Cuff Width Increases the Serum Biochemical Markers of Tourniquet-induced Skeletal Muscle Ischemia in Rabbits

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Abstract

Full article available online at Healio.com/Orthopedics. Search: 20120725-27

Tourniquet application is a widely accepted adjuvant technique in extremity surgery. The purpose of this prospective, randomized trial was to evaluate the effect of cuff width on skeletal muscle ischemia-reperfusion injury. A 2- or 4-cm wide curved tourniquet cuff was applied around the midthigh of 36 New Zealand White rabbits and inflated to a pressure of 200 or 400 mm Hg for 2 hours: group A = 2 cm to 200 mm Hg; group B = 2 cm to 400 mm Hg; group C = 4 cm to 200 mm Hg; group D = 4 cm to 400 mm Hg. Blood levels of potassium, lactic acid, urea, lactate dehydrogenase, and creatinine phosphokinase MM isoenzyme (CPK-MM) were measured as basic indicators for limb ischemia before tourniquet inflation and 1, 5, and 30 minutes after cuff release.

Potassium values did not differ among the 4 groups. Lactic acid and urea concentrations were always higher in the 400 mm Hg groups (B and D) (P < .001). However, cuff width did not affect their levels (P > .16). Lactic dehydrogenase and CPK-MM values were also greater in the 400 mm Hg groups at all times (P < .001). Further subgroup analysis of 200 mm Hg pressure groups showed higher lactic dehydrogenase (P < .02) but not CPK-MM (P > .9) concentrations in group C than in group A during the 30-minute period. At 400 mm Hg, lactic dehydrogenase and CPK-MM values were higher in group D compared with group B only 30 minutes after cuff deflation (P < .001).

Broad tourniquets are associated with significantly greater and prolonged elevation of serum biochemical markers of inducible skeletal muscle ischemia-reperfusion injury compared with narrow ones. This difference is more prominent when a wide cuff is inflated to a high pressure.

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doi: 10.3928/01477447-20120725-27
neumatic tourniquet use in upper- and lower-extremity surgery is a common practice that aims to facilitate a bloodless surgical field. However, prolonged application of the inflated cuff may cause significant biochemical and ultrastructural changes in skeletal muscles and nerves due to subsequent limb ischemia. As a result, deep venous thrombosis, pulmonary and peripheral embolism, fall of arterial pressure, and neuromuscular lesions may be encountered.

In an attempt to decrease the incidence of such complications, reduction in inflation time and cuff pressure and frequent intervening reoxygenation intervals during long surgical procedures have been suggested. Cuff width may also influence the soft tissue response according to contact area and to the longitudinal and transversal distribution of pressures. However, the effect of cuff width on skeletal muscle ischemia-reperfusion injury has not been clearly evaluated. The hypothesis of the current study was that wide cuffs produced the same serum metabolic changes as observed with narrow cuffs.

**MATERIALS AND METHODS**

**Animals and Experimental Design**

The experimental protocol was approved by the Institutional Animal Care and Use Committee of “G. Papanikolaou” Hospital. All animals received humane care.

Thirty-six New Zealand White rabbits weighing between 2.5 and 3.5 kg and aged between 6 and 12 months were anesthetised via subcutaneous injection of ketamine (50 mg/kg) and fentanyl (0.2 mg/kg) prior to tourniquet application. They were placed in the supine position (Figure 1). A 2- or 4-cm-wide curved tourniquet cuff was wrapped around the mid-portions of the thigh (right hindlimb) and secured with circumferential tape to prevent distal displacement. Both cuffs had the same 19-cm length as recommended by Pedowitz. After gravity ex-sanguination, the tourniquet was inflated to either 200 or 400 mm Hg.

Combining 2 levels of tourniquet width (2 or 4 cm) and cuff pressure (200 or 400 mm Hg) produced 4 groups of 9 animals each: group A=2-cm cuff and 200 mm Hg pressure; group B=2-cm cuff and 400 mm Hg pressure; group C=4-cm cuff and 200 mm Hg pressure; group D=4-cm cuff and 400 mm Hg pressure. The method of randomization was a 1-to-1 allocation.

The tourniquet was applied for 2 hours. Blood samples were taken from the ipsilateral femoral vein, proximally to cuff location, before tourniquet inflation and 1.5, and 30 minutes after cuff release. The serum levels of potassium, lact acid, urea, serum creatinine phosphokinase MM isoenzyme (CPK-MM), and serum lactic dehydrogenase were measured as indicators of local limb ischemia. The rabbits were euthanized with a barbiturate overdose (100 mg/kg of pentobarbital intravenously).

**Statistical Analysis**

Statistical evaluation was performed with SPSS version 17 software package (SPSS Inc, Chicago, Illinois). Matched pair t test was used to detect changes in biochemical parameters. Data were subjected to 1-way analysis of variance and pairwise multiple comparison procedures (Holm-Sidak method) to look for differences among the 4 groups. P < .05 was considered significant.

**RESULTS**

In all groups, blood serum potassium concentration increased in the first minute following cuff release (P < .001) but returned to normal levels after 30 minutes (P > .12). Potassium values did not differ among the 4 groups (Figure 2A).

