ORIGINAL ARTICLE

A strategy for the one-stage treatment of open Pilon fractures based on an accelerated rehabilitation surgical concept

Una estrategia para el tratamiento en una sola etapa de las fracturas de pilón abiertas basada en un concepto quirúrgico de rehabilitación acelerada

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Abstract

Objective: *The objective of the study was to study the strategy of one-stage emergency treatment of open Pilon fracture with the concept of accelerated rehabilitation surgery.* **Methods:** *The data of 18 patients with open Pilon fracture treated by first-stage emergency debridement, fracture internal fixation, bone grafting, negative pressure closed drainage covering the wound, leg incision reduction, and second-stage skin grafting or flap transfer in the Department of Orthopedics of our hospital from January 2014 to December 2018 were retrospectively analyzed. Joint surface reduction was evaluated by radiological evaluation criteria such as Burwell-Charnley, fracture healing quality was evaluated by Merchant score, and ankle joint function was evaluated by Tornetta and other criteria at the last follow-up.* **Results:** *All 18 patients were followed up, and the anatomical reduction rate was 94% (17/18) according to radiological evaluation criteria such as Burwell-Charnley. According to Merchant scoring criteria, the fracture healing rate was 83.3% (15/18). At the last follow-up, the ankle function was evaluated according to Tornetta and other criteria, and the excellent rate was 88.9% (16/18).* **Conclusions:** *Using the concept of accelerated rehabilitation surgery to treat open Pilon fractures in the first emergency can effectively avoid soft-tissue complications and is an effective treatment strategy.*

Keywords: *Open Pilon fracture. Emergency incisional reduction and internal fixation. Vacuum sealing drainage. Accelerated rehabilitation surgery.*

Resumen

Objetivo: *Estudiar la estrategia de tratamiento de emergencia en una sola etapa de la fractura abierta de pilón con el concepto de cirugía de rehabilitación acelerada.* **Métodos:** *Se analizaron retrospectivamente los datos de 18 pacientes con fractura abierta de pilón tratados en primera etapa con desbridamiento de emergencia, fijación interna de fractura, injerto óseo, drenaje cerrado a presión negativa cubriendo la herida, reducción de la incisión de la pierna y transferencia de injerto de piel en una segunda etapa o colgajo, en el servicio de ortopedia de nuestro hospital, de enero de 2014 a diciembre de 2018. La reducción de la superficie articular se evaluó por criterios de evaluación radiológica como Burwell-Charnley, la calidad de la cicatriz de la fractura se evaluó por la puntuación de Merchant y la función articular del tobillo se evaluó según Tornetta y otros criterios en el último seguimiento.* **Resultados:** *Se realizó seguimiento a los 18 pacientes, con una tasa de reducción anatómica del 94% (17/18) según los criterios de evaluación radiológica Burwell-Charnley. Según los criterios de Merchant, la tasa de curación de la fractura fue del 83.3% (15/18). En el último seguimiento, la función del tobillo fue evaluada de acuerdo con Tornetta y otros criterios, y fue excelente en el 88.9% (16/18).* **Conclusiones:** *El uso del concepto de cirugía de rehabilitación acelerada*

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para tratar fracturas abiertas de pilón en la primera emergencia puede evitar eficazmente las complicaciones de los tejidos blandos y es una estrategia de tratamiento eficaz.

Palabras clave: *Fractura abierta de pilón. Reducción incisional de emergencia y fijación interna. Drenaje sellado al vacío. Cirugía de rehabilitación acelerada.*

