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The tourniquet revisited as an adjunct to lower limb revascularization

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Purpose: The purpose of this study was to evaluate the role and efficacy of the tourniquet in lower limb revascularization.
Methods: During a 3-year period, 195 patients underwent 205 infrainguinal reconstruction operations in the lower extremity. These patients underwent bypass with a tourniquet and inflow occlusion (group 1) or bypass without a tourniquet (group 2). The type of infrainguinal reconstruction, tourniquet ischemia time, blood loss, and complications related to tourniquet use were recorded. A subset of patients underwent serial muscle biopsies. Specimens from calf muscle were taken just (1) before application of the tourniquet, (2) before tourniquet release, and (3) once wound closure was initiated. These biopsy specimens were studied by histochemical staining and also analyzed for phosphorylase enzyme, a marker for subcellular ischemia.
Results: One hundred eleven patients underwent 117 infrainguinal reconstruction procedures in which the tourniquet and inflow occlusion were used. These patients were matched against 84 patients who underwent 88 infrainguinal reconstructions without the use of the tourniquet. Complete hemostatic control in group 1 was obtained in 108 of the procedures (92%). Eight percent of the procedures required minor additional techniques to obtain complete hemostasis; in two instances, the tourniquet was removed because it did not provide hemostasis. Mean tourniquet time was less than 1 hour for all reconstruction groups. There were no instances of neurologic deficit, thrombosis of distal vessels, or vascular injury that was related to the use of a tourniquet. A comparison of the two groups revealed no differences with regard to overall blood loss ($P = .63$) or duration of operation ($P = 0.60$), observations that reflect the complexity of the cases rather than the use or nonuse of a tourniquet. When tourniquet control was used, we noted a definite decrease in the time for the distal dissection, because total vascular control with extensive dissection was unnecessary. Histochemical analysis with phosphorylase revealed a conversion of tissue with active enzyme activity to a low level with tourniquet use ($P < .05$).
Conclusion: The use of a tourniquet for lower limb revascularization is safe and effective and improves visualization of the operative field. Less dissection of the target vessels is required. With a combination of the nonuse of clamps and other occluding devices, we project a decrease in host hyperplastic response that will, in turn, impact favorably on patency rates. The possibility exists that early failure may be prevented by avoiding the application of traumatic forces to diseased and brittle or calcified arteries. In this study, tourniquet time had no impact on overall operative procedural time, although certain phases of the operation were clearly shortened and facilitated, particularly in complex and difficult reconstructions. Histochemical changes found in muscle biopsy specimens did not adversely impact patients clinically, but further investigation is required to elucidate subcellular events. (J Vasc Surg 2000;31:436-42.)

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Distal vascular control during lower extremity arterial reconstruction can be problematic. Vascular clamps, silicone rubber vessel loops, flow arresters, and intraluminal balloon catheters are commonly used methods to secure vascular control. These devices may result in poor control with calcified vessels, may cause local intimal injury to the vessel, and may hinder suturing by cluttering the field and obstructing the view. Often the target vessel is small

Table I. Demographics and risk factors

	Tourniquet (group 1)					*No tourniquet (group 2)*				
	AK Pop	*BK Pop*	*Crural*	*DP*	*TOTAL*	*AK Pop*	*BK Pop*	*Crural*	*DP*	*TOTAL*
Patients (n)	8	16	80	7	111	22	30	25	7	84
Mean age (y)	71	74	74	70	73	71	73	72	66	72
Gender (M:F)	1:3	1:2	1.4:1	6:1	1.1:1	1:1.2	1:1.1	2.1:1	1.3:1	1:1
Diabetes, n (%)	5 (62)	7 (43)	54 (67)	7 (100)	73 (65)	14 (64)	15 (50)	15 (60)	7 (100)	51 (60)
Hypertension, n (%)	5 (62)	9 (52)	51 (63)*	5 (71)	70 (63)	15 (68)	21 (70)	9 (36)*	4 (57)	49 (58)
Heart disease, n (%)	7 (87)	7 (43)	49 (61)	4 (29)	67 (60)	14 (63)	23 (76)	14 (56)	3 (43)	54 (64)
Renal failure, n (%)	2 (25)	2 (12)	13 (16)	0 (0)	17 (15)	4 (18)	6 (20)	7 (28)	0 (0)	17 (20)

AK Pop, Above-knee popliteal procedure; *BK Pop*, below-knee popliteal procedure; *DP*, dorsalis pedis.
*$P < .05$ (Crural subset, hypertension).

