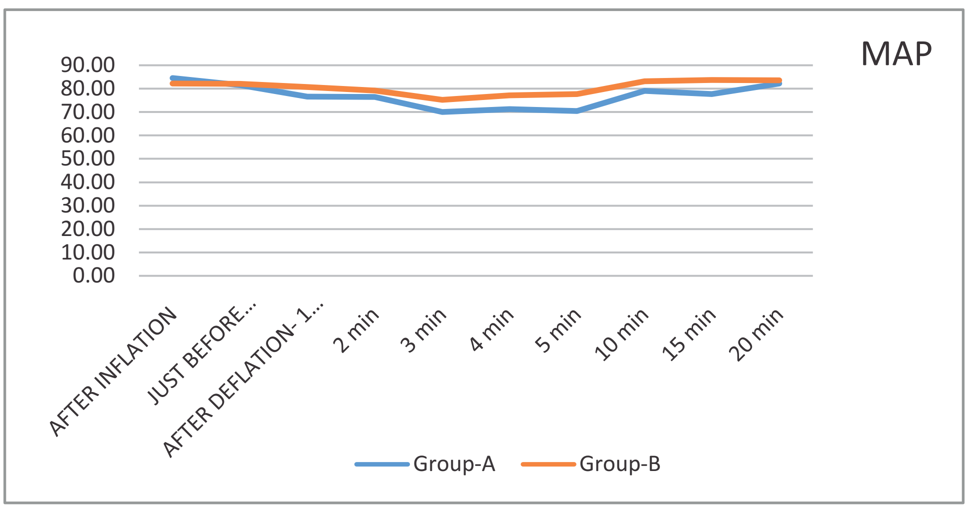

Figure 3: Comparison of variation in MAP between Groups A and B

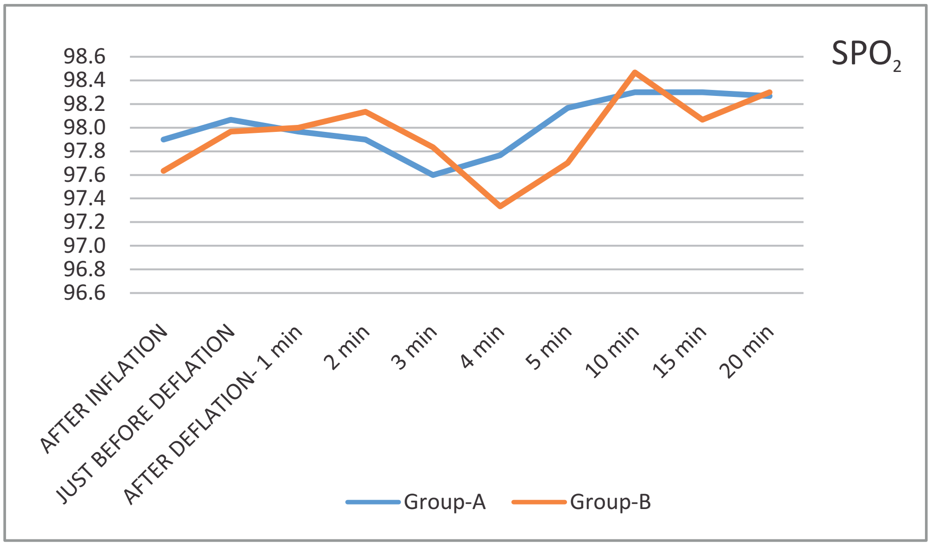

Figure 4: Comparison of variation in SPO_2 between Groups A and B

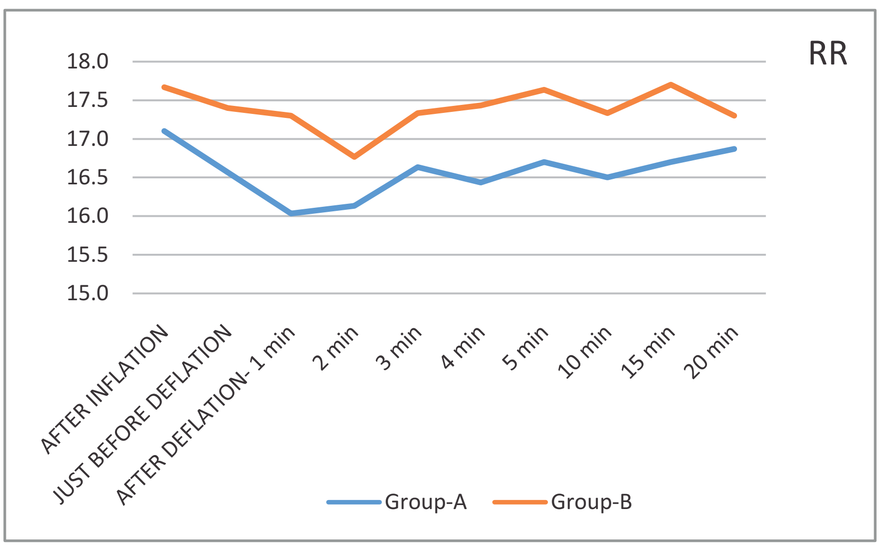

Figure 5: Comparison of variation in respiratory rate between Groups A and B

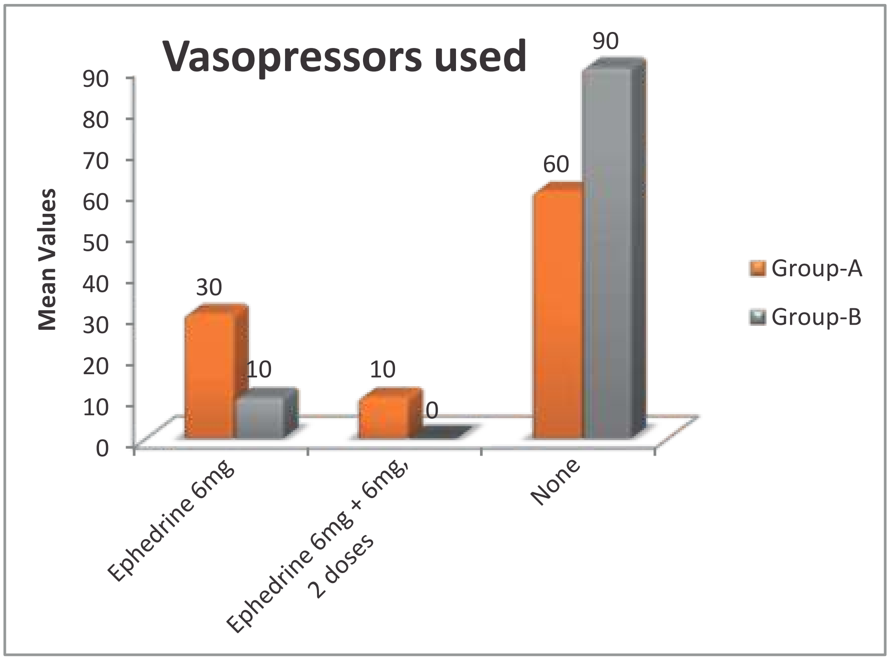

Figure 6: Comparison of requirement of vasopressors between Groups A and B

Table 4: Comparison of arterial blood gas, sample 2 (after tourniquet deflation)

ABG	Group A	Group B	*p*
PO_2 (mmHg)	135.93 ± 41.08	143.60 ± 46.03	0.499 ^{NS}
PCO_2 (mmHg)	39.83 ± 3.77	38.63 ± 4.03	0.238 ^{NS}
HCO_3^- (mmol/L)	22.76 ± 2.05	24.06 ± 1.22	0.004 ^{S}
Lactate (mmol/L)	1.73 ± 0.43	1.35 ± 0.42	0.001 ^{S}

Values expressed in Mean ± SD, NS=Not Significant, S=Significant
PO2:Partial Pressure of Oxygen, PCO2: Partial Pressure of Carbon-dioxide, HCO3: Bicarbonate

Table 5: Comparing arterial bloodgas, samples 1 and 2 within the groups

ABG	Sample	Group A	*p*	Group B	*P*
PO_2 (mmHg)	1	160.60 ± 49.13	0.000 [S]	152.53 ± 58.84	0.232 [NS]
	2	135.93 ± 41.08		143.60 ± 46.03	
PCO_2 (mmHg)	1	41.20 ± 5.71	0.151 [S]	40.17 ± 5.25	0.208 [NS]
	2	39.83 ± 3.77		38.63 ± 4.03	
HCO_3^- (mmol/L)	1	22.72 ± 2.68	0.928 [NS]	22.72 ± 2.68	0.928 [NS]
	2	22.76 ± 2.05		22.76 ± 2.05	
Lactate (mmol/L)	1	1.49 ± 0.60	0.05 [S]	1.79 ± 1.83	0.189 [NS]
	2	1.76 ± 0.40		1.35 ± 0.42	