Introduction

Pilon fractures, involving the lower shinbone (tibia) near the ankle joint, are the most complex fractures in foot and ankle injuries. Caused by high-impact events, they account for a small portion (1%) of all lower leg fractures but a significant number (7-10%) of tibia fractures[1]. The tibia's minimal soft-tissue covering makes these fractures prone to severe soft-tissue damage and instability (10-30% are open fractures, often accompanied by fibula fractures)[2]. Despite significant developments in the treatment of these fractures in recent years, a staged approach with initial external fixation followed by internal fixation after soft-tissue healing remains common, especially for severe fractures (AO/OTA type C). However, this approach can lead to lengthy hospital stays, external fixation loosening, increased infection risk, and delayed surgery hindering proper bone alignment[3]. Open Pilon fractures present a treatment dilemma. While there is no consensus on urgent fracture fixation, early wound debridement and fracture stability maintenance are crucial[4]. This study explores the effectiveness of a one-stage surgical approach for open Pilon fractures, building on the concept of accelerated rehabilitation surgery. This technique combines emergency debridement, internal fixation, bone grafting, and Vacuum-assisted closure therapy (VSD) with drainage in a single surgery, potentially minimizing complications associated with staged procedures. We retrospectively analyzed 18 open Pilon fracture patients treated at our hospital's Department of Traumatology and Orthopedics between January 2014 and December 2018. The aim was to evaluate the clinical efficacy of this one-stage surgical strategy.

Methods

Inclusion and exclusion criteria

INCLUSION CRITERIA

- Unilateral open Pilon fracture with time of injury $\leq$ 6 h;
- Combined with ipsilateral lower fibula fracture;
- Patients underwent emergency one-stage debridement, incision and internal fixation, reduction of the calf incision, and negative-pressure closure and drainage; and
- Complete clinical data with more than 1 year of follow-up.

Exclusion criteria

- Multiple injuries, combined with other fractures of the foot and ankle;
- Closed Pilon fracture, Gustilo III C;
- Pathologic fracture; and
- Poor physical condition, inability to tolerate emergency surgery, or incomplete follow-up data.

General information

Eighteen patients admitted to our Department of Traumatology and Orthopedics between January 2014 and December 2018 with open Pilon fractures were retrospectively analyzed according to the inclusion criteria. These patients included 14 males and 4 females, with ages ranging from 24 to 58 years old (average 40.2 years). All fractures were fresh and combined with ipsilateral lower fibula fractures. The causes of injury were: car accident (6 cases), fall from height (8 cases), and heavy object smash (4 cases). Gustilo fracture classification revealed: 3 type I, 4 type II, 6 type IIIA, and 5 type IIIB fractures. OA/ATO fracture classification identified 8 type 43-B and 10 type 43-C fractures. Ruedi-Allgower typing showed 6 type II and 12 type III fractures (Table 1). Preoperative workup routinely included frontal and lateral X-rays, CT scan, and three-dimensional reconstruction of the affected ankle joint.

Surgical techniques

Upon admission, patients received cefoperazone sulbactam sodium sedation followed by a quick physical examination. General anesthesia was administered in the operating room. Patients were positioned

Table 1. Patient demographics and mechanism of injury

Age (year)	Age range
Mean (and standard deviation)	40.2 ± 2.3
Median (range)	40.2(24~58)
Sex	
Male	14 (78)
Female	4 (22)
Mechanisms of injury	6 (33)
Car accident injury	
Fall from a height	8 (45)
Bruise	4 (22)
AO fracture classification	
B1	2 (11)
B2	3 (17)
B3	3 (17)
C1	2 (11)
C2	4 (22)
C3	4 (22)
Ruedi-Allgower classification	
II	6 (33)
III	12 (67)
Gustilo classification	
I	3 (17)
II	4 (22)
IIIA	6 (33)
IIIB	5 (28)

The values are given as the number of patients, with the percentage in parentheses.

supine on the healthy side. The wound was thoroughly debrided after initial evaluation of soft tissue damage and contamination. This debridement involved using soap, water, hydrogen peroxide, saline, and iodine volts to clean the trauma, remove contaminants, and deactivate devitalized soft tissues. Large bone fragments with blood flow were preserved for potential repair.

After initial debridement, the surgical field was disinfected with a surgical sheet. The original trauma site was extended, and further debridement was performed to eliminate contaminants and bone fragments from the bone surface. The fracture ends were again irrigated with hydrogen peroxide, iodine, and a large amount of saline. Gloves and instruments were changed, and the surgical procedure continued according to the preoperative plan.

The first incision was made posterolaterally on the fibula, followed by anatomical reduction and strong internal fixation. A straight incision was made on the anterolateral aspect of the tibial crest to access and examine the distal tibial articular surface. The crushed four-column cortex of the distal tibia was addressed (Fig. 1).

