



# Therapeutic management and amputation options in a long time delayed blunt popliteal artery injury

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## Abstract

**Purpose** To report the experience of treatment on blunt traumatic popliteal artery injury (PAI) combined orthopedic injuries and determine the amputation-associated factors.

**Methods** From January 2008 to December 2019, 55 patients in level I trauma center with traumatic blunt PAI were retrospectively reviewed. Variables were retrospectively collected and statistically analyzed. Patients with PAI with limb salvage, primary amputation, and secondary amputation were retrospectively grouped and compared.

**Results** A total of 55 patients with a median age of 41.4 years (range 18–70), of which 45 were males (81.8%) and 10 were females (18.2%), were enrolled. The overall amputation rate was 36.4% because 88.6% of patients faced more than 6 h of delay before treatment. The average injury severe score (ISS) and abbreviated injury score (AIS) were 10.4 (range 9–34) and 8.2 (range 5–16), respectively. Multivariate regression analysis showed that the number of hospitalization days was a significantly related factor to amputation. After a median follow-up of 56 months (range 12–132), no death, another limb loss, or claudication was found in all patients.

**Conclusions** Patients with PAI are commonly accompanied by multiple injuries that increase the risk of amputation; therefore, timely treatments are urgently required. Reducing the severity of ischemia by fasciotomy, not losing time by performing preoperative imaging or diagnostic tests, and repairing the associated venous injury can help to optimize the rates of limb salvage. However, impact factors, such as the gender and age of the patient, injured mechanisms, concomitant injuries, AIS, ISS, and surgical times, are not associated with the outcomes of amputation. Nonetheless, endeavors to salvage the limbs as far as possible should be made.

**Keywords** Popliteal artery injury · Trauma · Blood vessels · Blunt injury · Fracture · Dislocation

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## Introduction

Popliteal artery injury (PAI) is relatively rare (0.2–1%) in traumatic lower extremity lesions. It is the second most common vessel injury in the lower limb, resulting in a higher amputation rate (21–30%) [1–3]. The initial evaluation and intervention of PAI have evolved from routine use of angiogram to computed tomography angiography (CTA) correlated with the physical exam findings, for diagnosis and establishing a surgical protocol [4]. Endovascular repair is suitable for special cases such as intimal disruption [5]. Open repair is still the optimal alternative for treating traumatic popliteal vascular injury [6]. Blunt PAIs are mostly associated with peri-knee fractures, concomitant mass soft tissue injury, or knee dislocation, leading to poor rates of limb salvage and significantly devastating outcomes. [7–10]

Therapeutic management and amputation alternatives for blunt PAI are still debatable [11–13]. It is still controversial whether strategies, such as bone-first fixation or vessel-first patency, can give a rational outcome in patients with bone fractures diagnosed with blunt PAI [11, 14]. Moreover, the utilization of autologous vein or prosthetic grafts during revascularization is debatable.<sup>15, 16</sup> In this study, we investigated the amputation-associated factors and diagnostic and therapeutic variables for managing patients with PAI due to blunt trauma. We retrospectively collected the data of patients with PAI and them divided into three groups according to the outcome of limb salvage, primary amputation, and secondary amputation.

## Materials and methods

### Patients' cohort

The study protocol was approved by the Institutional Review Board Committee of Qilu Hospital of Shandong University and was conducted in accordance with the Declaration of Helsinki. From January 2008 to December 2019, a total of 55 patients with acute blunt traumatic PAI associated with lower extremity fractures or dislocation around the knee were admitted to a Level I trauma center in the Qilu Hospital of the Shandong University in the East of China were enrolled to build a 12-year population-based retrospective review of blunt popliteal artery injuries.

### Data collection

The medical data were retrospectively collected to analyze the following variables patient demographics, the mechanism of injury, the location of injury (e.g., right or left lower extremity), associated lower extremity injuries, concomitant systemic injuries (i.e., cerebral injury, neurological dysfunction such as paralysis and mangled extremities), injury severe score (ISS), abbreviated injury scale (AIS), limb ischemia time, associated injuries, such as concomitant bone and nerve injuries, and time from injury to revascularization, treatment strategies, limb salvage, the length of stay (as presented in Table 1).

