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Reconstructive

Efficacy of Orthoplastic Management in the Treatment of Traumatic Popliteal Artery Injury

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Background: Popliteal artery injury (PAI) is a challenging condition. Even with appropriate initial treatment and reconstruction of the associated injuries, extensive soft-tissue necrosis may occur, requiring lower leg amputation. There are no reports on the effectiveness of orthoplastic surgery in treating traumatic PAI. However, orthoplastic surgery is also considered very effective in PAI treatment, which requires delicate handling of soft-tissue and blood vessels. This study aimed to examine the treatment outcomes of traumatic PAI at a trauma center with the capacity for orthoplastic management.

Methods: Patients with PAI who were treated at our institution between August 2013 and December 2021 were included in this study. The surgeons included multiple orthoplastic surgeons with capabilities in vascular repair, bone and ligament reconstruction, and soft-tissue reconstruction. Patient demographics, injury characteristics, degree of ischemia, and treatment were investigated. We also investigated whether soft-tissue reconstruction and lower limb amputation were necessary as outcomes of treatment.

Results: Fifteen limbs of 14 patients with PAI met the inclusion criteria. Extensive soft-tissue necrosis was observed in three limbs. Two of these limbs were covered with a free latissimus dorsi flap and could be salvaged. In the remaining limb, lower limb amputation was unavoidable because of unexplained cardiac arrest during the initial surgery, but a fillet flap was used to successfully preserve the knee joint.

Conclusion: Orthoplastic management has the potential to improve limb salvage rates and provide good outcomes for the treatment of traumatic PAI. *(Plast Reconstr Surg Glob Open 2024; 12:e5696; doi: 10.1097/GOX.0000000000005696; Published online 25 March 2024.)*

INTRODUCTION

The incidence of popliteal artery injury (PAI) in trauma around the knee joint is rare (0.2%–1%); however, the amputation rate of the lower extremities is reportedly 10%–16%.[1–5] PAI is a challenging trauma that requires prompt and accurate treatment because the probability of lower limb amputation increases as the ischemic time increases. The initial treatment for PAI requires early resumption of blood circulation with a temporary vascular shunt (TVS), prompt arterial reconstruction, fasciotomy to prevent compartment syndrome, and temporary stabilization of the knee joint using an external fixator. After the hemodynamics of the lower limbs have stabilized, appropriate reconstructive surgery is required for the associated bone and ligament injuries. However, even with appropriate initial treatment and reconstruction of the associated injuries, extensive soft-tissue necrosis may occur during the treatment course, requiring lower leg amputation. It is possible to salvage the limb by predicting the occurrence of extensive soft-tissue necrosis and performing soft-tissue reconstruction at an appropriate time. Therefore, it is desirable to perform management that considers future soft-tissue reconstruction required from the initial treatment stage. Orthoplastic surgery is known as "the principle and practice of specialties of orthopedic and plastic surgeons applied to a clinical problem either by a single provider or teams of providers working in concert for the benefit of the patient."[6] There have been many reports on the effectiveness of orthoplastic management in treating open fractures of the lower extremities.[6–8] However, there are no reports on the effectiveness of orthoplastic

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surgery for treating traumatic PAI. Orthoplastic surgery is also considered to be very effective in PAI treatment, which requires delicate handling of the soft-tissue and blood vessels.

Our trauma center is staffed by multiple orthoplastic surgeons who can consistently perform TVS, vascular repair, bone and ligament reconstruction, and soft-tissue reconstruction. This study aimed to examine the treatment outcomes of traumatic PAI at a trauma center with the capacity for orthoplastic management and to demonstrate its effectiveness in orthoplastic management in the treatment of traumatic PAI. We also examined and reported predictors of the need for soft-tissue reconstruction in patients with traumatic PAI.

MATERIALS AND METHODS

This study was approved by the institutional review board of the authors' affiliated institutions. Patients with PAI who were treated at our institution between August 2013 and December 2021 were included in this study, and their treatment outcomes were investigated. The surgeons included multiple orthoplastic surgeons with capabilities in vascular repair, bone and ligament reconstruction, and soft-tissue reconstruction. During the acute phase of treatment, patients were consistently treated by their respective surgeons. Patients with insufficient medical records were excluded.