Iliac bone graft was harvested from the ipsilateral side to reconstruct any articular surface defects based on the degree of collapse. Cancellous bone from the distal tibia was used to restore the articular surface flatness. An L-shaped locking steel plate (Zimmer) was applied to the distal tibia to achieve fracture fixation and maintain articular surface alignment. The medial column was stabilized with two Kirschner pins inserted after anatomical reduction of the inner ankle.

The posterior tibial tendon soft tissue was repositioned to cover the traumatic defect. Following internal fixation, the tibial incision was thoroughly irrigated again with hydrogen peroxide and saline solution before suturing. To achieve tension-free closure of the anterior tibial incision, various techniques were employed based on calf tension. These techniques included: anterolateral calf reduction, posterior shallow reduction, posterior deep reduction, or medial and lateral full reduction. Barbed wire was used for tension-free closure of the skin edges. Finally, a VSD was placed over the original open incision and the reduction incision for drainage. The VSD was changed weekly until the trauma healed (Fig. 2).

Second stage wound management: following the one-stage surgery, the VSD was removed based on the granulation tissue formation within the trauma. The lateral reduction incision was tightened with barbed wire, and the skin edges were approximated without tension. The tension of the anterior tibial incision was maintained. The granulation tissue of the original open wound was assessed. If wound closure was possible, the skin defect area was measured. A medium-thickness flap was harvested from the ipsilateral thigh to cover the defect. The harvested skin was meshed with an oleo-sand dressing and shaped into a medium-thickness flap for transplantation onto the defect area. The resurfaced area was covered with a VSD, which was removed 1 week later to assess flap viability (Figs. 3 and 4).

Postoperative treatment

Postoperative management included cefoperazone sulbactam sodium for infection prevention, lower limb elevation to reduce swelling, low-molecular-weight heparin to prevent blood clots, and initial short leg cast immobilization. VSD was used in two phases: Phase I employed a pressure of 0.03 MPa to facilitate drainage of deep-seated contaminants, while Phase II utilized a lower pressure of 0.015 MPa to promote uniform skin graft adherence and prevent pressure-induced tissue

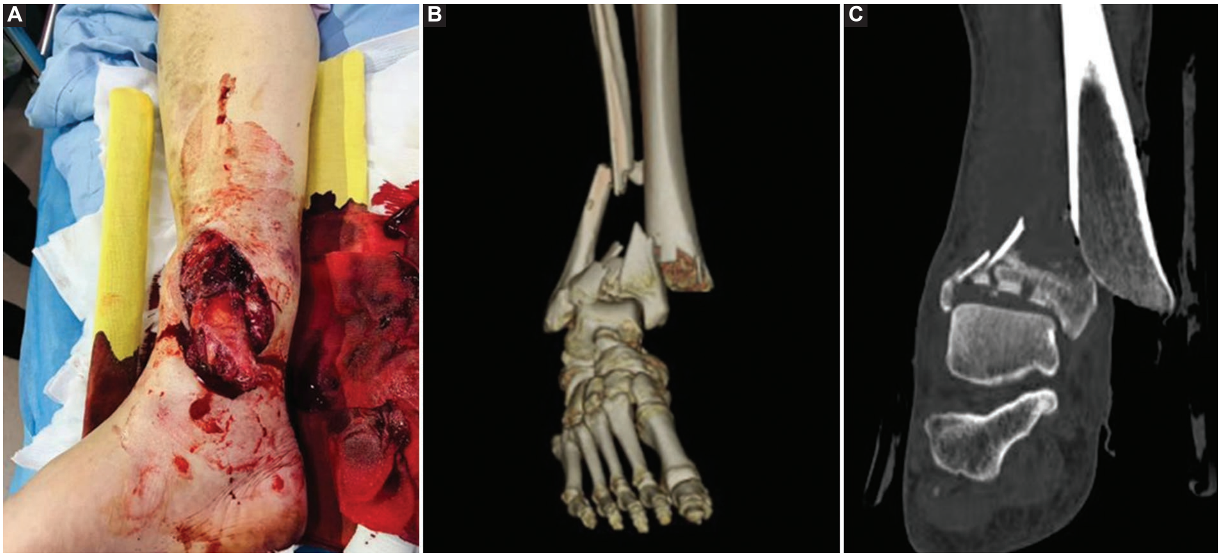

Figure 1. A: *examination of the right ankle reveals a soft tissue defect on the medial aspect of the distal tibia. The exposed distal tibia is contaminated.* **B** *and* **C:** *a post-injury computed tomography scan confirms a comminuted fracture of the distal tibia with bone defects on the articular surface.*