### Patients' management

The patients were postoperatively administered anticoagulant, anti-infective, and anti-vasospasm drugs immediately after the operation. Low-molecular-weight heparin (i.e., nadroparin, 4100 IU/q12h) was administered for

**Table 1** The demographic and clinical characteristics of patients with blunt popliteal artery injury

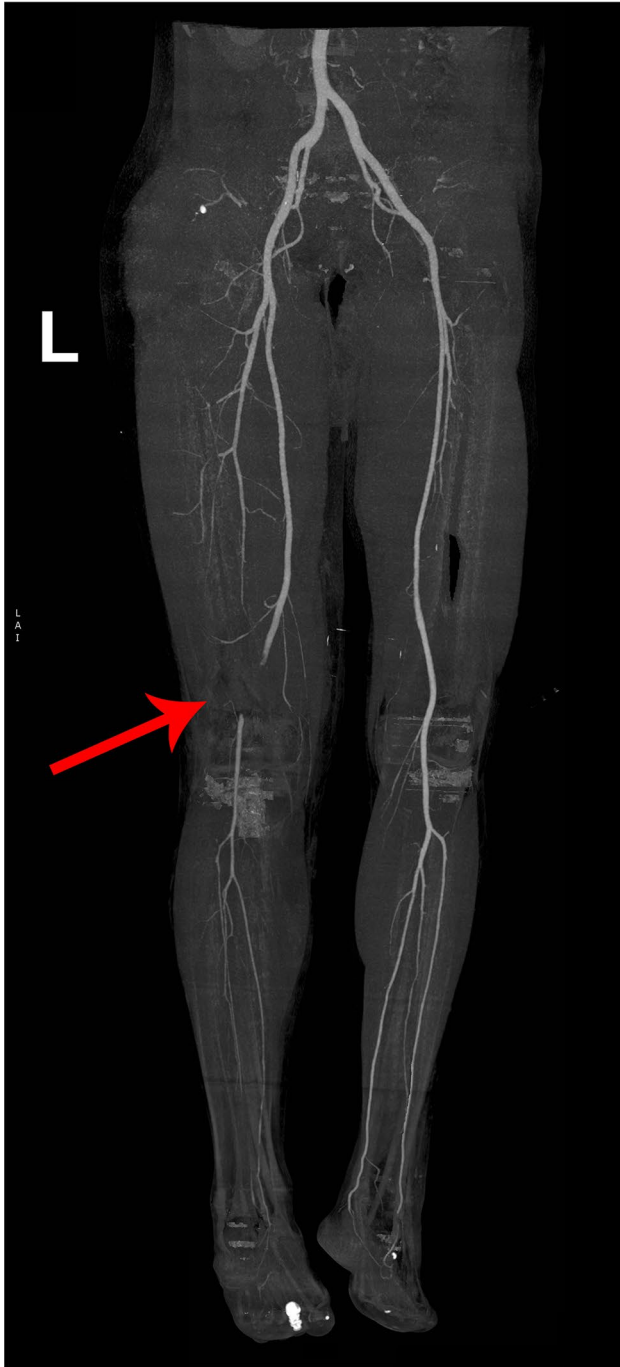
Variable	Number	Range/percentage
Total	55	100%
Age (year, mean $\pm$ SD)	41.4 $\pm$ 13.9	18–70
Gender		
Male	45	81.8%
Female	10	18.2%
Time interval (hour, mean $\pm$ SD)	20.4 $\pm$ 23.4	2–96
Mechanisms of blunt injury		
MVA	30	54.6%
FFH	6	10.9%
CA	13	23.6%
FO	6	10.9%
Limb involved		
Right	26	47.3%
Left	29	52.7%
Concomitant injuries		
Knee dislocation	19	34.6%
Femoral fracture alone	16	29.1%
Tibial or fibular fracture alone	31	55.4%
Floating knee	10	18.2%
Ligament or tendon lesions	5	9.1%
Acute compartment syndrome	36	65.5%
Nerve injury		
Femoral nerve	2	3.6%
Tibial nerve	29	52.7%
Common peroneal nerve	28	50.9%
ISS at presentation (mean $\pm$ SD)	10.40 $\pm$ 4.37	9~34
AIS at presentation (mean $\pm$ SD)	8.24 $\pm$ 2.50	5~16
Hemorrhagic shock	11	20.0%