Patient demographics and injury characteristics were obtained from the medical records. Associated injuries were evaluated using plain radiography and CT. Soft-tissue injury was evaluated using photographs and medical records taken at the time of transportation. As the degree of ischemia in the injured extremities at the time of transportation to our institution, the presence or absence of pulsation, Doppler ultrasound of the dorsalis pedis artery, and degree of motor paralysis of the lower extremities were investigated. In many patients, sensory loss of the lower limbs was not sufficiently recorded; therefore, these data were excluded from the survey. CT angiography (CTA) was performed to evaluate blood flow in the extremities at the time of transportation. Patients in whom arteries on the distal side were not enhanced were considered to have no collateral circulation. Patients in whom arteries on the distal side were enhanced, even though the main trunk of the popliteal artery at the injured site was interrupted, were considered to have preserved collateral circulation (Fig. 1). CTA of both lower extremities was performed simultaneously, and it was confirmed that the blood vessels of the lower extremity on the unaffected side, including collateral circulation, were enhanced. By doing so, we denied that collateral circulation on the affected side was not enhanced owing to the timing of imaging.

We investigated the presence or absence of TVS use during the initial surgery, time period between injury and TVS establishment, time from injury to the completion of popliteal artery reconstruction, presence or absence of fasciotomy, and types of secondary surgery. We also investigated whether soft-tissue reconstruction and lower limb amputation were necessary as outcomes of treatment.

Takeaways

Question: Does orthoplastic management improve the outcomes of popliteal artery injury (PAI) treatment?

Findings: We reported the case series of treatment outcomes of traumatic PAI in a trauma center with capacity for orthoplastic management, and treatment outcomes were excellent.

Meaning: Orthoplastic management has the potential to improve the limb salvage rate and provide good outcomes in the treatment of traumatic PAI.

All hemodynamic and neurological assessments of the lower extremities and judgments regarding the use of TVS were made by each patient's surgeon. Each surgeon individually determined the need for prophylactic fasciotomy after revascularization, considering the ischemia time, degree of swelling of the injured limb, and condition of the open wound. The initial surgery was completed by stabilizing the bones and joints using an external fixator and

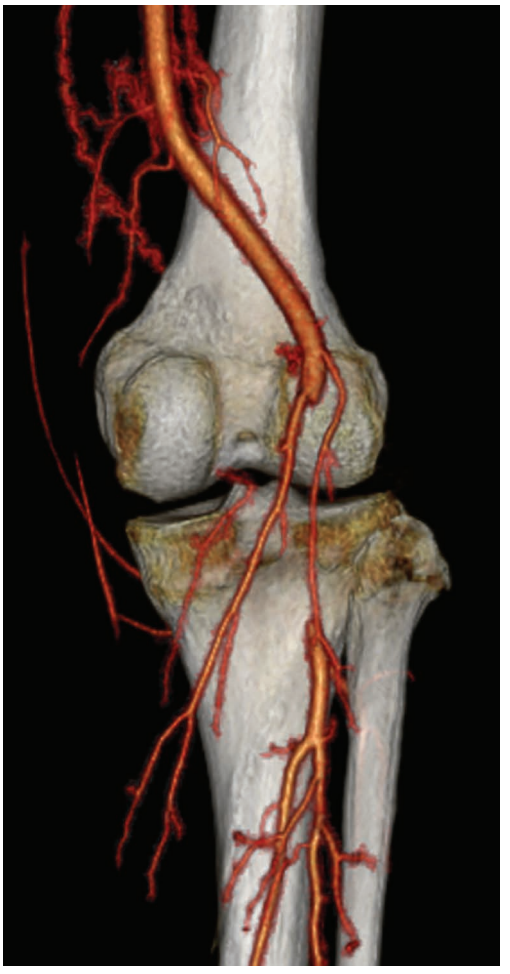

Fig. 1. CTA of PAI with residual collateral circulation. The main trunk of the popliteal artery is interrupted at the level of knee joint, but the artery is once again enhanced distally.

revascularizing the popliteal artery. Internal fixation of the fracture and ligament repair was performed a few days later as a secondary surgery. Soft-tissue reconstruction was performed after determining the extent of the skin and muscle necrosis.

STATISTICAL ANALYSIS

Statistical analysis was performed to determine predictors of extensive soft-tissue necrosis requiring soft-tissue reconstruction. The patients were divided into two groups: patients in whom extensive soft-tissue necrosis did not occur during the treatment course (group 1) and those in whom necrosis occurred (group 2). Predictors of extensive soft-tissue necrosis were investigated by comparing the age and sex of the patients, degree of ischemia, rate of TVS use, time from injury to repair of the popliteal artery, and fasciotomy rate between the two groups. A two-sided Fisher exact test was used to compare explanatory variables, and the Mann–Whitney *U* test was used to compare continuous variables. Statistical significance was set at a *P* value of less than 0.05. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R software (R Foundation for Statistical Computing, Vienna, Austria).[9] EZR is a modified version of the R commander and is designed to add statistical functions that are frequently used in biostatistics.