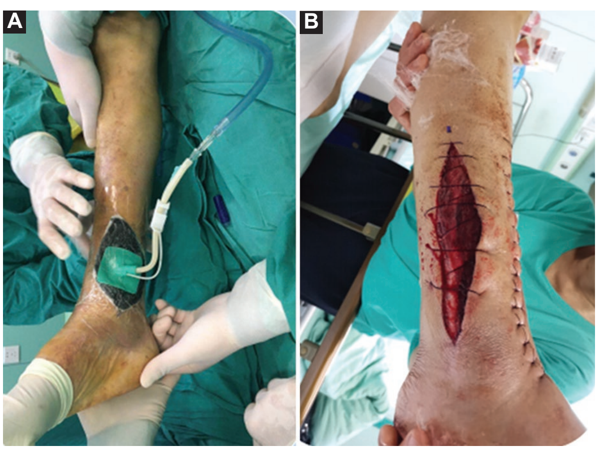

Figure 2. A: *following intraoperative debridement, a VSD was applied to cover the medial defect, effectively converting the open wound (Phase I) into a closed wound.* **B:** *the lateral fibula reduction incision was closed with barbed wire positioned close to the skin edge without tension to prevent skin retraction. The VSD provided continuous drainage, and the barbed wire tension was gradually adjusted as swelling subsided. VSD: Vacuum-assisted closure device.*

death. Physiotherapy began on the second postoperative day with quadriceps muscle strengthening exercises in bed. Four weeks after surgery, the cast was removed, and the affected limb was immobilized with crutches for non-weight-bearing ambulation in bed.

Evaluation of the efficacy of treatment

Treatment efficacy was evaluated by observing flap survival at the defect site 2 weeks after surgery, followed by assessment of flap shape, color, and sensation recovery during the final follow-up visit. Imaging examinations were performed at the outpatient clinic at weeks 1, 4, 8, and 12 to assess fracture healing, length of hospitalization, wound healing time, and potential complications like bone nonunion.

Evaluation of articular surface resurfacing

The Burwell and Charnley[5] radiologic criteria were used to assess the quality of distal tibial articular surface resurfacing after surgery. This evaluation includes: (1) Anatomical repositioning, which refers to the ideal alignment with minimal displacement. There should be no inward or lateral displacement of the medial and lateral ankle, no angular displacement, and minimal longitudinal displacement (< 1 mm) of the medial and lateral ankle. In addition, the posterior ankle block should have a proximal displacement of < 2 mm, and there should be no talar displacement; (2) Reset is possible, which indicates acceptable alignment with some displacement. There is still no medial or lateral displacement of the medial and lateral ankle, and no angular displacement. However, the longitudinal displacement of the medial and lateral ankle can range from 2 to 5 mm, and the proximal displacement of the posterior ankle block can also be between 2 and 5 mm. There should still be no talar displacement; (3) Poor repositioning, which signifies significant displacement of the bones, potentially

Figure 3. A: *after 1 week of VSD therapy covering the wound, the dressing was removed for wound evaluation. The wound bed appeared healthy with good granulation tissue and minimal edema. The VSD therapy was then reapplied.* **B:** *in another scenario, the VSD was used for 2 weeks. Upon removal, the wound appeared fresh and exhibited healthy, well-vascularized granulation tissue. The surgical procedure (implantation) was then performed. VSD: Vacuum-assisted closure device.*

