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Lower extremity arterial injuries over a six-year period: outcomes, risk factors, and management

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Purpose: Limb loss following lower extremity arterial injury is not uncommon and has serious implications on the patient's life and functionality. This retrospective study was performed to analyze the results of lower extremity arterial injuries and to identify the risk factors associated with amputation.

Methods: Between 2002 and 2009, retrospectively collected data on 140 patients with 173 lower extremity arterial injuries were analyzed.

Results: There were 133 males (95%) and 7 females (5%). The mechanism of injuries was gunshot wounds in 56.4% of cases, stab wounds in 30%, and blunt trauma in 13.4%. Associated injuries included vein injury in 45% of cases, nerve injury in 16.4%, and bone fracture in 31.4%. The most frequently injured artery was superficial femoral artery (31.2%). More than 1 artery was injured in 18.6% of patients. Surgery was carried out, with a limb salvage rate of 90.4% and a survival of 97.1%. Amputation was performed in 75% of patients in whom only 1 artery was repaired, although all crural arteries were injured. Multivariate logistic regression analysis showed that significant risk factors of outcome were below-knee multiple arterial injuries (odds ratio [OR] 6.62, $P < 0.001$), associated 2-bone fractures (OR 2.71, $P = 0.003$), development of compartment syndrome (OR 1.94, $P = 0.042$), and great soft tissue disruption (OR 1.74, $P = 0.010$).

Conclusions: Limb loss may be decreased by performing prophylactic fasciotomy more often and by repairing at least 2 crural arteries.

Keywords: lower extremity, artery, amputation, risk factor

Introduction

The successful management of patients with lower extremity arterial injuries has 2 goals. The first is to save the patient's life and the second is to save the extremity. The limb salvage rate following uncomplicated penetrating arterial injuries is over 95%. However an associated skeletal injury may still result in amputation rates as high as 70%, despite successful arterial repair. These results are most pronounced in the lower extremity, which has more tenuous vascular collaterals and more adverse consequences from nerve injury than the upper extremity.[1]

Limb loss following lower extremity arterial injury has been variously ascribed to extent of tissue damage, duration of ischemia prior to revascularization, associated venous injuries, popliteal artery involvement, development of compartment syndrome, injury mechanism, anticoagulation, and failed revascularization.[1–10] Several mangled extremity severity score (MESS) systems are available to help make a decision about amputation, but none has 100% sensitivity.[11,12]

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We reviewed our experience in a busy metropolitan vascular unit to identify risk factors associated with limb loss by using logistic regression analysis, with the goal of identifying what factors might be preventable.

Patients and methods

From September 2002 to June 2009, 140 patients with lower extremity arterial injury were surgically treated consecutively in our hospital. The patients suffering primary amputation without vascular repair were excluded. The decision on primary amputation was collectively agreed by the vascular surgeon, orthopedist, and plastic surgeon. The criteria for primary amputation include age, limb ischemia, gangrene, severe open fracture, gross tissue loss, gross contamination, presence of shock, and MESS. Diagnosis was made mostly by physical examination alone and by Doppler ultrasonography or angiography in suspicious cases with "soft signs" such as palpable but diminished distal arterial pulses, fracture or missile in proximity of major artery, and/or nonexpanding and nonpulsatile hematoma.

Vascular injuries were managed in the operating room under general anesthesia. In the beginning of the operation femoral dissection was carried out to clamp the common, superficial, and profunda femoral arteries in order to prevent bleeding.