MVA motor vehicle accident, FFH fall from height, CA crushing accident, FO falling object, ISS injury severity score, AIS abbreviated injury score

anti-coagulation lasting for 2–3 weeks. Then, cefazolin (0.5 g/q8h) was intravenously injected until 48 h after the operation. Papaverine (30 mg/q8h) was administered for anti-vasospasm for 1 week. During this period, a thrombelastography was tested to monitor the value of maximum amplitude (MA). When deemed necessary, aspirin (100 mg/qd) was orally administered for 2–3 weeks in accordance with the functional ability of platelets. Meanwhile, the trend of changes in myoglobin (MYO), urine output, and renal functions was closely monitored, and continuous renal replacement therapy (CRRT) was provided in time, when deemed necessary. Definitive reconstructions of the lower extremity were performed in a subsequent procedure. The fasciotomy wounds were irrigated regularly and the necrotic tissues were excised periodically until the wounds became clean and acceptable for closure or skin grafting.

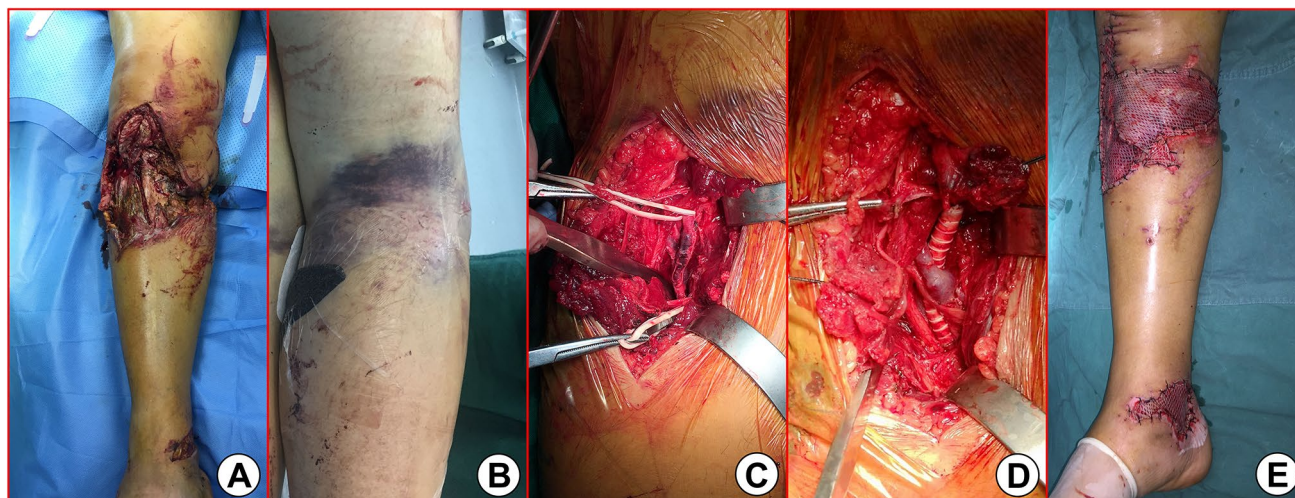
## Surgical protocol

After an initial physical examination such as that for sensory and motor dysfunctions, patients suspected of PAI were diagnosed with routine CTA (Fig. 1), and three-dimensional (3D) reconstructions of the entire lower extremity were performed to assess for the presence of fractures or dislocation around the knee simultaneously.



