Clinical Analysis of Classification for Tibial Plateau Fractures and Popliteal Artery Injury

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Abstract

Background To explore the association between the classification for tibial plateau fractures (TPF) and the popliteal artery injury (PAI).

Methods 22 TPF patients accompanied by PAI who were treated from May 2012 to July 2019 were retrospectively analyzed. There were 19 males and 3 females with an average age of 49.43 years. The Schatzker classification and three-column classification were performed for TPF. The severity of extremity injury was evaluated using the mangled extremity severity score (MESS). Except 3 patients treated with amputation, the remaining patients underwent surgical repair of popliteal artery and fracture external fixation. The outcome was evaluated using the Rasmussen score for tibial head fractures.

Results There were 10 cases of Schatzker type IV fractures, 1 case of type V fractures and 11 cases of type VI fractures. Based on the three-column classification, the posterior column was involved in 22 cases, 2 columns in 15 cases and 3 columns in 6 cases. The MESS was 6-10 points, with an average of 7.59 points. Except 1 case directly receiving amputation, 3 cases of segment P1 injury was observed via preoperative DSA + intraoperative exploration, while segment P2 in 6 cases and segment P3 in 12 cases. Popliteal artery was found completely ruptured in 11 cases, partially ruptured in 1 case, and severely contused with thrombosis in 10 cases. The Rasmussen score was given to 19 patients at the last follow-up, except for the cases undergoing amputation. The outcome was satisfied in 14 cases, unsatisfied in 5 cases.

Conclusion: In patients with complex TPF, the risk of PAI becomes higher with the increase of Schatzker classification level. Knee CT scan is helpful in determining the severity of fractures and evaluating PAI. Based on the three-column classification, PAI should be suspected when the fractures involve the medial and posterior column. PAI is mainly in the segment P3, and artery rupture or severe contusion with extensive thrombosis may occur.

Background

Popliteal artery injury (PAI) is the most dangerous among concomitant injuries of complex tibial plateau fractures (TPF), and the amputation rate can be up to 51.8% ^[1]. Liu et al ^[2] found that PAI may be caused by even mild TPF, and Magnotti ^[3] et al believed that early effective improvement of popliteal artery blood flow is the only effective factor ameliorating the postoperative knee function. However, the specific relation between the classification for TPF and PAI has been rarely reported. Therefore, a retrospective study was conducted about the association between the two.

In this paper, the data of 22 TPF patients accompanied by PAI who were treated from May 2012 to July 2019 and followed up were retrospectively analyzed, and the Schatzker classification, CT-based three-column classification and force mechanism were detected in patients, so as to explore the association between the classification for TPF and PAI. It is now reported as follows:

Methods

General data

A total of 22 patients were included in this study, including 19 males and 3 females aged 11-71 years old, with an average of 50 years old. Tibial plateau fractures were on the left side in 12 cases and on the right side in 10 cases. In terms of the cause of injury, there were 16 cases of traffic injury, 2 cases of falling injury and 4 cases of crushing injury. In terms of the concomitant injuries, ipsilateral knee dislocation occurred in 2 cases, fractures at other sites in 14 cases, popliteal vein injury in 7 cases, common peroneal nerve injury and tibial nerve injury in 6 cases, craniocerebral trauma in 5 cases, chest trauma in 2 cases and traumatic shock in 2 cases. The mangled extremity severity score (MESS) ^[4] was 6-10 points, with an average of 7.59 points. According to the Schatzker classification criteria ^[5], there were 10 cases of type IV fractures, 1 case of type V fractures and 11 cases of type VI fractures. Based on the CT-based three-column classification ^[6], the posterior column was involved in 22 cases, 2 columns in 15 cases and 3 columns in 6 cases. 19 patients were diagnosed with TPF accompanied by PAI in our hospital or other hospitals. In 2 patients, PAI was missed in diagnosis in other hospitals, but found after fracture internal fixation was performed, and then they were transferred to our hospital. The remaining 1 patient was diagnosed with PAI and treated with failed fracture fixation and repair of artery injury, and then he was transferred to our hospital. All patients underwent anteroposterior and lateral X-ray and CT scan of the knee joint. Whether there was PAI was determined using physical examination, and digital subtraction angiography (DSA) or CT angiography (CTA) was used promptly if failed. The details are shown in **Supplement Table S1**.