Table II. Indications for revascularization

	Tourniquet (group 1)					*No tourniquet (group 2)*				
Bypass type	*Claudication*	*Rest pain*	*Gangrene*	*Ulcer*	*TOTAL*	*Claudication*	*Rest pain*	*Gangrene*	*Ulcer*	*TOTAL*
AK Pop	1	1	5	1	8	2	5	7	9	23
BK Pop	2	9	3	2	16	3	8	13	6	30
Crural	7	26	38	15	86	0	9	12	6	27
DP	0	1	5	1	7	1	0	5	2	8
TOTAL	10	37	51	19	117	6	22	37	23	88

AK Pop, Above-knee popliteal procedure; *BK Pop*, below-knee popliteal procedure; *DP*, dorsalis pedis.

and calcified, resulting in poor vascular control. The use of tourniquets has been reported in the vascular surgical literature; but despite the advantages of limiting distal dissection, avoiding excessive target vessel trauma, and improving exposure of the operative field, its use has not gained universal acceptance. Critics have voiced concern about poor control when calcification of arteries is present and have warned of tissue ischemia with subsequent morbidity.[1,2] We have added the simple modification of inflow occlusion in our use of the tourniquet and have studied additionally the impact of tourniquet ischemia and ischemia/reperfusion with the use of histologic and histochemical analysis.

METHODS

Between July 1996 and July 1999, we performed 205 infrainguinal bypass procedures in 195 patients. In group 1, we used inflow occlusion and tourniquet compression; patients in group 2 underwent standard methods of vascular control, which included clamps and occasionally intraluminal occluding devices. Table I describes the subsets of the entire series and the demographics and incidence of critical risk factors. All these procedures were performed consecutively, but the tourniquet procedures were performed by two of the authors (HD, KW); control nontourniquet procedures were performed by two other members of our team (FS, FW). The numbers of patients who underwent specific types of bypass procedures in relationship to indications are summarized in Table II. For group 1, distal dissection was performed without mobilization of the vessel from its bed nor control of side branches. Only enough of the vessel was exposed to perform the anastomosis. Proximal inflow control, which established tunnels and conduit preparation, were then performed in the standard manner. Systemic heparinization (70 units/kg) was instituted, and a padded pneumatic tourniquet was placed on the thigh. If an in situ vein graft procedure is being performed, then the proximal anastomosis is completed at this stage. For reversed saphenous veins or if a prosthetic (such as the umbilical vein graft) is used, the distal anastomosis is performed first.

Before the distal anastomosis is begun, inflow occlusion is initiated first to decrease arterial inflow as venous blood is compressed from toe to thigh. The leg is elevated, and an Esmarck bandage is wrapped tightly from the foot to the tourniquet, which is then inflated to 280 mm Hg. The Esmarck bandage is then

Table III. Type of operation

		Tourniquet (group 1)						
		Type of conduit (n)						
Bypass type	*n*	*In situ GSV (%)*	*Reversed GSV (%)*	*UV (%)*	*PTFE (%)*	*TT (min)*	*Blood loss (mL)*	*dAVF, n (%)*
AK Pop	8	0 (0)	0 (0)	8 (100)	0 (0)	31 ± 15	258 ± 97	0 (0)
BK Pop	15	3 (20)	3 (20)	9 (60)	0 (0)	39 ± 18	354 ± 268	0 (0)
Crural	92	15 (17)	15 (17)	56 (61)	1 (1)	50 ± 24	335 ± 333	44 (50)
DP	7	5 (71)	2 (29)	0 (0)	0 (0)	45 ± 18	270 ± 67	0 (0)

TT, Tourniquet time; *dAVF*, distal arteriovenous fistula; *GSV*, greater saphenous vein; *UV*, umbilical vein; *PTFE*, polytetrafluoroethylene; *AK Pop*, above-knee popliteal procedure; *BK Pop*, below-knee popliteal procedure; *DP*, dorsalis pedis.