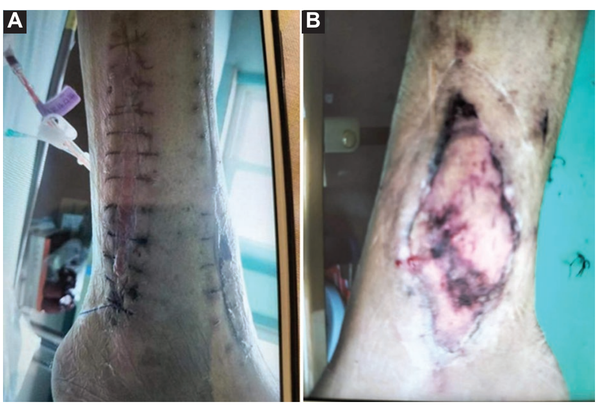

Figure 4. A: *after 1 week, the lateral VSD on the fibula was removed. The incision swelling had subsided, the edges were close together, and the barbed wire sutures were removed.* **B:** *the medial VSD was removed, revealing a viable skin flap with good color. VSD: Vacuum-assisted closure device.*

requiring further surgical intervention. This category includes any medial or lateral displacement of the medial or lateral ankle, a posterior displacement of the lateral ankle > 5 mm, or any talar displacement.

Evaluation of fracture healing

The Merchant[6] scale was employed to assess patient outcomes following surgery. This scale considers various factors, including function, pain level, gait, X-ray review, ankle stability, and mobility. The Merchant scale assigns a rating based on these criteria:

- Excellent: patients experience no pain in the affected area after surgery, and their joints move freely without impacting daily life;
- Good: patients may experience occasional pain that is manageable and has minimal impact on daily activities. Joint mobility is mostly restored;
- Fair: patients experience noticeable pain, sometimes requiring oral pain medication. Their joint movement is restricted, leading to some limitations in daily activities;
- Poor: patients experience significant pain and require pain injections for severe pain. Their joint movement is severely limited, affecting their ability to perform daily tasks independently.

Evaluation of ankle function

The Tornetta[7] criteria were used to assess ankle function after surgery. These criteria categorize function based on pain level, range of motion, and any angular deformity:

- Excellent: no pain, with excellent ankle movement (dorsiflexion > 5°, plantarflexion > 40°) and minimal angular deformity (< 3°).
- Good: occasional pain, manageable with readily available non-steroidal anti-inflammatory medications (NSAIDs). Ankle movement is acceptable (dorsiflexion 0-5°, plantarflexion 30-40°) with some valgus (outward angulation) deformity (3-5°) and limited inversion (< 3°).
- Fair: pain that interferes with daily activities and requires pain medication for relief. Ankle movement is further restricted (dorsiflexion – 5-0°, plantarflexion 25-30°) with a greater valgus deformity (5-8°) and some inversion limitation (3-5°).
- Poor: Intractable pain with severely limited ankle movement (dorsiflexion < –5°, plantarflexion < 25°). Significant valgus deformity (> 8°) and substantial inversion limitation (> 5°) are present.

General results

All 18 patients in our group were followed for a duration ranging from 14 to 27 months, with an average follow-up of 18.8 months. Complete bone healing was achieved in all fractures, with an average healing time of 4.2 months (range: 3-5 months). The average hospitalization time was 24.2 days (standard deviation [SD] ± 5.3), and the average wound healing time was 14.5 days (SD ± 1.6).

Figure 5. A-C: *at the last follow-up visit, the incision was well healed, the color and sensation of the skin flap at the traumatic defect implant were normal, and the mobility of the ankle joint was good.*