Vascular injury was repaired prior to bone, tendon, and nerve injury. Fogarty catheters were routinely passed distally to remove any thrombus if there was no run-off blood flow. Systemic heparinization was employed except for common and/or superficial femoral artery injuries with a great deal of soft tissue and muscle destruction. Polypropylene sutures were used. Primary repair was preferred, but if not possible the contralateral saphenous veins or very rarely polytetrafluoroethylene were used for interposition graft. Placement of a temporary vascular shunt was needed in only 15 patients with multiple arterial injury (in case of delayed patients with complete interruption of distal perfusion). Associated venous injuries were repaired whenever possible in an attempt to prevent postoperative venous hypertension and to minimize development of compartment syndrome. Repaired vessels were covered by soft tissue to avoid desiccation and disruption. If soft tissue was not adequate, suitable covers for the defect were developed by plastic surgeons who applied flap techniques. All patients with associated orthopedic injury underwent reduction of bone fracture and immobilization by internal or external fixation. Associated tendon and most of the nerve injuries were repaired at the same time. At the same session, immediately after revascularization, 4-compartment fasciotomy was performed through an anterolateral and a posteromedial skin incision therapeutically if compartment syndrome (the compression of nerves, blood vessels, and muscle inside a closed space, compartment, leading to tissue death from lack of oxygenation as a consequence of the raised pressure within the compartment) developed on admission, and prophylactically in case of preoperative pulse deficit with ischemia time longer than 6 hours and/or with major soft tissue disruption. Pain on passive extension, paresis, paresthesia, pallor, and pulselessness were considered the hallmark findings of compartment syndrome. Because it was technically impossible, intraoperative arteriography was not used to guide therapy.

Postoperatively, all of the patients were put on a strict protocol of anticoagulation (low-molecular-weight heparin) and dextran therapy was also given; however, in 10 patients anticoagulation was begun on the postoperative second day because of major soft tissue disruption (skin breakage >5 cm, devitalized edges and/or avulsion + muscle defect + extensive segmental vascular injury + combined nerve injury). The patients were discharged to home on oral aspirin 150 mg tablet/day for a period of 12 weeks and followed-up for at least 1 year.

All data on age, sex, mechanism of injury, anatomic location of arterial injury, associated vein, nerve, and/or tendon injury, bone fracture and its location, arterial repair techniques, fasciotomy procedure, presence of soft tissue disruption, compartment syndrome development, and clinical signs and symptoms on admission were gathered. MESS were calculated in accordance with the suggestions of Johansen et al.[13] MESS is a simple rating scale for lower extremity trauma, based on skeletal/soft-tissue damage, limb ischemia, shock, and age (Table 1). Besides arterial injury, 4 patients presented with abdominal organ injury and 1 patient with eye perforation which caused blindness.

Statistical analysis

Mean and standard deviation (SD) were calculated for continuous variables. The normality of the variables was analyzed by the Kolmogorov–Smirnov test. The means of independent groups were analyzed by Student's *t* test. Fisher exact and Pearson chi-square tests were used to analyze the categorical variables. Multivariate logistic regression analysis was performed to obtain the risk ratios (odds ratios) and to determine the predictors of amputation. Two-sided P values were considered statistically significant at $P < 0.05$.

Table 1 MESS (mangled extremity severity score)

Variables	Score
Skeletal/soft-tissue injury	
Low energy (stab; simple fracture; pistol gunshot wound)	1
Medium energy (open or multiple fractures, dislocation)	2
High energy (high speed MVA or rifle gunshot wound)	3
Very high energy (high speed trauma + gross contamination)	4
Limb ischemia	
Pulse reduced or absent but perfusion normal	1[a]
Pulseless; paresthesias, diminished capillary refill	2[a]
Cool, paralyzed, insensate, numb	3[a]
Shock	
Systolic BP always >90 mmHg	0
Hypotensive transiently	1
Persistent hypotension	2
Age (years)	
<30	0
30–50	1
>50	2

Note: [a]Score doubled for ischemia >6 hours.
Abbreviations: BP, blood pressure; MVA, motor vehicle accident.

Results

There were 133 males (95%) and 7 females (5%), ranging in age from 4 years to 67 years with a mean age of 26.14 ± 12.55 years. The time of arrival ranged from 30 minutes to 10 hours following injury. Time interval between injury and operation was approximately 2.5 hours.

The mechanism of injury was blunt trauma in 13.6% of patients, gunshot wound in 56.4%, and stab in 30%, and significant differences existed between these groups (Table 2). Complexity of stab wounds was less than that of other injuries (more involvement of only 1 artery, $P = 0.005$; less bone fracture, $P < 0.001$; less incidence of absent distal pulses, $P = 0.045$; lower MESS scores, $P < 0.001$; lower incidence of major soft tissue disruption, $P = 0.025$; less compartment syndrome development, $P = 0.002$; and shorter hospital length of stay, $P = 0.007$).