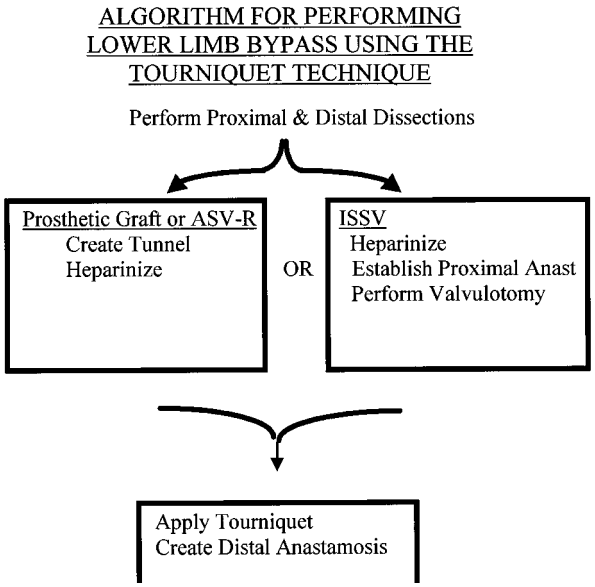

Fig 1. Algorithm for the performance of lower limb bypass procedures with the use of the modified tourniquet technique. *ASV-R*, Autogenous saphenous vein, reversed; *ISSV*, in situ saphenous vein.

removed, and the anastomosis is performed. At the completion of the anastomosis, both the tourniquet and inflow occlusion are released. Modifications of this technique were made for short bypass procedures and for in situ vein bypass procedures (Fig 1). In the case of the former, both anastomoses can be performed with tourniquet control. We generally perform the proximal anastomosis first and deflate the tourniquet for evaluation and tunneling if necessary. We reapply the Esmarck bandage, reinflate the tourniquet, remove the Esmarck bandage, and conclude by performing the distal anastomosis. For in situ vein bypass procedures or in any other case in which the proximal anastomosis is performed first, we generally do not fill the graft with heparin solution because the graft is compressed and heparin is systemically administered to the patient. The assessment of efficiency of the tourniquet was based on visual evidence of blood loss and ease of dissection and creating the anastomosis.

Calf muscle biopsies were performed in 17 cases to assess the impact of tourniquet ischemia and reperfusion. These biopsy specimens were harvested before tourniquet application (baseline), before tourniquet release (ischemia), and just preceding skin closure (reperfusion). The specimens were placed in OCT embedding medium (Tissue Tek; Miles Inc, Diagnostics Division, Elkhart, Ind), with their fibers perpendicular to the surface of a piece of cardboard and frozen in liquid nitrogen. Cross-sections, 6 μm thick, were taken from the midportion of the tissue blocks and cut on a cryostat at –25°C. Standard hematoxylin and eosin staining and modified Gomori trichome staining and alizarin red staining for calcium were performed on these frozen sections. Histochemical evaluation of each muscle biopsy specimen was also performed for intracellular phosphorylase activity.[3] Phosphorylase is the rate-limiting enzyme in glycogenolysis, degrading glycogen to glucose 6-phosphate. The histochemical technique depends on the synthesis of polysaccharide chains from glucose-1-phosphate, with the length of unbranched chains being proportional to phosphorylase activity. Because the color with iodine staining varies according to the length of the chains, high phosphorylase activity in skeletal muscle cells will stain darker. Phosphorylase activity was measured quantitatively with the SAMBO 4000 Cell Imaging Analysis System (IPE Imaging Products

No tourniquet (group 2)						
	Type of conduit (n)					
n	*In situ GSV (%)*	*Reversed GSV (%)*	*UV (%)*	*PTFE (%)*	*Blood loss (mL)*	*dAVF, n (%)*
23	0 (0)	8 (35)	11 (48)	4 (17)	277 ± 213	0 (0)
30	2 (7)	16 (53)	10 (33)	2 (7)	346 ± 464	0 (0)
27	7 (26)	16 (61)	4 (14)	0 (0)	402 ± 257	3 (12)
8	3 (37)	5 (63)	0 (0)	0 (0)	183 ± 68	0 (0)

International, Inc, Chantilly, Va), which automatically records three color zones: black, brown, and yellow, which represent high, medium, and low enzyme activity, respectively. Within a uniform specimen as determined by light microscopy, five microscopic areas from each muscle specimen were selected randomly for quantitative measurements of phosphorylase activity. Comparisons were then made between the mean values of phosphorylase activities for baseline versus ischemia versus reperfusion specimens with the Student *t* test.