RESULTS

Fifteen limbs of 14 patients with PAI met the inclusion criteria. The average age at the time of injury was 53.7 years (20–86 years) for 14 male limbs and one female limb. Among these, five limbs were injured by a farm tractor, four by a traffic accident, three by a fall, two by a crush injury, and one by a mowing machine. Crash injuries occurred in two limbs of the same patient. Associated injuries included knee joint dislocation in six limbs, proximal tibial fracture in three, distal femur fracture in one, and tibial shaft fracture in the other. A total of four limbs did not have any bone or ligamentous injuries. Soft-tissue injuries included open leg wound in four limbs, open popliteal wound in three limbs, gastrocnemius muscle injury in two limbs, tibialis anterior muscle injury in one limb, and popliteal crush injury in three limbs. The degree of ischemia at the time of transport was also evaluated. Blood flow in the lower extremities was measured by palpation of the dorsalis pedis artery or via Doppler ultrasound, which was confirmed in five limbs but not in the others. Three limbs did not show motor paralysis, five showed partial motor paralysis, and seven showed complete motor paralysis. CTA revealed interruption of the main trunk of the popliteal artery in all the cases, with collateral circulation in only 12 limbs (Table 1). A cross-limb vascular shunt (CLS) was performed in five limbs. Intravascular shunting (IVS) was not performed in our case series. The average time from injury to establish TVS was 5.2 (3–8) hours. The average time from injury to popliteal artery reconstruction was 8.8 (4–16) hours, and popliteal artery reconstruction was performed using end-to-end anastomosis or a greater saphenous vein graft from the uninjured side. Fasciotomies were performed on seven limbs.

During the treatment course, extensive soft-tissue necrosis occurred in three limbs, all of which were accompanied by complete motor paralysis with no collateral circulation on CTA. Two of these limbs were covered with a free latissimus dorsi flap and could be salvaged. In the remaining limb, unexplainable cardiac arrest occurred during initial treatment; therefore, arterial reconstruction could not be performed. After the patient's general

Table 1. Patient Demographics, Characteristics of Injuries, and Degree of Ischemia

No.	Age, y	Sex	Mechanism of Injury	Associated Injury	Soft-tissue Injury	Dorsalis Pedis A	Motor Paralysis	Collateral Circulation
1	80	Male	Fall accident	Knee dislocation	Open popliteal wound, gastrocnemius muscle injury	Inaudible	—	Remained
2	42	Male	Fall accident	Knee dislocation	—	Audible	—	Remained
3	35	Male	Fall accident	Knee dislocation	—	Inaudible	—	Remained
4	81	Male	Farm tractor	Distal femur fracture	—	Audible	Partial	Remained
5	39	Male	Mowing machine	—	Open popliteal wound, gastrocnemius muscle injury	Audible	Partial	Remained
6	39	Female	Traffic accident	Proximal tibial fracture	Open leg wound, tibialis anterior muscle injury	Audible	Partial	Remained
7	20	Male	Traffic accident	Knee dislocation	Open popliteal wound	Inaudible	Partial	Remained
8	42	Male	Farm tractor	—	Popliteal crush injury	Audible	Partial	Remained
9	77	Male	Farm tractor	Proximal tibial fracture	Open leg wound	Inaudible	Complete	Remained
10	24	Male	Traffic accident	Proximal tibial fracture	—	Inaudible	Complete	Remained
11	86	Male	Farm tractor	Knee dislocation	—	Inaudible	Complete	Remained
12	75	Male	Farm tractor	Knee dislocation	Open leg wound	Inaudible	Complete	Remained
13	28	Male	Traffic accident	Tibial shaft fracture	Open leg wound	Inaudible	Complete	—
14	69	Male	Crush injury	—	Popliteal crush injury	Inaudible	Complete	—
15	69	Male	Crush injury	—	Popliteal crush injury	Inaudible	Complete	—