**Fig. 1** Popliteal artery injury was confirmed by CTA

A vessel-first protocol with direct vascular reconstruction or with the use of vascular polytetrafluoroethylene (PTFE) was performed as soon as possible before any orthopedic procedure. Patients with confirmed PAI were immediately transferred to the operating room and placed in a lateral position under general anesthesia (Fig. 2A–E), and 4-compartment fasciotomy of the lower leg was performed through a single lateral incision as a prophylactic procedure or because of a clinically apparent compartment syndrome. If deemed necessary, an auxiliary medial incision was performed when facing insufficient decompression. Intraoperative catheter embolectomy was performed to retain the reperfusion of the lower limb. The treatment strategy of PAI involved primary anastomosis, autologous vein interposition, and prosthetic grafts (PTFE), and none of the patients who underwent the repair surgery with PTFE developed any infection or required secondary amputation. In acute compartment syndrome patients (65.5%), fasciotomy was performed before vascular reconstruction and bone/joint stabilization. Delay of > 6 h, severe extremity ischemia, and popliteal vein ligation were the selection criteria for fasciotomy based on our experiences. In 11 patients (20.0%), primary osteosynthesis was performed with an external fixation performed similarly to the vessel reconstruction procedure. A total of 16 patients (29.1%) required definitive fracture stabilization in the second stage. The muscular status of the lower leg was assessed according to the concept of “4C” (“Colour”, “Capacity of blood”, “Contractibility”, and “Consistency”), and most primary amputations were performed commonly for limb ischemia time > 6 h, although several patients were not amputated on the limbs after careful assessment and fortunately achieved successful limb salvage. A posterior approach was adopted with an approximate site of injury at its center, and an S-shaped incision was created to expose the vessels and nerves. The principle of vessel-first stratagem was adopted for most cases, indicating that arterial injuries were repaired before the orthopedic injuries. Moreover, a No.4 Fogarty embolectomy catheter was passed distally and proximally, and 20 mL of a solution containing 50 units of unfractionated heparin was injected, the backflow and inflow were assessed, and, finally, the calf was gently massaged after the catheter was removed to encourage evacuation of any thrombus in the anterior and posterior tibial arteries. The primary anastomosis was performed with a tension-free status. Whenever arterial grafting was required, reversed contralateral greater or small saphenous vein grafts or PTFE was used. If a venous injury was simple, it was repaired through a primary suture; however, complex injuries involved ligation. The neural injury was repaired simultaneously. Temporary external fixation was performed to stabilize the knee in the lateral position for protecting the vascular



**Fig. 2** A typical case who diagnosed with traumatic blunt popliteal artery injury suffering from motor vehicle accident. Patient with open lower limb injury were transferred to operation room immediately (A). Popliteal artery injury was confirmed (B). A posterior approach was made with the approximate site of injury at its center, and a

S-shaped incision was used to exposure the vessel and nerve (C). Artery was repaired by the artificial vessel graft and restoration of blood flow was identified (D). Anterior open injury was then treated (E)

graft. The vacuum-assisted closure (VAC) technique was employed to cover the wounds. At the end of the surgery, careful clinical reassessment of the leg was performed.

### Postoperative follow-up

The indications for anti-coagulation and the duration of postoperative thrombosis prophylaxis were based on clinical factors such as mobility and comorbidities. All patients received subcutaneous injections with low-molecular-weight heparin (LMWH; 4100 IU, twice daily) after the operation. Duplex ultrasound and CT arteriography were performed for the patency of the popliteal vessel and deep venous thrombosis of the lower extremities. All patients attended the standard follow-up visits at the outpatient clinic at a 1-month interval after discharge. The long-term outcomes were analyzed through a survey of all patients in December 2019, which assessed survival, limb salvage, and claudication (Fig. 3).

### Statistical analysis

Subgroup analysis was performed by dividing the overall cohort ( $n=55$ ) into 3 study groups, as described: Group 1 (limb salvage,  $n=35$ ), group 2 (primary amputation,  $n=11$ ), and group 3 (secondary amputation,  $n=9$ ). Analysis was performed between 3 groups. Moreover, a univariate analysis of different factors related to limb salvage was performed. The factors determined to be different between these groups were entered into a stepwise multivariate regression analysis to determine those that were associated positively and

negatively with the endpoint of early limb salvage. The data are presented as median values and the range for continuous variables and by absolute numbers and percentages for categorical variables. The data were compared with an independent Student's *t*-test or one-way analysis of variance (ANOVA), while categorical proportions with contingency table were tested with the Chi-square test or Fisher's exact test, as deemed appropriate.  $P < 0.05$  was considered to be statistically significant.