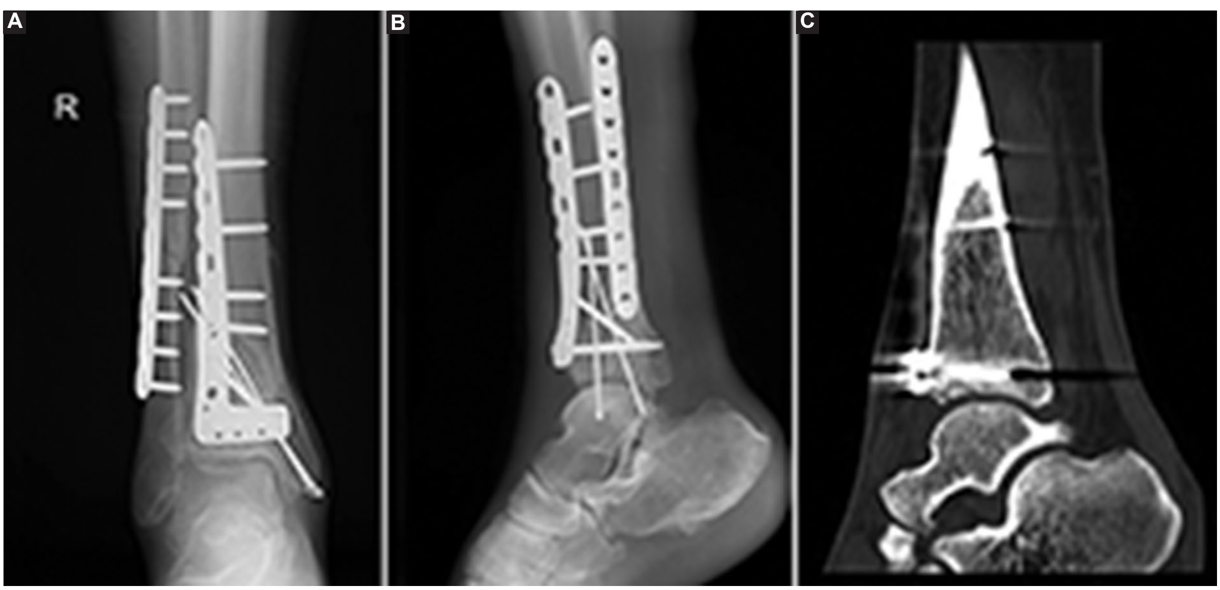

Figure 6. *Imaging findings at final follow-up.* **A:** *complete healing of the fracture, no loosening of the internal fixation, good lower limb force lines on orthogonal X-ray, and no internal or external deformity.* **B:** *lateral x-ray lower extremity lines of force without anterior-posterior angulation.* **C:** *computed tomography scan shows a flat articular surface.*

One patient developed partial skin necrosis at the edge of the anterior tibial incision. This was successfully treated with debridement and dressing changes, and the wound healed without further complications. All other patients experienced successful flap viability and no infections, implant necrosis, or osteomyelitis (Fig. 5).

Fracture reduction and fixation and healing

Postoperative anteroposterior (AP) and lateral X-rays of the ankle joint demonstrated successful surgical outcomes (Fig. 6). These X-rays revealed restoration of the distal tibial articular surface to a flat contour, realignment of the ankle joint and restoration of the lower limb weight-bearing line, and anatomical reduction and restoration of length in the fibula fracture. Utilizing the Burwell-Charnley radiologic criteria, 17 cases achieved anatomical reset (94.4%, 17/18), 1 case achieved reset possible, and no cases fell into the poor reset category. Furthermore, postoperative fracture healing was evaluated according to the Merchant scoring system, with results showing

Table 2. Ankle function was evaluated according to the criteria such as Tornetta in 18 patients up to the last follow-up

Evaluation criteria	Burwell-Charnley radiological evaluation	Merchant bone healing evaluation	Tornetta ankle functional evaluation
Clinical outcome	No. of patients	No. of patients	No. of patients
Excellent	17	15	15
Good		1	1
Moderate	1	1	1
Poor	0	1	1

15 cases achieving an excellent outcome (83.3%, 15/18), 1 case categorized as good, 1 case fair, and 1 case poor.

Eighteen patients were evaluated for ankle function according to the Tornetta et al. criteria by the time of the final follow-up, among which 15 were excellent, 1 was good, 1 was acceptable, and 1 was poor, with an excellent rate of 88.9% (16/18) (Table 2).

Discussion

Emergency soft-tissue debridement and antibiotic application

Adequate debridement is crucial for the successful treatment of open fractures. The risk of infection increases with the severity of the open wound. Type I fractures have the lowest risk (0-2%), followed by type II (2-10%) and type III (10-50%)[8]. Open Pilon fractures often involve skin and soft tissue injuries. The distal tibia has a poor blood supply, and the thin soft tissues are prone to complications. These complications include skin and soft-tissue necrosis, traumatic infections, and osteomyelitis. These complications are lengthy and expensive to treat, and can lead to some of the worst functional outcomes of all open skeletal injuries[9]. Healthy skin acts as a barrier to microorganisms and secretes fatty acids that limit bacterial colonization. When the skin is injured, this barrier is breached, increasing the risk of deeper tissue contamination and potentially severe tissue necrosis.