Table 2. Treatment and Outcomes

No.	TVS	Time to Establish TVS, h	Time to Artery Repair, h	Fasciotomy	Secondary Surgery	Soft-tissue Reconstruction	Amputation
1	—	—	9	+	Ligament repair	—	—
2	—	—	10	–	Ligament repair	—	—
3	—	—	12	+	—	—	—
4	—	—	6	+	—	—	—
5	—	—	4	–	—	—	—
6	—	—	16	–	Osteosynthesis	—	—
7	—	—	8	–	—	—	—
8	CLS	8	10	+	—	—	—
9	—	—	8	+	Osteosynthesis	—	—
10	—	—	10	+	Osteosynthesis	—	—
11	CLS	4	6	–	Ligament repair	—	—
12	CLS	8	10	+	—	—	—
13	—	—	10	–	Osteosynthesis	Free LD	—
14	CLS	3	4	–	—	Free LD	—
15	CLS	3	—	–	—	Pedicled fillet flap	Below knee

LD, latissimus dorsi flap. +, cases in which fasciotomy was performed. -, cases in which fasciotomy was not performed.

condition stabilized, the popliteal artery was reconstructed using a greater saphenous vein graft, and a fillet flap was performed, allowing the knee joint to be preserved and below-knee amputation. This was the only case that required amputation of the lower extremity (Table 2). No case developed compartment syndrome during the treatment course. Of the 12 limbs that did not develop extensive skin and muscle necrosis, one limb had partial necrosis of the tibialis anterior muscle but did not require soft-tissue reconstruction with a flap surgery. Although collateral circulation remained in this case, the injured limb was accompanied by complete motor paralysis, and the duration from injury to revascularization was 10 hours.

Three limbs with extensive soft-tissue necrosis were included in group 2, and the remaining 12 limbs were included in group 1. No significant differences were found between groups 1 and 2 in terms of age or sex ($P = 0.828$ and $P = 1$, respectively). Group 2 had a significantly higher proportion of limbs with no collateral circulation than group 1 ($P = 0.002$). Group 2 also had a higher rate of limbs with complete motor paralysis than group 1, but this difference was not significant ($P = 0.079$). No significant differences were found between the two groups in the rate of absence of pulsation and Doppler ultrasound of the dorsalis pedis artery, rate of TVS use, time from injury to reconstruction of the popliteal artery, or rate of fasciotomy ($P = 0.505$, $P = 0.242$, $P = 0.574$, and $P = 0.2$, respectively; Table 3). The absence of collateral circulation appeared to be the only predictor of extensive soft-tissue necrosis requiring soft-tissue reconstruction.

Table 3. Comparison of Results between the Two Groups

	All Patients (n = 15)	Group 1 (n = 12)	Group 2 (n = 3)	*P*
Age, y	53.7	53.3	55.3	0.828
Sex, n				1
Female	1	1	0	
Male	14	11	3	
Collateral circulation, n				0.002
Remained	12	12	0	
Interrupted	3	0	3	
Pulsation and Doppler, n				0.505
Presence	5	5	0	
Absence	10	7	3	
Motor paralysis, n				0.079
No/partial	8	8	0	
Complete	7	4	3	
TVS, n	5	3	2	0.242
Time to artery repair, h	8.8	9.1	7	0.574
Fasciotomy, n	7	7	0	0.2

CASE PRESENTATION

Cases 14 and 15: a 69-year-old man was injured when he was caught between a falling wall and the ground. The patient was transported to our trauma center 2 hours after the injury. Despite the absence of open wounds on either leg, a vacant area was observed under the skin in the popliteal fossa, and the degree of soft-tissue damage was judged to be severe. At the time of transportation, the dorsalis pedis arteries on both sides were not palpable and both lower limbs had complete motor paralysis. CTA revealed interruption of both popliteal arteries and no collateral circulation (Fig. 2). No associated bone or ligament injury was observed. Bilateral CLS was performed in the operating room and blood circulation resumed 3 hours after the injury. First, the left popliteal artery was explored from a medial approach, and the damaged area was excised. End-to-end anastomosis was performed, and popliteal artery reconstruction was completed 4 hours after injury. When an attempt was made to reconstruct the right popliteal artery from a medial approach, an unexplainable cardiac arrest occurred, and cardiopulmonary resuscitation was required. Therefore, right popliteal artery reconstruction was discontinued. After admission to the intensive care unit, the patient's general condition stabilized. A thorough examination ruled out reperfusion injury; however, the cause of the cardiac arrest remained unknown. On the fourth day after the injury, the right popliteal artery was reconstructed using a great saphenous vein graft (Fig. 3). This revascularization was performed with the aim of maximizing the area of remaining soft tissue, and