Mortality was not encountered among patients with blunt trauma and stab wound. The amputations were most common in blunt trauma injuries and less common in stab wounds (amputation rates were 21%, 10%, and 2%, respectively, for blunt trauma, gunshot, and stab injuries). Also functional disability was greater in the blunt trauma group. However differences between outcomes were not statistically significant ($P = 0.206$ for mortality, $P = 0.063$ for amputation, $P = 0.301$ for functional disability).

Mortality was 2.86% (4 of 140 patients). On admission to hospital 3 patients showed no signs of life, 1 was semiconscious. Hematocrit values of 4 nonsurvivors were 9, 13, 11, and 19 respectively. After performing resuscitation, they were operated on and injured arteries were revascularized. Two patients died 12 hours after the operation due to pulmonary embolism. The other deaths were because of multiple-organ failure and ischemic encephalopathy, one at the postoperative second day and the other at 52 days after surgery.

Overall, 173 arteries were injured in 140 patients. The most frequently injured artery was the superficial femoral artery (53 cases, 31.21%); however 56% of injured arteries in blunt traumas were crural arteries. The most common repair technique used was saphenous vein graft interposition (84 cases, 48.55%), followed by primary repair by end-to-end anastomosis (31 cases) or lateral arteriorrhaphy (20 cases). Thirty-five crural arteries were ligatured because of poor hemodynamic status and large segment defect, yet at least 1 of the crural arteries was patent or revascularized.

Amputation was performed in 13 patients (amputation rate for 136 live patients was 9.56%). The amputations resulted from poor distal perfusion secondary to repair failure in 12 patients and uncontrolled infection in extremity with patent graft in 1 patient. Analysis of the relationship between various factors and amputation is presented in Table 3. Nonsurvivors were excluded to obtain a reliable analysis.

Amputation rates were 17.4% for associated nerve injuries and 13.3% for combined arteriovenous injuries. There was no relationship between amputation and nerve injury, which was present in 23 survivors ($P = 0.163$). In 60 survivors, there were 80 associated venous injuries, 39 above-knee and 41 crural veins. Twenty-one (26.25%) veins were repaired primarily and 15 (18.75%) were repaired by saphenous vein graft interposition. In 24 survivors, 44 (55%) veins were ligated which resulted in amputation in 6 patients (amputation rate of vein ligation 25%). The presence of vein injury did not increase amputation rates, but with vein injury, vein ligation was closely related to amputation rate ($P = 0.440$ and $P = 0.005$, respectively). However, among these 6 patients, 5 had great soft tissue disruption, 3 suffered 2-bone fractures, and all had below-knee multiple arterial injuries.

Bone fractures were present in 43 survivors, 32 of whom suffered below-knee fractures of which 13 were 2-bone fractures (both tibia and fibula, a total of 56 bone fractures). Amputation rates were 23.26% for bone fractures. Amputation was performed in 5 of 13 patients with 2-bone fractures and in 9 of 32 patients with below-knee bone