Classification methods

In addition to the traditional Schatzker classification, namely the X-ray-based TPF classification, the CT-based three-column classification for TPF was also adopted in this paper. In the classification (Figure 1), from an aerial perspective of the tibial plateau, the point A, O, C and B indicates the tibial tubercle, the midpoint of the tibial spine line, the anterior border of the fibular head, and the crista medialis tibiae, respectively. The tibial plateau is divided into three parts (lateral column, medial column and posterior column) by the line OA, OC and OB, and column fractures are defined as cortical rupture involved. According to the bone landmarks, the popliteal artery is divided into three segments through the anatomical landmarks: segment P1: from hiatus of adductor to superior border of patella, segment P2: from superior border of patella to tibial plateau, and segment P3: from tibial plateau to the beginning of arteriae tibiae anterior (Figure 2). The classification results are shown in **Table 1 and 2**.

Table 1: Schatzker classification of 22 cases of TPF accompanied by PAI

Schatzker classification						
Classification	I	II	III	IV	V	VI
n	-	-	-	10	1	11

Table 2: Three-column classification of 22 cases of TPF accompanied by PAI

Three-column classification								
Classification	Simple compression fractures	L	M	N	L+M	L+N	M+N	L+M+N
n	-	-	-	1	-	5	10	6

Note: L: lateral column, M: medial column, N: posterior column. N: only posterior column involved, L+N: lateral column + posterior column involved, M+N: medial column + posterior column involved, L+M+N: lateral column + medial column + posterior column involved

Treatment methods

TPF patients accompanied by PAI initially diagnosed in our hospital or confirmed in other hospitals underwent related emergency examinations, and received operation after the surgical contraindications were excluded (2 cases of right lower extremity vein thrombosis shown in preoperative DSA were first treated with lower extremity vein filter implantation). Except 1 case directly receiving leg amputation, the remaining 21 cases underwent fracture reduction and external fixation + surgical repair of popliteal artery.

Operation methods

After anesthesia, routine disinfection and draping in a supine position (if osteofascial compartment syndrome occurred in the leg before operation, incision decompression of osteofascial compartment was performed first), 2 Schanz screws were percutaneously drilled into the distal femur and proximal tibia, the external fixation support was placed, and the screws were tightened at about 30° of knee flexion. Then after disinfection and draping again in a prone position, an S-shaped incision (about 20 cm long) was made at the posterior popliteal fossa, the skin and subcutaneous tissues were cut open, and the popliteal artery and popliteal vein were explored. If the popliteal artery defect was less than 2 cm, vascular anastomosis was performed directly. If the defect was larger than 4 mm after dissociation, the great saphenous vein on the unaffected side was taken for vascular anastomosis. The posterior incision at the knee joint was sutured properly, the leg was covered with VSD device for decompression, and the affected limb was wrapped with a semi-permeable membrane. After 2-3 weeks, the swelling of soft tissue subsided and the blood supply became stable, the external fixation was removed and replaced with internal fixation

Postoperative follow-up

All patients were followed up routinely in outpatient clinic at 1, 2 and 3 months after operation, and then in outpatient clinic once every 6 months. The blood supply of the affected limb, whether TPF was healed, and the mobility and stability of the knee joint were detected. At the last follow-up, the efficacy was evaluated using the Rasmussen score for tibial head fractures^[7]: 30-20 points (satisfied), 19-1 points (unsatisfied).