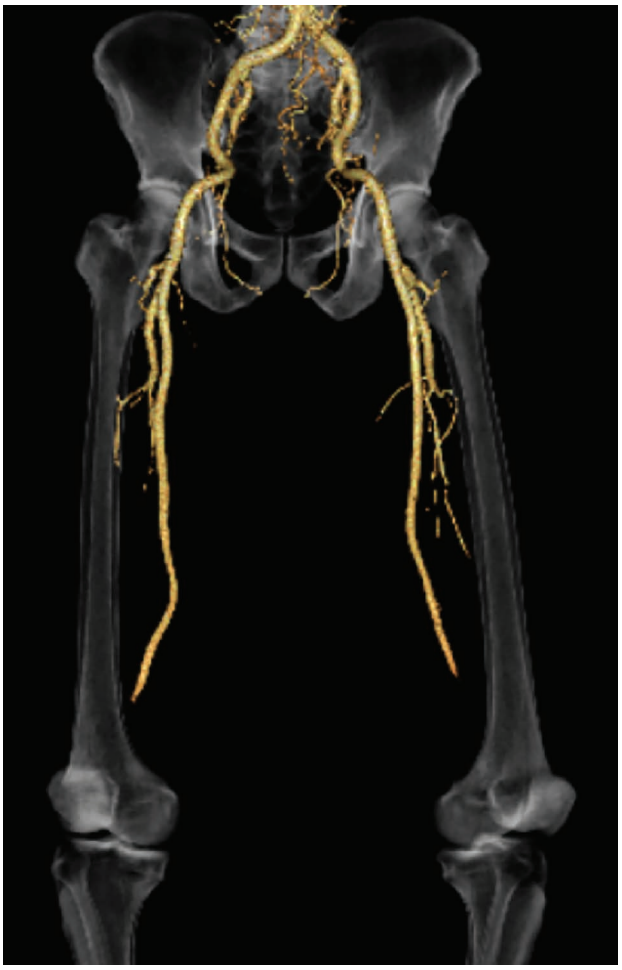

Fig. 2. CTA at the time of injury in cases 14 and 15. The popliteal arteries were interrupted at the level of femoral malleolus on both sides and no collateral circulation was observed.

Fig. 3. CTA after popliteal artery reconstruction in cases 14 and 15. The artery on the left was reconstructed on the day of injury, and the artery on the right was reconstructed fourth day after injury. The popliteal arteries are patent on both sides.

ensuring future spare parts surgery was possible, even if limb salvage would be difficult. In the left lower leg, skin and muscle necrosis occurred around the skin incision, on the medial side of the thigh, from 1 day after the injury. After confirming the extent of necrosis, a free latissimus dorsi flap was performed on the 13th day after the injury (Fig. 4). Extensive soft-tissue necrosis occurred in the right lower leg, and it was determined that it would be difficult to salvage the limb using soft-tissue transplantation. The right lower limb was amputated on the 19th day after the injury. Using the skin and muscles of the foot, where blood flow remained as a pedicled fillet flap, we preserved the knee joint and performed a below-knee amputation (Fig. 5). Three months after the injury, the soft-tissue condition stabilized, and the patient was able to walk with the right prosthetic leg (Fig. 6).

DISCUSSION

Of the 15 treated limbs, three developed extensive soft-tissue necrosis. It was possible to salvage two limbs by performing free-flap surgery at the appropriate time for soft-tissue defects. The patient with the remaining limb had an unexplainable cardiac arrest during the initial surgery, and early revascularization could not be performed and had to be amputated. However, after the patient's general condition stabilized, popliteal artery reconstruction was performed and the knee joint was preserved using a fillet flap. There are various reports regarding the lower leg amputation rate in PAI. The lower leg amputation rate in PAI among civilians in areas with high medical standards is 10%–16%. The amputation rate in our study was 6.7%, which was much lower than the reported amputation rate. Additionally, it is highly likely that limb salvage could have been achieved in all cases if the adverse event of unexplained cardiac arrest during the initial surgery did not occur. We believe that orthoplastic management improves the limb salvage rate in the treatment of traumatic PAI. Furthermore, even in cases where lower limb amputation is unavoidable, the knee joint can be preserved, and outcomes can be improved using free-flap surgery or fillet flap techniques.

Fig. 4. Clinical course of case 14. A, Extensive soft-tissue necrosis occurred on the inside of the left thigh. B, Soft-tissue reconstruction using a free latissimus dorsi flap was performed on the 13th day after injury.