Table 2 Characteristics of study population according to the injury mechanism

Variables	Gunshot wound (n = 79)	Stab wound (n = 42)	Blunt trauma (n = 19)	*P* value
Age	28.68 ± 11.26	22.25 ± 9.42	24.44 ± 20.89	0.096**
Male	75 (94.94%)	41 (97.62%)	17 (89.47%)	0.346*
Arterial injury				
1 artery	58 (73.42%)	41 (97.62%)	15 (78.95%)	0.005*
2 arteries	16 (20.25%)	1 (2.38%)	2 (10.53%)	0.018*
3 arteries	5 (6.33%)	0	2 (10.53%)	0.152*
Above-knee	46 (58.23%)	32 (76.19%)	10 (52.63%)	0.082*
Below-knee	33 (41.77%)	10 (23.81%)	9 (47.37%)	0.082*
Below-knee multiple	17 (21.52%)	0	4 (21.05%)	0.005*
Associated injuries				
Vein injury	43 (54.43%)	13 (30.95%)	7 (36.84%)	0.041*
Nerve injury	14 (17.72%)	8 (19.05%)	1 (5.26%)	0.344*
Bone fracture	33 (41.77%)	2 (4.76%)	9 (47.37%)	<0.001*
2 or more bony fractures	8 (10.13%)	1 (2.38%)	5 (26.32%)	0.017*
Arterial repair (n = 173)	n = 105	n = 43	n = 25	
Saphenous vein graft	57 (54.29%)	17 (39.53%)	10 (40%)	0.033*
End-to-end	12 (11.43%)	14 (32.56%)	5 (20%)	0.061*
Lateral repair	9 (8.57%)	7 (16.28%)	4 (16%)	0.353*
Ligation	26 (24.76%)	4 (9.30%)	5 (20%)	0.127*
PTFE	1 (0.95%)	1 (2.33%)	1 (4%)	0.579*
Consciousness				0.041*
Conscious	60 (75.95%)	41 (97.62%)	18 (94.74%)	
Semi-conscious	14 (17.72%)	0	1 (5.26%)	
Unconscious	5 (6.33%)	1 (2.38%)	0	
Systolic blood pressure	95.03 ± 28.23	102.22 ± 23.07	108.33 ± 25.5	0.228**
Hematocrit	29.09 ± 7.28	33.5 ± 6.6	32.25 ± 6.33	0.035**
Absence of distal pulses	41 (51.9%)	11 (26.19%)	9 (47.37%)	0.045*
Cold extremity	34 (43.04%)	8 (19.05%)	7 (36.84%)	0.065*
Cyanotic extremity	18 (22.78%)	2 (4.76%)	4 (21.05%)	0.070*
MESS	5.91 ± 1.58	2.88 ± 1.15	5.58 ± 1.39	<0.001**
Major soft tissue disruption	16 (20.25%)	1 (2.38%)	4 (21.05%)	0.025*
Compartment syndrome	23 (29.11%)	1 (2.38%)	6 (31.58%)	0.002*
Hospital LOS (day)	17.66 ± 14.07	9.76 ± 7.75	18.79 ± 11.89	0.007**
Outcome				
Mortality	4 (5.06%)	0	0	0.206*
Amputation	8 (10.13%)	1 (2.38%)	4 (21.05%)	0.063*
Functional disability	2 (2.53%)	2 (4.76%)	2 (10.53%)	0.301*

Notes: Mean ± SD for continuous variables, ratio of subjects to total subjects of that column presented in parentheses. *Fisher's exact test; **Student's *t* test.
Abbreviations: LOS, length of stay; MESS, mangled extremity severity score; PTFE, polytetrafluoroethylene.

fractures (both $P < 0.001$). However, below-knee bone fractures were associated with a high proportion of multiple arterial injuries (8 patients), great soft tissue disruption (6 patients), and 2-bone fractures (5 patients).

Multiple arterial injury was a devastating factor, amputation rates were 21% for patients with two arterial injury and 66.7% for patients with three arterial injury ($P = 0.070$ and $P < 0.001$, respectively). Of 25 patients with multiple arterial injury, only 5 had at least 1 above-knee arterial injury, amputation was performed on none. However 8 of 20 patients with below-knee multiple arterial injuries lost their limbs (40%, $P < 0.001$). Because of a worse clinical situation, only 1 artery was repaired in 4 patients in whom all of the crural arteries were injured, 3 (75%) patients resulting in amputation. On the other hand, no amputations were done among the 31 patients with below-knee 1-artery injury.

Amputation rates were 30% for major soft tissue disruptions and 25% for compartment syndrome ($P = 0.001$ and $P = 0.002$, respectively). Fasciotomies were performed in 40 patients, 30 therapeutic and 10 prophylactic. Among patients with compartmental hypertension, 2 died due to ischemic encephalopathy and multiple-organ failure, and 7 (25% of survivors) lost the injured limb compared with 6 of 108 (5.6%) survivors who did not develop compartment syndrome ($P = 0.002$). In the prophylactic fasciotomy group, only 1 (10%) patient had to undergo amputation because of extensive tissue damage combined with bony and vascular injuries. Amputation rate of patients with