While the ideal treatment protocol for open tibial fractures remains under debate, all experts agree on the importance of irrigation and debridement[10]. Early debridement is critical. As early as 1997, the British Orthopaedic Association and the British Association of Plastic, Reconstructive and Aesthetic Surgeons recommended performing the first debridement within 6 h of injury[11]. Multiple studies support the concept of a “golden window” for debridement. Patients who undergo debridement within 6 h of admission have lower infection rates[12]. Kreder and Armstrong found a 25% increase in infection risk for open tibial fractures in children when debridement was delayed beyond 6 h[13]. Antibiotics play a role in managing open fractures, but they are primarily used therapeutically rather than preventively. Gustilo and Anderson found that 70% of open wounds were already contaminated with bacteria at the time of injury[14]. A randomized trial by Patzakis and Wilkins showed a significant reduction in infection rates when antibiotics were administered within 3 h of injury (4.7%) compared to delayed administration (7.4%)[15].

Accelerated rehabilitation surgery concept for stage I wound coverage and strong internal fixation

Open Pilon fractures, although representing only 1% of all lower extremity fractures, pose significant challenges due to their complexity[16]. These high-energy injuries often involve comminuted fractures, severe soft tissue damage, and potential complications such as infection and bone exposure[17]. Conventionally, open Pilon fractures were treated with various surgical options, each with limitations. Incisional internal fixation, while restoring limb alignment, may compromise soft-tissue blood supply[18]. Minimally invasive plate internal fixation prioritizes soft-tissue preservation but may not achieve optimal anatomical reduction for all fractures[19]. External fixation, though useful for temporary stabilization, can lead to deformity and stiffness[20].

Recent advancements have revolutionized open Pilon fracture treatment. Early and thorough debridement minimizes infection risk and allows for definitive surgery, aligning with the concept of “total repair” in trauma management[21,22]. The ERAS protocol, a multimodal approach, emphasizes reducing anxiety, minimizing complications, and promoting faster recovery[23]. Following thorough debridement, early internal fixation and soft-tissue reconstruction facilitate bone healing and functional restoration[24,25]. VSD, also known as negative pressure wound therapy (NPWT), effectively manages open wounds by removing excess exudate, promoting blood flow, reducing tissue edema, protecting the wound bed, and enhancing granulation tissue growth[26,27]. For certain open Pilon fractures (Gustilo type III), achieving early fracture stabilization and soft-tissue coverage in a single surgery is ideal for reducing infection, restoring blood flow, and promoting healing[28]. This approach aligns with the concept of minimizing reconstructive procedures and their associated complications[29]. Our department adheres to the principles of early debridement, single-stage surgery, and NPWT for open Pilon fractures. This approach has yielded excellent clinical outcomes, including reduced infection rates, improved anatomical reduction, faster recovery, and minimized patient burden.

Conclusion

The characteristics of Pilon fractures dictate difficult and specific clinical management, and the acute management of open Pilon fractures remains a serious challenge for orthopedic surgeons. Multiple factors, including fracture severity, size of the trabecular defect, adequacy of debridement, timing of initial treatment, antibiotic use, and other variables in open fractures, contribute to the potential for infection and require prompt attention and treatment. Debridement of all open fractures according to the historical 6-h time window reduces the risk of infection, early administration of appropriate antibiotics has been shown to be a key factor in the reduction and treatment of open fractures, and early internal fixation and coverage of the trauma can be achieved only by ensuring that debridement is complete. The results of our study show that safe management can be obtained by intensive debridement, antibiotics, strong internal fixation, negative pressure closed drainage, and reduction of the calf incision with significant clinical results.