A two-group comparison showed that the absence of collateral circulation on CTA was a predictor of extensive soft-tissue necrosis that required soft-tissue reconstruction. Lin et al[10] reported that the presence of collateral circulation on CTA was correlated with a high limb salvage rate, which is consistent with our findings. Three limbs of cases with extensive skin and muscle necrosis were accompanied by relatively severe soft-tissue injury. If the accompanying soft-tissue injury is severe, collateral circulation may be interrupted, and the degree of ischemia may be severe; however, a soft-tissue defect itself, due to trauma, may also require flap surgery. If the absence of collateral circulation is diagnosed on CTA, or if severe soft-tissue damage is present, orthoplastic management should be considered in future soft-tissue reconstruction. Treatment of PAI requires multiple operations in a narrow area around the knee, including revascularization, osteosynthesis, ligament reconstruction, and soft-tissue reconstruction. Therefore, selecting an inappropriate treatment sequence or approach may result in insufficient treatment. Reports recommend soft-tissue reconstruction within 7 days after injury for open limb fractures to prevent complications, but no reports indicate the appropriate timing for soft-tissue reconstruction for PAI.[11] After reconstruction of the associated bones and ligaments, soft-tissue reconstruction using flap surgery should be performed immediately after determining the extent of soft-tissue necrosis. In cases without collateral circulation or with severe ischemia, it is necessary to keep in mind that soft-tissue reconstruction should be performed during the treatment course and that orthoplastic surgeons must determine the timing, order, and approach of operations to maximize treatment outcomes. Additionally, if soft-tissue reconstruction cannot be performed, the patient should be promptly transferred to a facility with orthoplastic management capabilities. Therefore, it is important to identify predictors of extensive soft-tissue necrosis.

Here, ischemia time and the presence or absence of TVS were not predictors of extensive soft-tissue necrosis. In

