



Traumatic Peripheral Arterial Injury with Open Repair: A 10-Year Single-Institutional Analysis

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Background: We report our 10-year experience with traumatic peripheral arterial injury repair at an urban level I trauma center.

Methods: Between January 2007 and December 2016, 28 adult trauma patients presented with traumatic peripheral arterial injuries. Data were retrospectively collected on demographic characteristics, the mechanism of injury, the type of vascular injury, and physiological status on initial assessment. The analysis also included the Mangled Extremity Severity Score (MESS), Injury Severity Score, surgical procedures, and outcome variables including limb salvage, hospital stay, intensive care unit stay, and postoperative vascular complications.

Results: Four (14.3%) patients required amputation due to failed revascularization. MESS significantly differed between patients with blunt and penetrating trauma (8.2 ± 2.2 vs. 5.8 ± 1.3 , respectively; $p=0.005$). The amputation rate was not significantly different between patients with blunt and penetrating trauma (20% vs. 0%, respectively; $p=0.295$). The overall mortality rate was 3.6% (1 patient).

Conclusion: Blunt trauma was associated with higher MESS than penetrating trauma, and amputation was more frequent. In particular, patients with blunt trauma had significantly higher MESS than patients with penetrating trauma (8.2 ± 2.2 vs. 5.8 ± 1.3 , respectively; $p=0.005$), and amputation was performed when revascularization failed in cases of blunt trauma of the lower extremity. Therefore, particular care is needed in making treatment decisions for patients with peripheral arterial injuries caused by blunt trauma.

Keywords: Blunt trauma, Penetrating trauma, Arteries, Revascularization

Introduction

Peripheral arterial injuries constitute approximately 4%–6% of all major traumas [1,2]. However, they comprise 80% of vascular injuries that manifest as fatal hemorrhage or limb-threatening ischemia [3]. Peripheral arterial injury in trauma patients can potentially progress to ischemia and amputation unless it is immediately diagnosed and revascularized.

The causes of peripheral arterial injuries are divided into penetrating trauma (e.g., bullets and knives) and blunt trauma (e.g., traffic accidents and falling down). Unlike in some other countries, the main cause of peripheral arterial injuries in Korea is blunt trauma, since individual firearms

are prohibited. Therefore, research on penetrating peripheral arterial injuries caused by gunshot wounds in Korea is very rare.

The aim of the present retrospective study was to analyze the prognosis of penetrating and blunt trauma, based on our 10-year experience with the repair of traumatic peripheral arterial injuries in an urban level I trauma center in Korea.

Methods

Patients

The study was conducted in accordance with the Decla-



Table 1. Comparison of variables according to the mechanism of injury

Characteristic	Total (n=28)	Blunt	Penetrating	p-value
Total	28	20 (71.4)	8 (28.6)	
Age (yr)	40.8±17.0	42.7±17.4	35.9±16.1	0.34
Male sex	21 (75.0)	15 (75.0)	6 (75.0)	1.0
Associated fracture	16 (57.1)	16 (80.0)	0	0.000
Associated major soft tissue disruption	13 (46.4)	12 (60.0)	1 (12.5)	0.038
Trauma-to-operation time (min)	388.9±339.9	426.0±313.5	296.0±406.3	0.029
Injury Severity Score at presentation	19.7±14.9	22.4±15.6	13.1±11.4	0.089
Mangled Extremity Severity Score at presentation	7.5±2.3	8.2±2.2	5.8±1.3	0.005
Glasgow Coma Scale score at presentation	13.5±2.2	13.7±2.2	13.0±2.3	0.412
Hospital stay (day)	77.1±81.3	96.5±86.9	28.6±35.3	0.004
Intensive care unit time (day)	6.3±6.8	7.7±7.4	2.8±3.6	0.086
Amputation	4 (14.3)	4 (20.0)	0	0.295
Mortality	1 (3.6)	1 (5.0)	0	1.0

Values are presented as number (%) or mean±standard deviation. Bold type is statistically significant.

ration of Helsinki and was approved by the Institutional Review Board at Pusan National University Hospital (reference no., H-1909-018-083). Informed consent was waived. Between January 2007 and December 2016, 28 adult patients presented to an urban level I trauma center with traumatic peripheral arterial injuries. Data were retrospectively collected by a single investigator and included basic demographic characteristics, mechanism of injury, type of vascular injury, and physiological status on initial assessment. The analysis also included the Mangled Extremity Severity Score (MESS), Injury Severity Score (ISS), surgical procedures, and outcome variables, such as limb salvage, hospital stay, intensive care unit stay, and postoperative vascular complications.