RESULTS

Patient demographics for each group were similar with respect to age and gender. The incidence of the major risk factors (diabetes mellitus, hypertension, and coronary artery disease) was also similar (Table I). The only statistically significant difference was for hypertension in the crural subset. In a comparison of both groups with respect to surgical indications, there was also no statistically significant difference in the incidence of gangrene, ulceration, rest pain, or claudication (Table II). As a tertiary referral institution, many of our patients have had previous reconstructions and compromised arterial outflow. This trend is reflected in the type of operation that was performed (that is, more crurals than popliteals and also the type of bypass conduit used). Overall more popliteal reconstructions were performed in group 2, and this was counterbalanced with a significantly lower number of crural operations compared with group 1 ($P < .01$). In the absence of autologous greater saphenous vein, our choice for prosthetic was umbilical vein. Distal arteriovenous fistulas were created in conjunction with the umbilical vein in the crural position. The conduits that were used in this study are shown in Table III. Also shown are the tourniquet times for each reconstruction type of group 1.

Tourniquet inflation time ranged from 17 to 95 minutes, with an average inflation time of 52 minutes. The lengthier cases were due to difficult anastomosis, such as those in which dense calcification was present. In some instances, time was increased because of difficult access to the vessels where limbs were large and muscles more bulky. Tourniquet hemostasis was totally inadequate in two cases. In seven other cases, placement of atraumatic vascular clamps was required in addition to the tourniquet. This was probably due to inadequate placement of the tourniquet or, in some instances, the inability to totally compress thigh arteries, as often occurs in patients who are receiving dialysis therapy. There were no complications directly attributable to the tourniquet technique. Our early graft patencies in this series were similar to our previously reported data in which standard means for vascular control with clamps was the primary method for securing vascular control.[4,5]

Operative times for uncomplicated cases ranged between 90 and 180 minutes. These times were doubled and sometimes even tripled when adjunctive procedures were used, such as the performance of an endarterectomy with a patch or angioplasty and stenting of the inflow circulation. In the crural group, time was always increased because additional time was required to create a distal arterial venous fistula. Average blood loss was 342 ± 307 mL in the tourniquet group and 317 ± 298 mL in the conventional clamping group, again findings that were related to adjunctive procedures in most cases. Operative time and blood loss differences were therefore not statistically significant between the groups. Nevertheless, in individual cases, the most time was spent on the performance of the distal anastomosis in the crural subset, as compared with all other groups. A correlation coefficient of $r = 0.56$ between operative time and blood loss indicated that complex cases take longer and are

Table IV. Phosphorylase activity in equivalent areas of high, medium, and low staining

	Specimens (n = 17 × [3/patient])		
Phosphorylase activity	*Baseline (area ± SEM)*	*Ischemia (area ± SEM)*	*Reperfusion (area ± SEM)*
High (black-stained cells)	70.97 ± 9.05	25.49 ± 7.52*	21.14 ± 5.14*
Medium (brown-stained cells)	26.54 ± 8.67	30.50 ± 15.97	29.40 ± 13.35
Low (yellow-stained cells)	2.49 ± 6.59	44.01 ± 21.25*	49.45 ± 15.86*

*$P < .05$ vs baseline.

associated with greater blood loss, observations that are unrelated to the tourniquet but rather to the addition of inflow and outflow procedures or the performance of an operation in a previously operated field.

Hematoxylin and eosin staining of muscle specimens revealed no gross changes in cell architecture between the three muscle biopsy groups. No calcium deposition or tissue necrosis was noted in any of the specimens. Intracellular phosphorylase activity, however, revealed decreased activity in the ischemic and reperfused specimens when compared with the baseline specimen (Fig 2). Pretourniquet (baseline) specimens were associated with areas of high enzyme activity. An inverse relationship, low enzyme activity, was found in the ischemic and reperfusion specimens. The baseline specimens showed that an average of 71% of the area was associated with high enzyme activity and a 2.5% area of low enzyme activity (Table IV). The ischemia and the reperfusion specimens revealed high phosphorylase activity areas of only 25.5% and 21.1%, respectively. Conversely, low enzyme activity areas were 44% and 49%, respectively. Both the ischemia and reperfusion phosphorylase activities were significantly different from baseline ($P < .05$).