Table 3 Analysis of different factors related to amputation in survivors

Variable	Patients without amputation (n = 123)	Patients with amputation (n = 13)	*P* value
Age (years)	25.54 ± 12.32	27.4 ± 9.99	0.620**
Male	120 (97.56%)	12 (92.31%)	0.546*
Injury mechanism			
Blunt trauma	15 (12.2%)	4 (30.77%)	0.067*
Gunshot wound	67 (54.47%)	8 (61.54%)	0.627*
Stab wound	41 (33.33%)	1 (7.69)	0.058*
Artery injured	Total 142	Total 25	
Femoral arteries	67 (47.18%)	2 (8%)	0.017*
Popliteal	27 (19.02%)	5 (20%)	0.190*
Crural	48 (33.8%)	18 (72%)	0.038*
Multiple arterial injury			
2 arteries	15 (12.2%)	4 (30.77%)	0.070*
3 arteries	2 (1.62%)	4 (30.77%)	<0.001*
Below-knee multiple arteries	12 (9.76%)	8 (61.54%)	<0.001*
Arterial repair	117 (82.39%)	16 (64%)	
Saphenous vein graft	69 (48.59%)	10 (40%)	0.877*
Primary repair	46 (32.40%)	5 (20%)	0.711*
PTFE	2 (14%)	1 (4%)	0.158*
Associated injuries			
Vein injury	52 (42.28%)	8 (61.54%)	0.440*
Vein ligation	24 (46.15%)	6 (75%)	0.005*
Nerve injury	23 (18.7%)	4 (30.77%)	0.163*
Bone fracture	33 (26.83%)	10 (40%)	<0.001*
1 bone	25 (20.33%)	5 (20%)	0.114*
2 bones	8 (6.5%)	5 (20%)	<0.001*
Above-knee fracture	10 (8.13%)	1 (4%)	0.950*
Below-knee fracture	23 (18.7%)	9 (36%)	<0.001*
Clinical findings on admission			
Conscious	113 (91.87%)	6 (46.15%)	<0.001*
No distal pulses	46 (37.4%)	11 (84.62%)	0.001*
Cold extremity	35 (28.46%)	10 (76.92%)	<0.001*
Cyanotic extremity	12 (9.76%)	9 (69.23%)	<0.001*
Major soft tissue disruption	14 (11.38%)	6 (46.15%)	0.001*
Compartment syndrome	21 (17.07%)	7 (53.85%)	0.002*
Systolic BP (mmHg)	100.31 ± 25.76	81.54 ± 3.36	0.005**
Hematocrit (%)	31.44 ± 6.48	26.81 ± 6.43	0.025**
MESS	4.84 ± 1.86	6.92 ± 2.02	<0.001**
Time interval between injury and operation (minute)	145.14 ± 107.25	167.5 ± 67.03	0.446**

Notes: Mean ± SD for continuous variables, ratio of subjects to total subjects of that column was presented in parentheses. *Fisher's exact test; **Student's *t* test.
Abbreviations: BP, blood pressure; MESS, mangled extremity severity score; PTFE, polytetrafluoroethylene.

2-bone fractures who underwent fasciotomy was 11.1% (1 of 9 patients), whereas all patients without fasciotomy underwent amputation ($P = 0.019$). Amputation rate of patients with below-knee multiple arterial injury who underwent fasciotomy was 31.25% (5 of 16 patients), whereas it was 75% (3 of 4 patients) for patients without fasciotomy ($P = 0.069$).

The multivariate logistic regression method was used to obtain the risk ratios (odds coefficients) of variables influencing limb salvage. Odds ratios (OR), confidence interval (95% CI), and significant results are presented in Table 4. Four risk factors – below-knee multiple arterial injuries, associated 2-bone fractures, great soft tissue disruption, and development of compartment syndrome – were found to be significant in the binary logistic model ($P < 0.05$).

Postoperative motor deficits were seen in 6 patients, of whom 3 had concomitant nerve injury, 2 had major soft tissue disruption, and 1 had malleol fracture. Chronic venous insufficiency developed in 1 patient whose superficial femoral vein was ligated. Clinical evidence of infection was noted in 19 patients (3 blunt traumas, 16 gunshot wounds); osteomyelitis developed in 1, the rest returned to health.

Table 4 Odds ratios, confidence interval (CI), and significant results of factors associated with limb loss obtained from logistic regression analysis

Risk factors	Odds ratio	95% CI	*P*
Below-knee multiple arterial injury	6.618	2.71–16.17	<0.001
Associated 2-bone fractures	2.71	1.8–4.1	0.003
Great soft tissue disruption	1.74	1.15–2.62	0.010
Compartment syndrome	1.94	1.28–2.94	0.042

Discussion

Vascular injuries of the extremities remain a major cause of limb amputation, if not treated early and competently.[12] Blunt traumas and gunshot wounds are more likely to affect the arterial supply at more than 1 level. More extensive injury to the vessel and surrounding structures leads to severe interruption of the main as well as collateral blood supply, complicating the management of these injuries and likely explaining the higher amputation rates compared with stab wounds.[4,5,9] Consistent with previous reports, we found that stab trauma in particular is associated with a 10-fold decreased risk of multilevel arterial injury, bone fractures, and tissue destruction compared with other injury patterns. However, although functional outcomes and limb salvage rates of stab wounds were better in this series, differences among the injury patterns were not significant.