### Results

From January 2008 to December 2019, there were 55 patients with blunt PAIs in the level I trauma center at Qilu Hospital of Shandong University. Demographics and clinical data of the patients are summarized in Table 1. There were 45 male patients (81.8%) and 10 female patients (18.2%) with a median age of 41.3 years (range 18–70). PAIs of most patients (54.6%) were caused by motor vehicle accidents (MVA), additional traumatic mechanisms such as falls from height (10.9%), crushing accidents (23.6%), and falling objects (10.9%). No predilection was present on the unilateral limb. In addition, concurrent injuries, such as knee dislocation (34.6%), proximal tibial fractures (84.5%), ligamentous lesions (9.1%), and acute compartment syndrome (65.5%), were commonly followed with PAI. More than half of the patients suffered nerve injury (more than 52.7%), and one-fifth of the patients suffered hemorrhagic shock (20.0%). The overall amputation rate was 36.4% due to 88.6% of patients with ischemia of more than 6 h, and

**Fig. 3** Limb salvage was achieved and three-year follow-up was performed (A, B)



20.5% patients was prolonged ischemia because of transportation time. After arterial reconstruction, total 20.5% patients were amputated. The average of ISS and AIS in this cohort was 10.4 (range from 9 to 34) and 8.2 (range from 5 to 16) respectively.

A total of nine patients (16.4%) performed secondary amputation due to severe complications. As shown in Table 1, 29 patients were diagnosed with tibial nerve injury. A total of 48.6% (17/35) of patients with a tibial nerve injury were present in the limb-salvage group. The primary amputation group with tibial nerve injury rate was 66.7% (7/11), and the secondary amputation with tibial nerve injury rate was 55.6% (5/9). The amputation level is classified as above and below the knee. The 30-day and 90-day mortality were both zero, and the overall mortality rate of the patients who sustained traumatic popliteal vascular injuries was also zero.

The overall limb-salvage rate was 63.6%. The information on the patients who underwent amputations is listed in Table 2. A total of 20 patients with PAI underwent primary or secondary amputation, and 35 patients underwent a primary intervention for a salvageable limb (Fig. 4A–F). Collectively, related indexes, including age ( $P=0.835$ ), time interval ( $P=0.824$ ), mechanisms of blunt injury, ISS ( $P=0.580$ ), AIS ( $P=0.637$ ), and the number of surgery times ( $P=0.682$ ) were compared which shows insignificance. Meanwhile, PAI patients with the outcome of limb salvage, primary amputation, and secondary amputation,

were retrospectively grouped and compared. A vessel-first approach was performed in all patients. During a median follow-up of 56 (range 12–132) months, all patients were alive, and no limb loss again or claudication was recorded. A multivariate logistic regression model was established to determine factors that were independently associated with early limb salvage (Table 3). Multivariate regression analysis indicated that variable, such as the number of days of hospitalization, was significantly associated with limb salvage ( $P=0.042$ , 95% CI 1.002–1.112, OR 1.056).

## Discussion

The cohort in our study included patients with blunt traumatic PAI and the majority were caused by traffic accidents. This retrospective study reported the experience with a large number of complex traumatic blunt PAI combined with limb fracture around the knee and investigated the outcomes from limb salvage, primary amputation, and secondary amputation groups, aiming to provide novel insights to improve outcomes of this morbid condition.

Historically, PAI occurs in 5–19% of civilians, and blunt thrombosis of the popliteal artery results in an amputation rate of over 30% of cases [2, 3]. CTA is a sensitive and specific non-invasive imaging modality for arterial evaluation [4, 17]. Routine CTA is conducive in PAI for predicting the