A typical case

A 42-year-old man suffered from right TPF accompanied by PAI due to a traffic accident. After treatment with fixed local holder and medication in another hospital for 10 d, disturbance of blood circulation of the right foot was found, and the pulse of dorsal pedal artery disappeared. It was shown in CTA that the right popliteal artery had no image. The MESS at admission was 8 points, and the patients had type IV fractures according to the Schatzker classification. In the three-column classification, the medial and posterior columns were involved. Then external fixation of right TPF and surgical repair of PAI were performed. Popliteal artery rupture and popliteal vein contusion with thrombosis was observed during operation, and the popliteal artery and popliteal vein were repaired. The blood supply of the right foot was restored after operation, and the patient was discharged at 2 weeks after operation. At the last follow-up, the Rasmussen score indicated the satisfied outcome (Figure 3A: Preoperative photos, Figure 3B: Preoperative anteroposterior and lateral X-rays of knee, Figure 3C: Preoperative CT cross section, Figure 3D: Preoperative CTA, Figure 3E: Intraoperative fracture external fixation, Figure 3F: Intraoperative exploration of popliteal artery rupture, Figure 3G: Intraoperative anastomosis of popliteal artery, Figure 3H: Postoperative review).

Results

According to the Schatzker classification criteria, there were 10 cases of type IV fractures, 1 case of type V fractures and 11 cases of type VI fractures. Based on the three-column classification, the posterior column was involved in 22 cases, 2 columns in 15 cases and 3 columns in 6 cases. The MESS at admission was 6-10 points, with an average of 7.59 points. PAI was confirmed in 10 cases via physical examination + DSA or CTA, 1 case via physical examination + vascular B ultrasound, and 11 cases via physical examination. 1 case directly underwent leg amputation, and the remaining 21 cases underwent surgical repair of popliteal artery + fracture reduction and external fixation. After operation, 2 cases had severe infection and muscle necrosis, and the leg was amputated. Finally, the limb was saved successfully in 19 cases. The first amputated patient was a 68-year-old elderly woman with a poor cardiopulmonary function, the MESS at admission was 9 points, and the duration from injury to admission was 9 h. Considering the poor cardiopulmonary function of patient, the left leg amputation was conducted to save her live. The second amputated patient was diagnosed with right TPF accompanied by PAI after trauma in another hospital, with the MESS at admission of 9 points. Then the patient underwent surgical repair of popliteal artery + fracture internal fixation. After operation, there was no significant improvement in the blood supply of the affected limb, and the pulse of dorsal pedal artery still failed to be felt. On the 5th day after injury, he was transferred to our hospital for further treatment. After emergency debridement of the right leg and surgical repair of popliteal artery, the blood supply of the affected limb was improved, but leg amputation was conducted ultimately due to severe infection with extensive muscle necrosis. The third amputated patient was transferred from another hospital to our hospital at 11 d after injury. At admission, the MESS was 10 points, and the right lower extremity was black and had skin vesicles. The right popliteal artery rupture was found in the emergency DSA in our

hospital, so emergency surgical repair of right popliteal artery was performed. However, due to extensive necrosis of muscles and soft tissues, the right leg was amputated. Except 1 case directly receiving amputation, the remaining patients underwent surgical repair of popliteal artery. After 2-3 weeks, when the soft tissue swelling decreased and recovery of blood supply, the external fixation was replaced by internal fixation.

According to the location of popliteal artery injury, there were 3 cases of P1 segment injury, 7 cases of P2 segment injury and 12 cases of P3 segment injury. **Table 3** and **Table 4** showed the details of location of PAI based on Schatzker and three-column classification.

Table 3 Location of PAI based on Schatzker classification			
Location of PAI	Schatzker type IV	Schatzker type V	Schatzker type VI
P1	2	0	1
P2	3	1	3
P3	5	0	7

Table 4 Location of PAI based on three-column classification				
Location of PAI	N	L + N	M + N	L + M + N
P1	0	1	2	0
P2	0	1	4	2
P3	1	3	5	3

According to the type of popliteal artery injury, 10 cases were contusion, 1 case was partial rupture, and 11 cases were complete rupture. **Table 5** and **Table 6** showed the details of type of PAI based on Schatzker and three-column classification.