A decision to primarily amputate a limb that stands a chance of salvage can have serious implications on the patient's life and functionality. Scoring systems for limb viability lack sensitivity because none has a 100% negative predictive value. Some injuries with high scores may well be salvageable by a diligent multidisciplinary team.[14] In this series, no amputation was performed in 14 patients with MESS score ≥ 8. We aim to repair all the vascular injuries unless very great tissue damage renders repair impossible, despite a high MESS score.

The time of preoperative evaluation should be as short as possible to minimize ischemia time and thus prevent potential necrotic changes. According to a recent study, in the management of extremities with soft signs of vascular injury, ankle brachial pressure index measurement should be the first-line diagnostic choice to exclude arterial injury in 99.5% of patients and to avoid unnecessary examinations in 90% of patients.[15] We avoided arteriography with the exception of suspicious cases with soft signs and in patients with gunshot wounds at more than 1 level. A previous publication recommended the use of preprocedural angiography for popliteal artery injuries in the operating room, which reduces the likelihood of amputation by decreasing time to initiating repair and thereby limiting limb ischemia.[16]

The severity of tissue ischemia depends not only on its duration but also on the level of arterial injury, the extent of soft tissue damage, and the efficiency of collateral circulation.[9] This explains the lack of correlation between ischemia time and our outcomes.

Binary logistic regression analysis of results derived from this study showed that below-knee multiple arterial injuries (OR 6.6), associated 2-bone fractures (OR 2.7), development of compartment syndrome (OR 1.9), and great soft tissue disruption (OR 1.7) are the main risk factors related to amputation.

Hafez et al[9] consider that it is more relevant to identify signs of severe ischemia such as compartmental hypertension or loss of sensation or function than to rely on the absolute ischemia time for predicting outcome. The sequelae of compartment syndrome are thought to be due to impairment of the microcirculation within the compartment leading to ischemia and irreversible damage to muscles and nerves. Ischemia tolerance of muscle tissue without irreversible damage is generally agreed to be 4 to 6 hours. Compartment syndrome has itself been linked to delay in restoration of blood flow, presence of associated venous injuries, lower extremity fractures, intraoperative blood loss, multiple arterial injury, and preoperative pulse deficit.[2,17] Early decompressive fasciotomy prevents this neuromuscular damage. The outcome after prophylactic fasciotomy was reported to be superior to that of early therapeutic decompression.[18,19] Clouse et al[20] performed fasciotomy on all patients suffering lower extremity vascular injury during the Iraq War. Woodward and colleagues[21] reported that temporary shunting and early fasciotomy assist timely definitive repair.

We performed prophylactic fasciotomy on the patients with an ischemia duration longer than 6 hours and/or major soft tissue disruption in case of pulse deficit. Major soft tissue disruption may render vascular repair impossible. Even if repair is possible, it may cause the development of compartmental hypertension by interrupting collateral blood supply to distal arteriolar bed. In this study, amputation rate was 2.5-fold greater in the patients with compartment syndrome, although fasciotomy was performed. On the other hand, amputation rate of patients with prophylactic fasciotomy was similar to that of patients overall. It was obvious that when compartment syndrome developed, amputation rate increased despite the protective effect of therapeutic fasciotomy. Nevertheless, the protective effect of fasciotomy was shown in patients, especially those with 2-bone fractures and/or below-knee multiple arterial injuries. Therefore our aim must be prevention of compartmental hypertension, and prophylactic fasciotomy is a good approach for this purpose.

Management of associated venous injuries remains controversial. Some reports insist on a correlation between venous injury and limb salvage.[2] However, in a review of 322 venous injuries, of which 70% had venous ligation, Timberlake and Kerstein[22] found no permanent sequelae of venous ligation. Likewise, we have been unable to demonstrate any adverse influences of venous injuries and even venous ligations on limb salvage.