**Table 2** The demographic, clinical characteristics, and treatment strategies of three independent groups

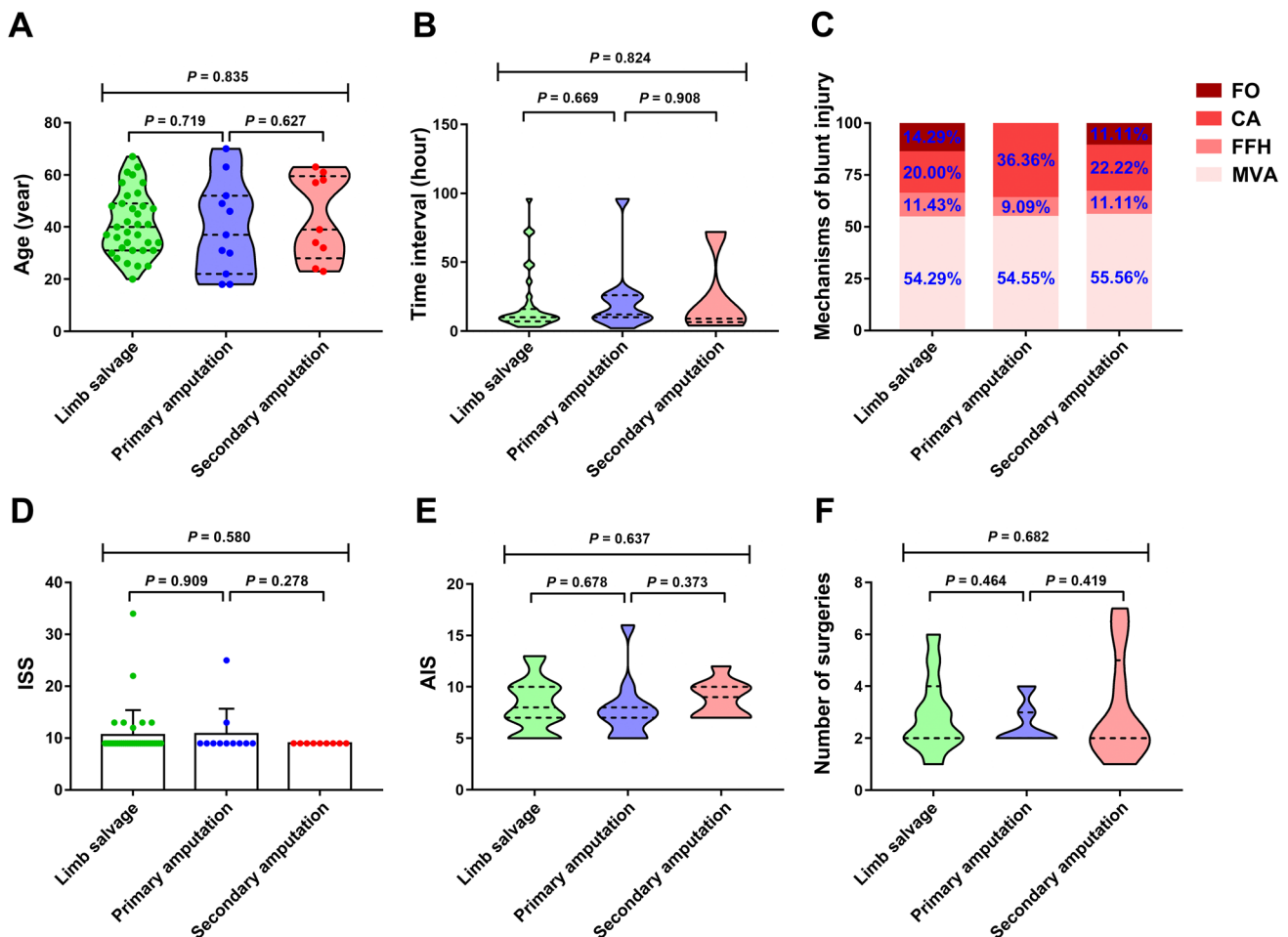
	Limb salvage	Primary amputation	Secondary amputation
Total ( <i>n</i> )	35	11	9
Age (year, mean $\pm$ SD)	41.3 $\pm$ 12.1	39.6 $\pm$ 17.8	43.4 $\pm$ 16.3
Time interval (hour, mean $\pm$ SD)	18.9 $\pm$ 22.1	22.4 $\pm$ 25.9	23.8 $\pm$ 27.9
Gender			
Male	28/35 (80.0%)	8/11 (72.7%)	9/9 (100.0%)
Female	7/35 (20.0%)	3/11 (27.3%)	0/9 (0.0%)
Mechanisms of blunt injury			
MVA	19/35 (54.3%)	6/11 (54.6%)	5/9 (55.6%)
FFH	4/35 (11.4%)	1/11 (9.1%)	1/9 (11.1%)
CA	7/35 (20.0%)	4/11 (36.4%)	2/9 (22.2%)
FO	5/35 (14.3%)	0/11 (0.0%)	1/9 (11.1%)
ISS at presentation (mean $\pm$ SD)	10.6 $\pm$ 4.8	10.8 $\pm$ 4.9	9.0 $\pm$ 0.0
AIS at presentation (mean $\pm$ SD)	8.2 $\pm$ 2.5	7.8 $\pm$ 3.1	8.9 $\pm$ 1.8
Anticoagulation	31/35 (88.6%)	NA	6/9 (66.7%)
Strategies priority			
Vessel-first	24/35 (68.6%)	NA	8/9 (88.9%)
Bone-first	11/35 (31.4%)	NA	1/9 (11.1%)
Popliteal vein ligation	4/35 (11.4%)	NA	2/9 (22.2%)
Reconstruction of artery			
Direct anastomosis	20/35 (57.1%)	NA	4/9 (44.4%)
Artificial vessels	7/35 (20.0%)	NA	2/9 (22.2%)
Veins bypass	8/35 (22.9%)	NA	3/9 (33.3%)
Number of surgical times	2.9 $\pm$ 1.5	2.6 $\pm$ 0.8	3.1 $\pm$ 2.1