Table 5 Type of PAI based on Schatzker classification			
Type of PAI	Schatzker type IV	Schatzker type V	Schatzker type VI
Popliteal artery contusion	4	1	5
Partial rupture of popliteal artery	1	0	0
Complete rupture of popliteal artery	5	0	6

Table 6 Type of PAI based on three-column classification				
Type of PAI	N	L + N	M + N	L + M + N
Popliteal artery contusion	0	4	4	2
Partial rupture of popliteal artery	0	0	1	0
Complete rupture of popliteal artery	1	1	6	3

According to the types of popliteal vein injury, 15 cases without obvious popliteal vein injury, 3 cases with popliteal vein contusion and 4 cases with popliteal vein rupture. **Table 7** and **Table 8** showed the details of type of popliteal vein injury based on Schatzker and three-column classification.

Table 7 Type of popliteal vein injury based on Schatzker classification			
Type of popliteal vein injury	Schatzker type IV	Schatzker type V	Schatzker type VI
No obvious popliteal vein injury	6	1	8
Popliteal vein contusion	1	0	2
Popliteal vein rupture	3	0	1

Table 8 Type of popliteal vein injury based on three-column classification				
Type of popliteal vein injury	N	L + N	M + N	L + M + N
No obvious popliteal vein injury	1	4	6	4
Popliteal vein contusion	0	1	1	1
Popliteal vein rupture	0	0	4	0

In the case of both popliteal artery and vein injuries, the patients received popliteal artery repair first and then popliteal vein repair. 20 patients underwent fracture reduction and external fixation, and then surgical repair of popliteal artery. 6 patients with osteofascial compartment syndrome underwent incision decompression. The Rasmussen score was given to 19 limb-saved patients at the last follow-up. The outcome was satisfied in 14 cases, unsatisfied in 5 cases.

Discussion

X-ray-based Schatzker classification (Schatzker [8]) is a traditional classification for TPF. Generally, the higher fracture classification corresponds to the greater injury, severer fracture displacement and more serious soft tissue injury. However, there are few studies on the relation between Schatzker classification and PAI, and its mechanism analysis. Wicky [8] and Macarini [9] et al found that using X-ray-based Schatzker classification alone may underestimate the severity of fractures, thus affecting the diagnosis and correct treatment of TPF, and also influencing the correct determination of degree of soft tissue injury

and PAI. Therefore, CT-based three-column classification was introduced to evaluate the severity of TPF more comprehensively, so as to discover the association between classification for TPF and PAI.

In this study, in terms of the cause of TPF, there were 16 cases of traffic injury, 2 cases of falling injury and 4 cases of crushing injury, and all patients had high-violence injury. According to the analysis of injury mechanism, such patients are injured mostly under flexion or semi-flexion of knee joints, and fractures of the posterior coronal plane, namely posterior column fractures, can be caused when subjected to axial stress. At this moment, Schatzker type V fractures can be caused when subjected to varus stress. In other words, the fracture line leans posteriorly, and the medial and posterior columns are further involved, so the popliteal artery is squeezed or crushed by posterior bone blocks, resulting in popliteal artery contusion or rupture. If the knee joint is subjected to axial stress and valgus stress under flexion or semi-flexion, the fractures will involve both lateral and posterior columns, and the popliteal artery may also be injured. In the case of extremely great axial stress, varus stress and valgus stress under flexion of knee joints, the lateral, medial and posterior columns will be affected simultaneously, causing Schatzker type VI fractures. The reason is that the medial articular surface is larger and its strength is greater than that of lateral articular surface. Therefore, ligament, vascular and nerve injuries are likely to occur in the case of medial plateau fractures often caused by great violence. Moore et al ^[10, 11] also argued that the risk of vascular and nerve injuries is the highest in Schatzker type IV fractures. In this study, Schatzker type VI fractures accounted for 50%(11/22), type V fractures for 4.54%(1/22), and type IV fractures for 45.45%(10/22). Based on the CT-based three-column classification, the posterior column was involved in all 22 cases, 2 columns in 15 cases, 3 columns in 6 cases, and only the posterior column in 1 case. Therefore, it is believed that PAI should be suspected when the posterior column is involved in complex TPF, and the risk of PAI is the highest when the medial and posterior columns are involved in TPF.