DISCUSSION

The use of a tourniquet as a life-saving maneuver to stop hemorrhage is an ancient maneuver, but despite this and its demonstrable value during wartime,[6] this modality has failed to achieve universal acceptance for use in lower extremity revascularization procedures. Vascular surgeons have been slow to use this technique despite the successful application in the fields of orthopedics, trauma, and podiatry.[7-9] This may be due to not only the lack of familiarity with the procedure but also because unfounded concern for potential complications, such as compartment syndrome, muscle necrosis, and nerve injury. Scheinin and Lindfors[10] first reported the use of a thigh tourniquet for vascular reconstruction in 1979, describing the repair of four popliteal aneurysms with proximal tourniquet occlusion. The usefulness of tourniquet techniques in lower limb revascularization were also reported in 1980 by Bernhard et al,[11] in 1992 by Collier,[12] and in 1993 by Wagner et al.[1] Because of one case that developed thrombosis and nerve injury in the series by Bernhard et al,[11] many surgeons were reluctant to introduce this method into their practice,[2] even with the appreciation of the fact that heparin had not been used in that case. No similar events have been reported since, most likely because of the universal use of heparin anticoagulation before tourniquet inflation.[7,13,14] Ochoa et al[15] reported histologic changes in peripheral nerves concentrated at the edge of the tourniquet when inflated to pressures of 500 mm Hg or 1000 mm Hg. Others, however, showed no nerve injury with pressures of 250 mm Hg for less than 2 hours.[16]

Inflow occlusion combined with a tourniquet is a simple and elegant method to secure vascular control. It can be established rapidly and enables a bloodless field in 92% of the cases. Although the present series describes the use of the tourniquet and inflow occlusion for primary revascularization, this procedure is also useful for redo cases, thromboembolectomy, and graft revisions. Once exposure of the target vessel is complete, tourniquet application takes only several minutes, and a bloodless operative field is easily secured.

We experienced failure in only two cases in which the artery to be compressed was densely calcified. In seven other cases, oozing was controlled by the use of atraumatic vascular clamps in addition to maintenance of tourniquet control. Clearly, failure will occur where the thigh vessels are incompressible, most often in patients with end-stage renal disease. It may also be due to faulty application of the tourniquet. We believe that the use of inflow occlusion is a useful adjunct, although this study does not provide a control series to validate this point. Nonetheless, based on historic controls, we have noted that the frequent occurrence of residual oozing of blood in tourniquet cases can be prevented most times by the use of inflow occlusion.

Without clamps, vessel loops, and intraluminal occluders, the distal anastomosis is technically easier to perform, and sutures can be placed with exacting