Among the lower extremity arterial injuries, the most challenging cases were those with concomitant bony and soft tissue injuries.[1,3,6–9,12] Mullenix et al[5] identified 4 factors independently associated with amputation: ipsilateral fracture, complex soft tissue disruption, nerve injury, and elevated extremity abbreviated injury score. In this study, nerve injury was associated with functional disability, but not with limb loss. On the other hand, 2-bone fracture was a major predictor of amputation, free from level of fracture.

Also multilevel vascular injuries and more than 1 crural arterial injury are associated with a high rate of limb loss.[5,9] Moniz et al[6] found amputation rates of 33% for 2-vessel tibial arterial injuries and 100% for 3-vessel tibial arterial injuries. Hafez et al[9] demonstrated a leg amputation rate of 45% with combined above- and below-knee vascular injury, with an OR for amputation of 4.4 in multivariate analysis. Guerrero and colleagues[2] reported an increased risk of limb loss in association with popliteal artery injury. Kohli and Singh[12] determined that "patients who underwent infrapopliteal graft repairs, those with delayed presentation in whom the no-reflow phenomenon hampered revasularization are at high risk of secondary amputation".

Similar to previous reports, amputation rates were 21% for 2-arterial vessel injuries and 66.7% for 3-arterial vessel injuries. Multiple arterial injury represents multilevel vascular injury, more soft tissue and bone injury, complete interruption of distal blood flow, and so more development of compartment syndrome, which causes failure of revascularization of the main arterial trunk. Experience with lower limb revascularization for critical limb ischemia due to atherosclerosis has clearly demonstrated that successful femorotibial bypass to a single, remaining, patent infragenicular vessel provides limb salvage in the vast majority of cases. Some have suggested that ligation of crural vessels is safe as long as 1 patent artery remains in continuity with the foot, provided that the artery is not the peroneal.[23] Others argue that there is a 14% amputation rate after ligation of 1 tibial artery, which further increases to 65% after ligation of 2 arteries; therefore, any injury to the crural arteries, with the exception of isolated peroneal injury, should be repaired.[24] In this study, a 75% amputation rate was obtained after ligation of 2 tibial arteries. Limb loss in patients with multivessel, infra-popliteal arterial trauma might be related to the associated neuro-musculoskeletal trauma, and/or due to more extensive, irreversible distal microvascular arteriolar thrombosis. However, amputation rates did not exceed 38% even in patients with major soft tissue disruption, 2-bone fractures, and compartment syndrome. Thus we conclude that at least 2 crural arteries must be repaired for limb salvage, even if there is a very large segmental defect, if the patient's hemodynamic status is favorable. Especially in blunt or firearm injuries, graft failure may be seen due to vasospasm of the native artery and/or compartment syndrome. If 2 or more crural arteries are repaired, at least 1 may continue to be patent, and thus the chance of limb salvage increases. In addition, in traumatic cases no collateral network contributes to the distal flow as in atherosclerotic cases.

Some authors advocate full administration of heparin and/or thrombolytic injection distally as a routine.[2,7,14] According to a previous report, the incidence of limb loss in patients who were started on perioperative anticoagulation was significantly lower than if anticoagulation was started later (3.3% versus 15%, $P = 0.03$).[2] We prefer the routine intraoperative use of anticoagulation (in particular heparin) except in severely injured patients who present a risk of bleeding at sites other than the extremity injury. However, in a certain group of patients and in spite of satisfactory completion of angiography and a stable postoperative course, graft occlusion still occurs. In these patients, graft failure is most likely due to small-vessel thrombosis and adequate heparin use. The use of intraoperative thrombolysis may be of some benefit in these patients.[9]

In conclusion, logistic regression analysis has shown that below-knee multiple arterial injuries, associated 2-bone fractures, great soft tissue disruption, and development of compartment syndrome are significant predictors of outcome in lower extremity arterial injuries. The first 3 factors may not be preventable, but the worst of their effects and development of compartmental hypertension may be prevented by performing prophylactic fasciotomy more often. In addition, we recommend the repair of at least 2 crural arteries for limb salvage.

Disclosure

The authors disclose no conflicts of interest in this work.

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