The results in this study also indicate that when the posterior column or tibial shaft is involved in complex TPF, the popliteus can pull the entire tibial plateau or fracture blocks of posterior column move backwards due to great violent injury. As a result, the popliteal artery is directly impacted, and stabbed, squeezed or crushed by fracture blocks, thus resulting in popliteal artery rupture or severe contusion and then extensive thrombosis.

In this study, in terms of the type and location of PAI, PAI was in the segment P1 in 3 cases, segment P2 in 6 cases and segment P3 in 12 cases. It can be seen that the possibility of PAI was the highest in segment P3 (57.14%), and the same conclusion was made regardless of Schatzker classification or CT-based three-column classification. The possible reason is that the popliteal artery at the same plane (segment P2 and P3 of popliteal artery) is directly squeezed or crushed by the posterior border of tibial plateau and fracture blocks of posterior column. However, during surgical exploration of PAI, it is recommended that an S-shaped incision be made at the posterior popliteal fossa, and the popliteal artery be explored from the distal end. This is because the residual end may retract to the distal and proximal ends after PAI, so exploring from far to near can effectively avoid omissions.

It was found via intraoperative exploration that the popliteal artery was completely ruptured in 11 cases, partially ruptured in 1 case, and severely contused with thrombosis in 10 cases. At the same time, popliteal vein rupture and popliteal vein contusion with thrombosis were found in 3 cases and 3 cases, respectively, so the popliteal vein was also repaired during operation. It is believed that in TPF accompanied by PAI, both popliteal artery rupture and severe popliteal artery contusion with extensive thrombosis may occur regardless of Schatzker type II fractures or Schatzker type VI fractures, consistent with the research results of Drapanas et al^[12]. Moreover, the popliteal vein injury is more likely to occur in Schatzker type II TPF accompanied by PAI, which was also confirmed by the CT-based three-column classification that the risk of popliteal vein injury was the highest when the medial and posterior columns were involved in fractures. In clinic, the pulse of dorsal pedal artery can still be felt in some TPF patients with PAI in the early stage. Meek^[13] et al found that the weaker pulse than normal can be felt at the distal end in about 22% of patients with injury of major limb arteries, also consistent with the findings in this study that the weaker pulse of dorsal pedal artery than that at the contralateral side could be felt in 5 cases in the early stage. The possible reason is that the popliteal artery has not been completely ruptured but severely contused in some patients with PAI, causing damage to the artery intima and thrombosis, so some blood supply remains in the initial stage. Later, due to the worsening of thrombosis, the artery becomes completely occluded, the blood supply of popliteal artery completely disappears, and lower limb ischemia is gradually enhanced, leading to limb necrosis. Therefore, it is necessary to determine whether PAI is accompanied in TPF in the clinical examination, rather than only based on the presence or absence of pulse of dorsal pedal artery. Besides, bilateral comparison is needed, and CTA or DSA should be performed promptly for definite diagnosis if it is unable to determine accurately. If there are no conditions for CTA or DSA in a hospital, the patients should be transferred to the conditional hospital in time to avoid missed diagnosis.

In this study, the MESS of the 22 patients at admission was 6-10 points, with an average of 7.59 points. In the case of $\text{MESS} \geq 9$ points, the possibility of amputation was greatly raised. There were 20 cases with the $\text{MESS} \geq 7$ points, and the amputation rate was 15%, lower than the traditional rate in PAI (30-50%)^[6]. The amputation rate was 60% when the $\text{MESS} \geq 9$ points. Therefore, PAI patients with the MESS at admission ≥ 9 points should be highly alerted, in which case the amputation rate is significantly increased. In addition, Mullenix et al^[14] argued that incision decompression is needed for patients with the increased pressure of osteofascial compartment. Similarly, the results in this study demonstrate that therapeutic or prophylactic incision decompression is necessary when the pressure of osteofascial compartment rises in the leg. At the same time, the deep fascia and other osteofascial compartments should be completely separated during incision decompression. Otherwise, the decompression effect will be unsatisfactory, and the treatment of PAI will not be benefited.