The response system of our trauma center consists of a team of specialists from the disciplines of emergency medicine, cardiovascular surgery, general surgery, orthopedic surgery, and neurosurgery. Members of all disciplines remain at the trauma center at all times and are activated immediately after receiving a transfer request. Criteria for considering primary amputation include dense ischemia (Rutherford class 3) with an ischemic time of greater than 6 hours, or bone or soft tissue defects that are considered impossible to reconstruct by the orthopedic surgeon. Nonetheless, despite these guidelines, the final decision is made on a case-by-case basis after discussing treatment options with the patient, the patient's family, and the interdisciplinary team.

The diagnosis of peripheral arterial injury is established using enhanced computed tomography (CT) angiography. There is an emergency room in the trauma center, and the CT room of the trauma center is always ready for trauma

patients. Therefore, if their vital signs were stable, all patients suspected of vascular damage underwent CT to diagnose vascular damage. At our trauma center, the choice between limb relief and primary amputation is made after evaluation by the full team.

The intervention was classified as surgical ligation, primary repair, or surgical bypass of the main bleeding branch. Surgical ligation was performed between the proximal and distal ends of the arterial injury. Primary repair was performed through resection and re-anastomosis in patients with local arterial injuries that required resection of <2 cm of vessels with appropriate residual length to avoid undesirable tension. The opposite veins were used for surgical bypass, and prosthetic conduits were used without veins. In combined vascular and orthopedic procedures, vascular repair was performed first, unless decided otherwise by the multidisciplinary team. The need for fasciotomy was assessed at the end of the period of vascular regeneration based on a physical examination.

Statistical analysis

The patients were divided into 2 groups according to the mechanism of injury and compared. The Wilcoxon rank-sum test was used for continuous variables and the Fisher exact test was used for categorical variables. All analyses were performed using SAS ver. 9.3 (SAS Institute Inc., Cary, NC, USA) and a p-value <0.05 was considered to indicate statistical significance.

Results

Demographics

During the 10-year period, 28 patients were identified and treated at our institution. Their mean age was 40.8 ± 17.0 years (range, 7–72 years), and the majority of patients were male ($n=21$, 75%). The basic demographic data of patients are summarized in Table 1. There were 20 patients (71.4%) with blunt trauma and 8 patients (28.6%) with penetrating trauma. The most common causes of blunt trauma included auto-pedestrian collisions (28.6%) and crush injuries (21.5%). The majority of cases of penetrating trauma involved stab wounds by a knife or broken glass (Table 2). No statistically significant differences were found in the demographic variables, ISS, GCS, intensive care unit stay, and mortality rates between those with blunt and penetrating trauma. There were statistically significant differences in the concomitant injuries, including associated fractures (16% versus 0%, respectively; $p=0.00$) and major soft tissue disruption (60% versus 12.5%, respectively; $p=0.038$) between those with blunt and penetrating trauma. Statistically significant differences between patients with blunt and penetrating trauma were found in the trauma-to-operation time (426.0 ± 313.5 minutes versus 296.00 ± 406.3 minutes,

respectively; $p=0.029$) and hospital stay (96.5 ± 86.9 days versus 28.6 ± 35.3 days, respectively; $p=0.004$).

Vascular injuries

There were 28 peripheral artery injuries, including 11 (39.3%) in the popliteal artery, 7 (25%) in the femoral artery, 5 (17.9%) in the axillary artery, 3 (10.7%) in the brachial artery, and 2 (7.1%) in the ulnar or radial artery. The surgical procedures for each injury are summarized in Table 3. Amputation was performed in 4 cases (3 of 11 cases of popliteal artery injury and 1 of 7 cases of femoral artery injury). Amputation was not performed in any cases of peripheral artery injuries of the upper limb. Vascular interventions included primary repair ($n=9$, 32.1%), saphenous vein graft (SVG) interposition ($n=7$, 25.0%), polytetrafluoroethylene (PTFE) graft interposition ($n=9$, 32.1%), and arterial ligation ($n=3$, 10.7%). The types of arterial injury according to the mechanism of injury are summarized in Table 4. In blunt trauma, occlusion was observed in 9 cases (45%), and transection was observed in all cases of penetrating injuries.