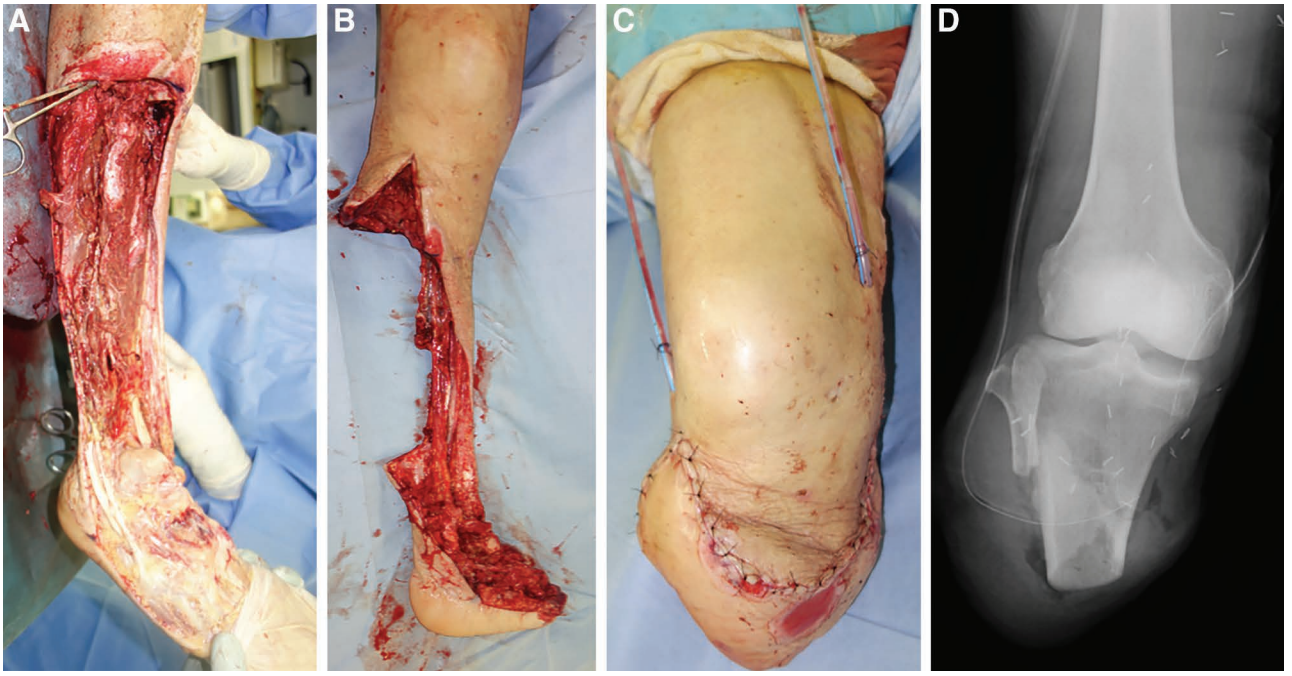

Fig. 5. Clinical course of case 15. A, As extensive soft-tissue necrosis occurred in the right lower leg, it was judged that limb salvage would be difficult. B, Necrotic area was removed and the skin and muscle of the foot with the remaining blood flow were used as a fillet flap. C, Below-knee amputation was performed and the stump of the limb was covered with a fillet flap. D, Plain radiograph after below-knee amputation. The knee joint was preserved.

Fig. 6. Appearance 3 months after surgery in cases 14 and 15. A, Soft-tissue condition was stable in both limbs. B, Prosthesis was attached to the right leg and walking training was initiated.

the case where blood circulation of the popliteal artery was interrupted for the longest time (16 hours), revascularization was performed without TVS; however, muscle necrosis did not occur. In the case with residual collateral blood flow on CTA, without severe motor paralysis, there is relatively more residual blood flow to the injured limb. In such cases, it is assumed that problems arising from muscle ischemia are unlikely to occur, even if there is a delay in repairing the popliteal artery. However, in cases with a severe degree of ischemia, it is certain that prolonged ischemia leads to irreversible muscle necrosis, and previous studies have shown that ischemia lasting longer than 6 hours leads to lower limb amputation.[12] In our study, one limb with residual collateral artery and complete motor paralysis had partial necrosis of the tibialis anterior muscle, and there were 10 hours from injury to revascularization. In cases with severe ischemia, the extent of skin and muscle necrosis can be minimized by shortening the ischemia time. Two types of TVS, IVS and CLS, have been used to decrease the ischemic time in limb vascular injuries. IVS is used to temporarily resume blood flow to the injured limb by connecting the stumps of the major injured vessels using a tube.[12,13] As a damage control adjunct, IVS improves the rate of limb salvage in wartime vascular injury.[14–16] In IVS, the shunt tube is inserted directly into the exposed blood vessel to secure sufficient blood flow to the peripheral side. However, this procedure has a drawback in that the shunt tube must be removed and blood flow to the peripheral side must be blocked during vessel reconstruction. Furthermore, in closed injuries, including PAI, it takes a relatively long time to resume blood circulation because it is necessary to evaluate and maintain the vessels. CLS involves sending blood from an artery in a healthy body part to a peripheral vessel in an injured one to immediately resume blood flow to the injured limb and has been used for traumatic extremity major amputation.[17,18] CLS does not require direct exploration of the injured vessels and can be performed in the emergency room; therefore, blood circulation can be resumed relatively quickly (Fig. 7). Therefore, CLS is an effective TVS method for treating traumatic PAI with severe ischemia or soft-tissue damage.[19,20] However, because CLS is a nonphysiological method for vascular perfusion, sufficient blood flow cannot be obtained, particularly in the lower limbs. Although IVS and CLS have the same purpose of shortening the ischemic time, they differ in the time required to establish perfusion, amount of perfusion, and pathological conditions to which they should be applied. In cases where collateral blood circulation is not enhanced by CTA, blood flow should be resumed as soon as possible; therefore, CLS, which can be established in a short period of time, should be selected. Proper use of CLS can minimize the extent of skin and muscle necrosis. Appropriate indications for IVS and CLS should be considered in future studies.

This study had several limitations. First, as this study was retrospective in nature, multiple surgeons performed the operations, and there was no unified standard of treatment selection. In addition, the quality of the surgery depends on the surgeon. Moreover, because PAI is rare,

Fig. 7. Appearance of CLS in the left PAI (case 12). CLS was performed in the emergency room. A 6-Fr arterial sheath was placed in the right femoral artery and a 4-Fr arterial sheath was placed in the left dorsalis pedis artery. The two arterial sheaths were connected to a simple polyethylene extension tube and three-way stopcocks. Arterial blood was diverted from the right femoral artery to the left dorsalis pedis artery, and the injured limb was revascularized.

the number of cases was limited and statistical comparisons using multivariate analyses were difficult. Therefore, further studies with larger sample sizes are warranted.