MVA motor vehicle accident, FFH fall from height, CA crushing accident, FO falling object, NA not available, ISS injury severity score, AIS abbreviated injury score

location of the arterial injury and recommending the evaluation of vascular status. Meanwhile, it will be clear whether the limb arterial injury is combined with multi-planar injury. Previous studies have proposed the effectiveness of CTA investigation for suspicious vascular injuries [18]. Three D reconstructions of lower extremities can also be performed precisely to reduce unnecessary movements and recanalization intervals for identifying the site of vascular injury. Recently published data showed increasing support for selective angiography to reduce additional ischemia delay [19]. However, both catheter-based angiography and duplex ultrasonography may not be available all the time, and they are highly operator-dependent diagnostic techniques.

Previous studies have claimed that lower limb ischemia persisting for more than 6–8 h results in limb loss [20, 21]. Considering hypoxia tolerance and nutrition deprivation in tissues, most surgeons have accepted this theory. However, in the cases included in this study, we noticed that several patients arriving at the center with an overdue window period were suffering from limb salvage, which eventually resulted in moderate treatment outcomes. In patients with excessively prolonged ischemia, the flexible angle of the knee joint can be adjusted according to the length of the area of vascular injury to reduce anastomotic stoma tension.

Moreover, a single lateral incision can be selected for 4-compartment decompression. Collectively, the lateral position is convenient for decreasing the difficulty of external fixation and lowering the higher risk of anastomotic tear when changing the position again. Moreover, decompression with a single lateral incision was used to understand the muscle activity of the calf fascia compartment, especially the anterior, lateral, posterior superficial, and deep compartments. In the case of insufficient posterior compartment decompression, a conventional medial decompression incision was designed after treating vascular injury and external fixation across the knee. Generally, a longitudinal S-shaped incision at the joint line levels was used. The level of vascular injury should be determined per the preoperative CTA and 3D reconstructions of the lower extremity. When accompanied by tibial plateau fractures, avoiding the damage of the adjacent flap during posterior incision exposure is crucial. When the popliteal fossa is exposed, a sufficient length should be explored to assess arterial anastomotic stoma tension after resecting the injured segment. Generally, a less-than-3-cm arterial defect can be repaired by bending the knee and performing an end-to-end anastomosis. For a 6-mm-diameter artificial vessel, evaluating its length without tension is essential. Moreover, surgeons should pay



**Fig. 4** Subgroup analysis was performed by dividing the overall cohort ( $n=55$ ) into 3 study groups as limb salvage ( $n=35$ ), primary amputation ( $n=11$ ) and Secondary amputation ( $n=9$ ). Total twenty patients with PAI were experienced with primary or secondary ampu-

tation, and thirty-five patients were performed as primary intervention for a salvageable limb. Related indexes including age (A), time interval (B), mechanisms of blunt injury (C), ISS (D), AIS (E) and number of surgeries (F) were compared which shows insignificance

attention to removing the thrombus from the distal artery and moderately squeezing the limbs, which are conducive to removing the distal thrombus and evaluating the distal blood flow. Endeavors to salvage the limb as much as possible are advantageous to subsequent functional recovery in patients. The ultimate multivariate regression analysis in this study indicated that variables for evaluating limb salvage, except for hospitalized days, were insignificant, and factors affecting limb salvage were ascribed to hospitalized days. This result is probably because of the low number of patients, and further studies are necessary to validate the hypothesis.