Outcomes

Four patients (14.3%) required amputation due to failed revascularization. The details of these patients are summa-

Table 2. Mechanisms of injury

Mechanism	No. (%)
Penetrating	8 (28.6)
Stab wound (knife)	4 (14.3)
Stab wound (broken glass)	4 (14.3)
Blunt	20 (71.4)
Auto-pedestrian collision	8 (28.6)
Motorcycle collision	2 (7.2)
Motor vehicle collision	2 (7.2)
Fall	2 (7.2)
Crush injury	6 (21.5)

Table 3. Vascular reconstruction

Artery injured	Blunt/penetrating	Procedures (n)				
		Primary repair	SVG interposition	PTFE graft interposition	Ligation	Postoperative amputation
Axillary	5/0	0	2	3		
Brachial	1/2	2	1			
Ulnar or radial	0/2	1			1	
Femoral	6/1	3	1 ^{a)}	3		1
Popliteal	8/3	3	3 (1 ^{a)})	3	2 ^{a)}	3
Total	20/8	9	7	9	3	4

SVG, saphenous vein graft; PTFE, polytetrafluoroethylene.

^{a)}Amputation.

Table 4. Types of arterial injury

Type of arterial injury	Total	Blunt trauma	Penetrating injury
Occlusion	9 (32.1)	9 (45.0)	0
Partial transection	6 (21.4)	4 (20.0)	2 (25.0)
Complete transection	13 (46.4)	7 (35.0)	6 (75.0)

Values are presented as number (%).

Table 5. Amputations in the presence of peripheral arterial injuries

Patient	Mechanism	ISS	MESS	Fracture location	Vascular injuries	Procedures	Reason for amputation	Days to amputation from repair procedure	Outcome
1	Auto-pedestrian collision	41	9	Femur	SFA, CFV complete transection	SVG interposition	Rhabdomyolysis	8	Alive
2	Fall	9	13	Knee dislocation	PA, PV occlusion	SVG interposition	Necrosis	35	Alive
3	Motor vehicle collision	34	9	Femur, Tibia	PA occlusion	Ligation	Necrosis	5	Alive
4	Crush injury	14	8	Fibula	PA occlusion	Ligation	Necrosis	9	Alive

ISS, Injury Severity Score; MESS, Mangled Extremity Severity Score; SFA, superficial femoral artery; CFV, common femoral vein; SVG, saphenous vein graft; PA, popliteal artery; PV, popliteal vein.

rized in Table 5. There was a statistically significant difference in MESS (8.2 ± 2.2 versus 5.8 ± 1.3 , respectively; $p=0.005$) between patients with blunt and penetrating trauma. However, no statistically significant difference was found in the amputation rate between those with blunt and penetrating trauma ($n=4$, 20% versus $n=0$, 0%, respectively; $p=0.295$) (Table 1). In 1 case, amputation was performed due to rhabdomyolysis secondary to reperfusion injury, and in 3 cases, amputation was performed due to postoperative necrosis. Amputation was performed in both cases of ligation of the popliteal artery where vascular reconstruction was impossible due to a severe degloving injury, and in 2 cases without ligation that were accompanied by deep vein damage.

The overall mortality rate in this series was 3.6% (1 patient). This patient was placed in a forklift truck and arrived with pulseless electrical activity; spontaneous circulation was achieved with aggressive fluid resuscitation and the advanced cardiac life support protocol. He underwent primary repair of the superficial femoral artery and external fixation of a femur fracture; he died on postoperative day 7 due to septic shock from late-diagnosed severe bowel necrosis.

Discussion

The incidence of vascular trauma has increased in recent years [4-7]. Nevertheless, deciding on a treatment approach is challenging, because there can be damage to several organs. This study presents 10 years of experience with peripheral artery trauma at the largest independent trauma center in Korea.

In this study, blunt trauma ($n=20$, 71.4%) was more common than penetrating trauma ($n=8$, 28.6%). In many stud-

ies outside of Korea [8-10], the most common cause of vascular trauma was penetrating trauma caused by gunshots. This difference may be due to the fact that guns are illegal in Korea, so there are few gun accidents. In this study, there were no cases of penetrating trauma due to firearms; instead, the most common causes of penetrating trauma were injuries due to knives ($n=4$) and glass ($n=4$).