CONCLUSIONS

Here, we reported the treatment outcomes of 15 limbs with traumatic PAI at a trauma center with orthoplastic management capabilities. Orthoplastic surgery has the potential to improve limb salvage rates and provide favorable outcomes. The absence of collateral circulation on CTA is a predictor of extensive soft-tissue necrosis, and treatment must be performed with soft-tissue reconstruction in mind from the initial treatment.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

1. Kauvar DS, Sarfati MR, Kraiss LW. National trauma databank analysis of mortality and limb loss in isolated lower extremity vascular trauma. *J Vasc Surg.* 2011;53:1598–1603.
2. Mullenix PS, Steele SR, Andersen CA, et al. Limb salvage and outcomes among patients with traumatic popliteal vascular injury: an analysis of the National Trauma Data Bank. *J Vasc Surg.* 2006;44:94–100.
3. Parker S, Handa A, Deakin M, et al. Knee dislocation and vascular injury: 4-year experience at a UK major trauma center and vascular hub. *Injury.* 2016;47:752–756.
4. Perkins ZB, Yet B, Glasgow S, et al. Meta-analysis of prognostic factors for amputation following surgical repair of lower extremity vascular trauma. *Br J Surg.* 2015;102:436–450.
5. Sillanpää PJ, Kannus P, Niemi ST, et al. Incidence of knee dislocation and concomitant vascular injury requiring surgery: a nationwide study. *J Trauma Acute Care Surg.* 2014;76:715–719.
6. Azoury SA, Stranix JT, Kovach SJ, et al. Principles of orthoplastic surgery for lower extremity reconstruction: why is this important? *J Resonstr Microsurg.* 2021;37:42–50.
7. Chummun S, Wright TC, Chapman TWL, et al. Outcome of the management of open ankle fractures in an ortho-plastic specialist centre. *Injury.* 2015;46:1112–1115.
8. Hourani KA, Stoddart M, Khan U, et al. Orthoplastic reconstruction of type IIIB open tibial fractures retaining debrided devitalized cortical segments: the Bristol experience 2014 to 2018. *Bone Joint J.* 2019;101:1002–1008.
9. Kanda Y. Investigation of the freely available easy-to-use software "EZR" for medical statistics. *Bone Marrow Transplant.* 2013;48:452–458.
10. Lin CH, Consuegra MDL, Lin TS. Revisiting management strategies for popliteal artery injuries. *Ann Plast Surg.* 2022;88(1s Suppl 1):S44–S49.
11. D'Alleyrand JCG, Manson TT, Dancy L, et al. Is time to flap coverage of open tibial fractures an independent predictor or flap-related complications? *J Orthop Trauma.* 2014;28:288–293.
12. Hossny A. Blunt popliteal artery injury with complete lower limb ischemia: is routine use of temporary intraluminal arterial shunt justified? *J Vasc Surg.* 2004;40:61–66.
13. Hornez E, Boddaert G, Ngabou UD, et al. Temporary vascular shunt for damage control of extremity vascular injury: a toolbox for trauma surgeons. *J Visc Surg.* 2015;152:363–368.
14. Chambers LW, Green DJ, Sample K, et al. Tactical surgical intervention with temporary shunting of peripheral vascular trauma sustained during Operation Iraqi Freedom: one unit's experience. *J Trauma.* 2006;61:824–830.
15. Rasmussen TE, Clouse WD, Jenkins DH, et al. The use of temporary vascular shunts as a damage control adjunct in the management of wartime vascular injury. *J Trauma.* 2006;61:8–12; discussion 12.
16. Taller J, Kamdar JP, Greene JA, et al. Temporary vascular shunts as initial treatment of proximal extremity vascular injuries during combat operations: the new standard of care at Echelon 2 facilities? *J Trauma.* 2008;65:595–603.
17. Lee JW, Pan SC, Lin YT, et al. Cross-limb vascular shunting as an auxiliary to major limb revascularisation. *Br J Plast Surg.* 2002;55:438–440.
18. Lee YC, Lee JW. Cross-limb vascular shunting for major limb replantation. *Ann Plast Surg.* 2009;62:139–143.
19. Edwards J, Treffalls RN, Abdou H, et al. Lower extremity staged revascularization (LESR) as a new innovative concept for lower extremity salvage in acute popliteal artery injuries: a hypothesis. *Patient Saf Surg.* 2022;16:39.
20. Izawa Y, Futamura K, Murakami H, et al. Cross-limb vascular shunting for traumatic popliteal artery injury. *Ann Vasc Surg.* 2024;99:305–311.