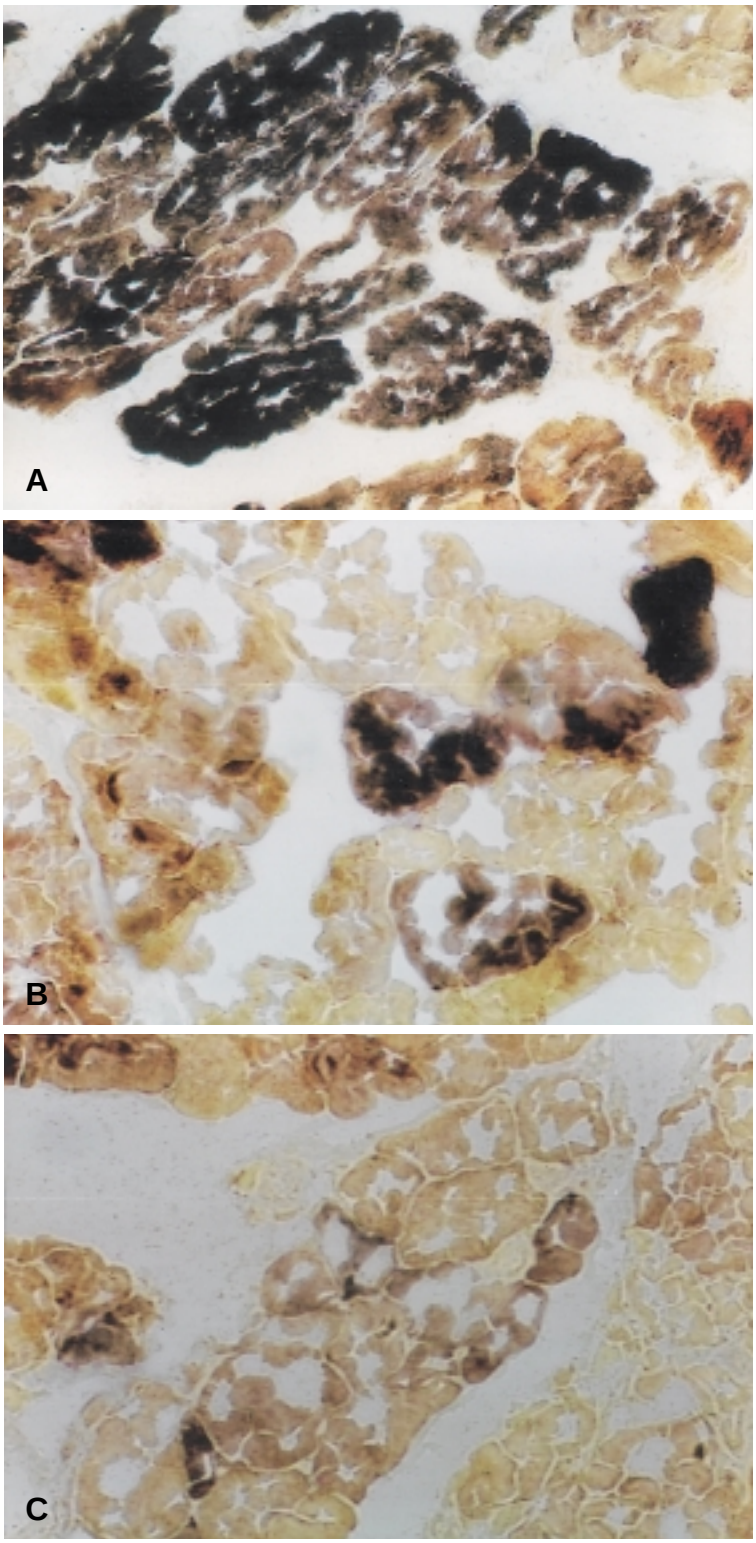

Fig 2. Phosphorylase enzyme activity (*brown areas*) in calf muscle biopsy sections. (A) Before tourniquet inflation. (B) Before release of the tourniquet. (C) Before skin closure. *Black-stained areas* reflect high enzyme activity, although *brown and yellow–stained areas* reflect medium and low enzyme activity, respectively. Note the significant decrease in activity in the ischemic and reperfusion specimens. (Original magnifications, ×40.)

precision. In most cases, the recipient artery tends to "fall open" after the arteriotomy is performed because there is no distortion of the vessel or compression by adjacent clamps. The only exception is with a densely calcified artery. Another major advantage in the use of a tourniquet is that complete dissection of vessels from their bed or controlling side branches is unnecessary. Operative time for this phase of the operation is reduced, and potential trauma is obviated. This is especially helpful in the creation of a distal arteriovenous fistula.[5] The artery and the accompanying vein can be left undisturbed in its bed, except for the clearance of the anterior surface of these vessels. This makes the entire procedure much simpler. Time for performing the anastomosis is comparable for both groups, approximately 20 minutes for popliteal anastomosis and 50 minutes for crural reconstructions in which distal arteriovenous fistulas are also constructed. The real time savings comes with the dissection of these vessels because total control is unnecessary, which means that branches of arteries or veins do not have to be dissected and loops are often not required to secure the target vessels. It is also possible, as some authors have reported,[17-19] that patency rates might improve because of reduced distal anastomotic intimal hyperplasia.

There were no morphologic changes (such as calcium deposition) that would indicate tissue necrosis on the muscle sections stained with hematoxylin, eosin, and Gomori stains. Histologic study of the muscle biopsy specimens with these stains also did not show any pathologic changes for any of the samples examined. On the other hand, the phosphorylase enzyme histochemical analysis did show decreased phosphorylase in the ischemia and reperfusion muscle specimens. Clearly, there was a metabolic deterioration within the skeletal muscle cell; but despite this difference, there was no clinical evidence for an adverse outcome in any patient.

CONCLUSION

We have concluded that the tourniquet enhances the performance of lower limb revascularization and should be used for all cases. The tourniquet produces a bloodless operative field and avoids clamp trauma and vessel distortion. The addition of proximal inflow occlusion reduces blood leakage even with calcified arteries. The tourniquet facilitates the operation, provides an environment for improved technical performance, and can decrease certain segments of the overall operative time. The possibility also exists for fewer early failures by preventing trauma to diseased or brittle and calcified arteries that might otherwise occur when standard vascular clamps are applied. Enzyme changes that occur with the use of the tourniquet have not correlated with clinical events, but these subcellular findings require further study.

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