Lactic acid levels significantly increased in all groups throughout the 30-minute period (P < .001). Peak values were observed within 1 minute after cuff release. Lactic acid concentration was always significantly higher in the 400 mm Hg groups (B and D) compared with the 200 mm Hg groups (A and C) (P < .001). However, cuff width did not affect the levels because no significant difference was found between groups A and C (P > .22) and groups B and D (P > .16) (Figure 2B).

A continuing increase in urea concentration was observed (P < .001). Groups B and D had higher values than did groups A and C at all times (P < .001). However, between groups of the same inflation pressure (group A vs C and group B vs D), no significant difference was identified (P > .17 for both) (Figure 2C).

The concentration of lactic dehydrogenase progressively increased in all groups (P < .001). The values were significantly higher in the 400 mm Hg groups (B and D) compared with the 200 mm Hg groups (A and C) (P < .001). Subgroup analysis revealed that lactic dehydrogenase concentration was higher in group D compared with group B after 30 minutes (P < .001) but not earlier. Between groups A and C, lactic dehydrogenase levels were higher in group C at all time points (P < .02) (Figure 2D).

Creatinine phosphokinase MM isoenzyme values were continuously elevated in all groups (P < .001). Groups B and D showed higher values compared with groups A and C (P < .001). Compared with group B, group D had significantly higher CPK-MM concentration after 30 minutes (P < .001) but not earlier. Between groups A and C, no difference was found (P > .9) (Figure 2E; Table).

![Photograph of the experimental setup. A 2- or 4-cm tourniquet cuff was applied to the rabbit’s back right hindlimb and inflated to a 200 or 400 mm Hg pressure.](image-url)
**DISCUSSION**

Serum levels of lactic dehydrogenase and CPK-MMA were significantly greater when using wide cuffs with a high inflation pressure (400 mm Hg). Under a lower pressure (200 mm Hg), only lactic dehydrogenase values were significantly higher with wide cuffs compared with narrow ones. Kokki et al\(^2\) conducted a prospective, open-randomized study in 26 patients to determine whether the use of a low-pressure tourniquet system with a wide,
A more physiologic and evenly distributed pressure. Furthermore, the pressure gradients in soft tissues are smaller and subsequently limit skeletal muscle necrosis or nerve dysfunction. Wide cuffs stop blood flow without complete collapse of the arteries, possibly due to the frictional resistance of the fluid flow along the compressed length. However, the current results failed to confirm these findings because wide cuffs caused significantly more skeletal damage compared with narrow ones.

According to the current study, high inflation pressures strongly affect skeletal muscle damage, particularly when combined with wide cuffs. Previous studies have shown that transmission of external cuff pressure to soft tissues and minimum arterial occlusion threshold may change according to the tourniquet’s width. Graham et al reported the Doppler occlusion pressure in the upper and lower extremities of 34 normotensive volunteers. A constant inverse relationship existed between occlusion pressure and the ratio of cuff width to limb circumference. Crenshaw et al reported that wide cuffs were associated with a greater variety of applied pressure values as a result of the larger contact area. Broad cuffs transmitted more pressure to deep tissues compared with conventional cuffs, and, therefore, lower pressures were required to interrupt limb circulation. Pedowitz et al reported more focal fiber necrosis and local cellular infiltration in rabbits’ thigh muscles following tourniquet application with 350 mm Hg rather than 125 mm Hg cuff pressures. Using the same animal model, Nitz et al reported that cuff pressure level was the main factor responsible for nerve injury.

Regarding the clinical effect of cuff width, wider cuffs may be more easily tolerated by obese patients because they could achieve blood occlusion at lower pressures. Estebe et al reported that a wide tourniquet cuff is less painful than a narrow cuff if inflated at lower pres-
pressures and that at these lower pressures it is still effective at occluding blood flow. Newman and Muirhead\textsuperscript{11} reported that broad cuffs combined with lower pressures performed well in terms of patient satisfaction and complication rates post-operatively. Specifically, a 12.5-cm pneumatic tourniquet inflated to a relatively low pressure was found to provide the same level of satisfaction but fewer post-operative distal paresthesias compared with a 9-cm tourniquet inflated to an arbitrary but significantly higher pressure.\textsuperscript{11} In addition, Mittal et al\textsuperscript{14} investigated the effect of different width cuffs on the motor nerve conduction of the median nerve and reported that wider cuffs resulted in more severe changes in nerve conduction velocity than narrow ones. Although a wide cuff submits a greater mass of tissue to compression, its effectiveness at lower inflation pressures may reduce the risk of nerve injury.\textsuperscript{11}

The current study’s methodology was in accordance with previous studies that used the same blood biochemical markers to evaluate the level of skeletal muscle ischemia-reperfusion injury.\textsuperscript{16,18,19,24,25,35} However, the study had 2 limitations. No subcutaneous, muscular, or nerve tissue samples under the tourniquet were received for histologic examination. Therefore, the specific effect of cuff breadth on muscle function, metabolism, and nerve conduction was not explored. Second, the same cuff pressures were applied in both tourniquet types. Because wide tourniquet cuffs have been advocated to be equally effective and safer at low pressures, the values of biochemical-examined parameters may be different if the selected inflation pressures were adjusted according to the minimum arterial occlusion threshold value.

**CONCLUSION**

Serum biochemical markers of inducible skeletal muscle ischemia-reperfusion injury were increased using a wide cuff with a high inflation pressure. Under the same inflation pressure, broad tourniquets caused greater skeletal muscle damage compared with narrow ones.

**REFERENCES**