It is reported by Wani et al^[15] that the amputation rate is 42.1% in patients undergoing operation 6 h after PAI, the success rate of popliteal artery repair is 89% within 8 h, and the amputation rate is up to 86% after 8 h. Wager et al^[16] also thought that the success rate of blood circulation reconstruction will dramatically decline with the prolongation of duration of limb ischemia. In this study, the amputation rate

was 20% in patients undergoing operation after 6 h. It is believed that the duration of injury is not the absolute criterion for deciding whether amputation is needed. Limb salvage can still be considered if the patients have no severe infection or extensive leg muscle necrosis. This is because PAI patients are mostly adult men, and they have higher expectations and shoulder greater social pressure^[17]. Therefore, retaining the good function of knee is of great importance for the quality of life after operation.

Glass^[18] and Percival^[19] et al showed that whether fractures or vascular injury should be treated first during operation depends on the duration of ischemia. In the case of duration of injury <6 h, the fractured bones should be fixed first, followed by vascular repair. On the contrary, in the case of duration of injury >6 h, the blood vessels should be repaired first, followed by fixation of the fractured bones, so as to reduce the time of tissue ischemia and hypoxia. However, it is believed that except acute open PAI in which surgical repair is needed first, fracture reduction and external fixation should be considered first in other cases, so that the re-rupture of damaged artery can be avoided when the patient's posture is changed after artery repair.

Conclusion

In the case of a higher Schatzker classification level, and involvement of both medial and posterior columns according to CT-based three-column classification, the risk of PAI significantly rises. PAI is mainly in the segment P3, and artery rupture or severe contusion with extensive thrombosis may occur. In the case of Schatzker type IV fractures, and involvement of both medial and posterior columns, the possibility of popliteal vein injury also significantly rises, so it is also important to repair the popliteal vein injury. If the MESS is ≥ 9 points, the possibility of amputation is greatly raised.

Abbreviations

TPF: tibial plateau fractures; PAI: popliteal artery injury; MESS: mangled extremity severity score

Declarations

Ethics approval and consent to participate

The study was reviewed and approved by the institutional review board and the ethics committee of our institution. Patients or their family members agreed to our study and signed the informed consents.

Consent for publication

Written informed consent for publication was obtained from all participants.

Availability of data and materials

All data generated or analyzed during this study are included in this published article and its supplementary information files.

Competing interests

All authors state that they have no competing interests.

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Authors' contributions

All authors were involved in the conception and design. Study design: YLY, WBY, LY, XSW, LW and CZJ. Study conduct: YLY, LW and WBY. Data collection and analysis: YLY, WBY and LY. Data interpretation: WBY, XSW, CZJ and LY. Drafting of the manuscript: YLY, WBY, and LY. All authors take responsibility for the integrity of the data analysis. The author(s) read and approved the final manuscript.

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Figures

Figure 1

Schematic diagram for three-column classification

Figure 2

The popliteal artery is divided into three segments through the anatomical landmarks: Segment P1: from hiatus of adductor to superior border of patella, segment P2: from superior border of patella to tibial plateau, and segment P3: from tibial plateau to the beginning of arteriae tibialis anterior.

Figure 3

A typical case. A 42-year-old man suffered from right TPF accompanied by PAI due to a traffic accident. (A) Preoperative photos; (B) Preoperative anteroposterior and lateral X-rays of knee; (C) Preoperative CT cross section; (D) Preoperative CTA; (E) Intraoperative fracture external fixation; (F) Intraoperative exploration of popliteal artery rupture; (G) Intraoperative anastomosis of popliteal artery; (H) Postoperative review.

Supplementary Files

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