Whether bone-first fixation or vessel-first patency will lead to a rational outcome in patients with bone fractures diagnosed with blunt PAI is controversial [11, 14, 22]. Favorable skeletal fixation is optimal for vessel repair, whereas the bone-first strategy is beneficial for severe orthopedic injuries that are in the range of ischemia. Popliteal artery revascularization in the early

stage considerably increases the possibility of limb salvage [23]. In this study, we preferred to perform vessel-first on most patients with PAI. The vessel-first strategy is predominant in limb salvage, especially in patients with long-term ischemia, considering limb salvage outcomes. Reassessing the arterial blood supply of the distal limbs after revascularization to observe the far-end capillary filling of the hind limb and venous filling might be critical. Based on such reassessment, an external fixation strategy across the knee can be selected. The key segment of the posterior displacement of the tibial plateau should be fixed with a screw or Kirschner wire provisionally because the soft tissue freeness is sufficient for limited internal fixation in a short period. To avoid problems such as a prolonged waiting time for the second-stage reconstruction process, owing to the joint capsule attachment of key fracture, this limited fixation procedure can decrease anastomosis stoma tension and secondary injury risk.

**Table 3** Multivariate regression analysis of different factors related to limb salvage

Study variable	OR	95% CI	P value
Gender	0.956	0.154–5.947	0.961
Age	0.991	0.943–1.042	0.732
Time interval	0.972	0.941–1.004	0.084
Mechanisms of blunt injury			
MVA			
FFH	0.176	0.011–2.922	0.226
CA	0.402	0.015–10.677	0.586
FO	0.462	0.030–7.050	0.578
Knee dislocation	0.382	0.077–1.894	0.239
Concomitant injury	1.277	0.244–6.672	0.772
Nerve injury	3.004	0.471–19.170	0.245
Hemorrhagic shock	4.874	0.463–51.294	0.187
ISS at presentation	1.046	0.878–1.247	0.614
AIS at presentation	0.918	0.656–1.285	0.618
Number of surgical times	0.766	0.406–1.445	0.410
Hospitalized days	1.056	1.002–1.112	0.042*

OR odds ratio, CI confidence interval, MVA motor vehicle accident, FFH fall from height, CA crushing accident, FO falling object, ISS injury severity score, AIS abbreviated injury score

\* $P < 0.05$

The vascular repair type is controversial in the literature [11–13]. Selecting the reversed vein or prosthetic interposition graft has been argued to repair popliteal vessel injuries because of defects after debridement. Thus, popliteal arteries should be thoroughly sutured without tension. Obtaining the saphenous vein is laborious for patients with multiple trauma with fractures around the knee. Previous studies have shown no differences in the patency and infection rates of repair with an artificial vessel or reversed vein. The end-to-end anastomosis in our cases without tension and artificial vessel repair was the fast, efficient, and perfect method of restoring popliteal vascular injuries with prolonged ischemia at our trauma center in recent years. No difference exists in our series between using autologous veins and prosthetic grafts.

Invasive strategies are suitable for urgent PAI, whereas procedures taken almost with similar aims of decompression. First, prophylactic calf compartment decompression is effective for evaluating muscular vitality in acute compartment syndrome. Second, surgical decompression is of vascular priority for the maximal protection of muscular vitality. Third, the value of limb preservation in prolonged ischemia can be evaluated objectively by combining indicators including the limb damage severity score (also known as The Mangled Extremity Severity Score), MYO, and renal functions, and the willingness of patients' family members. Fourth, preventive measures for ischemia–reperfusion injury after revascularization should

be followed. Fifth, balancing the incision of decompression and reconstruction based on second-stage definitive fixation is necessary.

For patients with prolonged ischemia, postoperative infective conditions should be monitored carefully. In the case of a vascular crisis, a second-look exploration should be performed in time. The rehabilitation training of the knee overcomes the limitation of joint extension caused by a scar in the popliteal fossa. Thus, theoretically, a serial surgical intervention for damage control and endeavors to salvage the limb as much as possible can achieve the expected limb salvage rate in patients with long-term ischemia.

**Author contributions** CQ and LC contributed equally on this study. XYL and ZFL participated in the study design. CQ, LC and LLW collected data and analyzed the data. CQ and LC co-drafted the manuscript. XYL and ZFL revised the manuscript and supervised this study. All authors have read the final manuscript and agree with this publication.

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**Data availability** The data underlying this article are available in the article.

## Declarations

**Conflict of interest** The authors declare that they have no any competing interests.

**Ethical approval** The institutional review board approved this study.

**Consent for publication** All authors approve this version for publication and are accountable for its content.

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