Values expressed in Mean ± SD, NS=Not Significant, S=Significant
PO2:Partial Pressure of Oxygen, PCO2: Partial Pressure of Carbon-dioxide, HCO3: Bicarbonate

Discussion

A tourniquet is a device which is used to control the flow of blood from an extremity and provide a bloodless operative field to expedite surgery. Tourniquet deflation is associated with many haemodynamic and metabolic changes. Hypotension is a well-known complication of tourniquet deflation and is associated with decreased systemic vascular resistance due to the removal of occlusion of artery, bleeding because of unligated vessel, release of ischaemic tissue metabolites and hypovolemia. Application and release of the extremity tourniquet causes several metabolic changes. Arterial pH, PaO_2, $PaCO_2$, lactic acid and potassium levels change significantly after release, the degree largely dictated by the duration of ischaemia time. Tourniquet deflation has ischemic reperfusion effects with increase in oxygen-free radicals and lipid peroxides making the patients more labile to haemodynamic instability with acid base and electrolytes disturbances [10]. These changes are generally well tolerated, but in elderly patients, those undergoing mechanical ventilation who are unable to compensate for the metabolic load, and in patients with poor cardiorespiratory reserve, these changes may become clinically important.

To attenuate the effects of ischaemic reperfusion injury, many trials and multiple drugs have been studied (Dexmedetomidine, propofol, ketamine, lidocaine, pregabalin, hydroxyethyl starch, *N*-acetyl cysteine, nitric oxide, mannitol, vitamins C and E) with variable results regarding haemodynamic, acid base parameters, analgesia and sedation effects. Ischaemic Preconditioning (IPC) technique seems superior in controlling these drawbacks without need to use systemic drugs [11-19].

IPC is defined as an intervention whereby brief intermittent ischemic episodes are induced in a limb (usually three or four cycles, each cycle lasting for 5 min of arterial occlusion bouts, interspersed with 5 min of reperfusion) either at the site of interest (IPC) or at a distance from the site of interest [remote IPC (RIPC)]. This phenomenon has been used as a clinical tool in order to enhance tissue tolerance to ischemia-induced injury [20-21]. The deflation techniques followed in our study was based on this idea. A cyclic tourniquet deflation resulted in more stable haemodynamic, less tachycardia and hypotension, less acidosis, less hyperlactatemia and less hyperkalaemia. This may be attributed to preconditioning action and slowly interrupted blood pooling in ischemic limb allowing compensatory mechanisms to take place and counteract these negative effects.

Elbadrawy *et al.* (2021) concluded that compared to gradual deflation, intermittent deflation of tourniquet in middle and old aged, total knee arthroplasty patients resulted in more stability in hemodynamic and acid base parameters [22].

Almeida *et al.* (2019) compared the haemodynamic effect after gradual deflation and sudden deflation. Gradual tourniquet deflation reduced the incidence of tachycardia and hypotension after total knee arthroplasty and allowed more stable hemodynamic with better myocardial oxygen consumption [23].

Jason *et al.*, (2013) used a similar technique with some modification regarding times of deflation and reinflation. They concluded that the staggered tourniquet release was associated with greater hemodynamic stability and reduced the rate of acute systemic metabolic changes associated with limb reperfusion. The reapplication of a tourniquet seemed to halt further reperfusion, providing a window period for patient evaluation and management [24].

Song *et al*. (2012) evaluated the effect of tourniquet deflation on hemodynamic in 28 geriatric patients undergoing total knee replacement surgery, under general anaesthesia. MAP, CO and SV showed significant decrease within 10 min after tourniquet deflation ($p < 0.05$) [25].

Our haemodynamic findings in non-cyclic deflation group were in consonance with above study. The findings of non-cyclic deflation were similar to Girardis *et al*. (2000) [26] and Lynn *et al*. (1986) [27]. In both the studies also there was increase in lactate and lower bicarbonate values after sudden deflation. Based on our present study, we can conclude that, cyclic deflation causes less hypotension and releases metabolites slowly, thereby preventing fatal arrhythmias, cardiac arrest, reperfusion syndrome and other complications.

Conclusion

Based on our study, we can conclude that, in patients undergoing lower limb surgeries using occlusive arterial tourniquet under spinal anaesthesia, cyclic deflation is a better method of deflation in comparison to non-cyclic deflation with respect to hemodynamic stability and release of metabolites into blood stream after deflation. This is of particular importance in surgeries requiring long duration of arterial tourniquets, bilateral lower limb surgeries, extremes of age groups, patients with cardiac disease etc.

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