The amputation rate was 14.3% ($n=4$), which is similar to the results of previous studies. Although the reported range of amputation rate is 2%–33%, the mechanisms and sites of injury vary among studies [11,12]. The amputation rate in cases of blunt trauma was higher than in cases of penetrating trauma in this study; however, the difference was not statistically significant. According to Liang et al. [13], blunt trauma has a higher rate of delayed amputation, with a rate of 23% for in-hospital amputations and 30% if eventual elective amputations are considered. This may partly be attributable to the high proportion of high-energy blunt trauma within the blunt injury group, which represents a cohort with greater overall injury severity. In this study, associated fractures and major soft tissue disruptions were more common in those with blunt trauma than in those with penetrating trauma. Therefore, the higher-energy damage in blunt trauma could result in a higher amputation rate. In a meta-analysis of more than 3,100 patients undergoing vascular repair Perkins et al. [11] showed that major soft tissue damage, compartment syndrome, multiple arterial damage, ischemic duration of more than 6 hours, associated fractures, blast or blunt damage mechanism, age, the ISS, and iliac or patellar injuries were associated with increased amputation rates, while shock and nerve or vein injuries were not.

The MESS is the most commonly used method to assess the severity of mangled extremities in vascular trauma [14].

The MESS was higher in cases of blunt trauma than in cases of penetrating trauma, because the trauma-to-operation time in cases of blunt trauma was longer than 6 hours (426 ± 313.5 minutes), a statistically significant difference from that in cases of penetrating trauma. Burkhardt et al. [14] studied the relationship between flow recovery time and functional extremity salvage in a large animal model. Neuromuscular recovery in animals with an initial recovery of flow (<3 hours) was almost complete, but not if the flow stopped for 6 hours. Histopathological changes in degeneration, necrosis, and fibrosis are associated with reperfusion time. The long trauma-to-operation time in patients with blunt trauma occurred because many of these patients did not come directly to our hospital after trauma, but were referred by other hospitals or from remote areas. No statistically significant difference was found in the ISS; however, because the ISS was higher in cases of blunt trauma than in cases of penetrating trauma, the preoperative resuscitation time and evaluation of other injuries would have been more time-consuming.

Additionally, all cases of penetrating trauma involved low-energy injuries. In this study, MESS was statistically significantly higher in patients with blunt trauma than in patients with penetrating trauma (8.2 ± 2.2 versus 5.8 ± 1.3 , respectively; $p=0.005$); it tended to be greater than 7 in those with blunt trauma, while it was less than 7 in those with penetrating trauma. The MESS was introduced by Johansen et al. [15] in 1990, and a cutoff score of 7 has classically been used to predict the future viability of limb salvage procedures. In all cases of amputation, the MESS was higher than 7. To date, however, no study has found that a MESS >7 can predict amputation with absolute certainty [16]. MESS can quantify the overall severity of limb injuries and aid in decision-making regarding management; however, limb salvage decisions should also consider the patient's overall condition. Even in cases of severe limb trauma, we now have a variety of functional structures available that could not have been conceived in 1990. For instance, various new forms of fracture fixation have been introduced [17], as have negative-pressure devices [18] and free tissue transfers [19] to treat what would previously have been unmanageable soft tissue defects. Further innovations include successful major nerve reanastomoses [20] and the revascularization of traumatized limbs by endovascular methods [21].

When vascular reconstruction is performed in patients with trauma, it is very difficult to achieve tension-free end-to-end anastomosis. As this is the most common repair method for SVG interposition, it is preferable to use the

SVG in the non-traumatic part [22]. In this study, penetrating trauma was the more common mechanism of injury to the brachial and ulnar or radial arteries. As a result, primary repair could be performed in relatively many cases. PTFE graft interposition is typically avoided due to the low patency rate and increased risk of infection [23,24]. In this study, however, due to the accompanying damage, adequate SVG interposition could not be achieved in many cases, resulting in a relatively high rate of PTFE graft interposition (32.1%) and a relatively low rate of SVG interposition (25%). Nonetheless, the amputation rate was not higher than that reported in previous studies.

The limitations of this study include the small number of cases of vascular trauma, the presence of fewer cases of penetrating trauma than of blunt trauma, and the non-randomized, retrospective, observational design of the study. Of particular note, the amputation rate was higher in patients with blunt trauma than that in patients with penetrating trauma; however, this difference was not statistically significant. Further studies may be needed to analyze the long trauma-to-operation time and to review the causes of low SVG interposition and high PTFE graft interposition in vascular reconstruction.

In conclusion, in this study, blunt trauma caused a higher proportion of peripheral arterial injuries than in reports from other countries. Blunt trauma was associated with a higher MESS than penetrating trauma, and amputation was more frequent. Specifically, patients with blunt trauma had a MESS higher than 7, and amputation resulted when revascularization failed in cases of blunt trauma of the lower extremity. Therefore, particular care is needed in making treatment decisions for patients with peripheral arterial injuries caused by blunt trauma.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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