Limitations

There are some limitations of this study: (1) This was a retrospective study conducted at a single center with a relatively small number of participants, which may introduce bias into the results; (2) We excluded patients with Gustilo type IIIC fractures, potentially limiting the generalizability of our findings; and (3) the follow-up period was relatively short. Long-term follow-up is necessary to assess the durability of the treatment outcomes.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed complied with the ethical standards of the responsible human experimentation committee and adhered to the World Medical Association and the Declaration of Helsinki. The procedures were approved by the institutional Ethics Committee.

Confidentiality, informed consent, and ethical approval. The authors have followed their institution's confidentiality protocols, obtained informed consent from the patient. This retrospective study was approved by the Ethics Committee of the Affiliated Zhongshan Hospital of Dalian University (No.6, Jiefang Street, Zhongshan District, Dalian). All patients agreed and signed informed consent forms.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

References

1. Osman W, Alaya Z, Kaziz H. Treatment of high -energy pilon fractures using the Ilizarov treatment. J Pan Afr Med J. 2017;27:199.
2. Boraiah S, Kemp TJ, Erwteman A, Lucas PA, Asprinio DE. Outcome following open reduction and internal fixation of open pilon fractures. J Bone Joint Surg Am. 2010;92:346-52.
3. Tang X, Liu L, Tu CQ, Li J, Li Q, Pei FX. Comparison of early and delayed open reduction and internal fixation for treating closed tibial pilon fractures. Foot Ankle Int. 2014;35:657-64.
4. Sirkin M, Sanders R, Dipasqale T, Herscovici D Jr. A staged protocol for soft tissue management in the treatment of complex pilon fractures. J Orthop Trauma. 2004;18:S32-8.
5. Burwell HN, Chamley AD. The treatment of displaced fractures at the ankle by rigid internal fixation and early joint movement. J Bone Joint Surg Br. 1965;47:634-60.
6. Merchant TC, Dietz FR. Long-term follow-up after fractures of the tibial and fibular shafts. J Bone Joint Surg Am. 1989;71:599-606.

7. Tornetta P 3rd, Weiner L, Bergman M, Watnik N, Steuer J, Kelley M, et al. Pilon fractures: treatment with combined internal and external fixation. J Orthop Trauma. 1993;7:489-96.
8. Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma. 1984;24:742-6.
9. Sung JK, Levin R, Siegel J, Einhorn TA, Creevy WR, Tornetta P 3rd. Reuse of external fixation components: a randomized trial. J Orthop Trauma. 2008;22:126-30; discussion 130-1.
10. Byrd HS, Spicer TE, Cierney G 3rd. Management of open tibial fractures. Plast Reconstr Surg. 1985;76:719-30.
11. Penn-Barwell JG, Murray CK, Wenke JC. Early antibiotics and debridement independently reduce infection in an open fracture model. J Bone Joint Surg Br. 2012;94:107-12.
12. Pollak AN, Jones AL, Castillo RC, Bosse MJ, MacKenzie EJ, LEAP Study Group. The relationship between time to surgical debridement and incidence of infection after open high-energy lower extremity trauma. J Bone Joint Surg Am. 2010;92:7-15.
13. Kreder HJ, Armstrong P. A review of open tibia fractures in children. J Pediatr Orthop. 1995;15:482-8.
14. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am. 1976;58:453-8.
15. Patzakis MJ, Wilkins J. Factors influencing infection rate in open fracture wounds. Clin Orthop Relat Res. 1989;243:36-40.
16. Craig S, Bartlett III, Lon S, Browner B, Jupiter J, Levine A, et al., editors. Fracture of the tibial pilon. In: Skeletal Trauma. 3rd ed. Singapore: Elsevier; 2003. p. 2257.
17. Switaj PJ, Weatherford B, Fuchs D, Rosenthal B, Pang E, Kadakia AR. Evaluation of posterior malleolar fractures and the posterior pilon variant in operatively treated ankle fractures. Foot Ankle Int. 2014;35:886-95.
18. Lau TW, Leung F, Chan CF, Chow SP. Wound complication of minimally invasive plate osteosynthesis in distal tibia fractures. Int Orthop. 2008;32:697-703.
19. Poyanli O, Esenkaya I, Ozkut AT, Akcal MA, Akan K, Unay K. Minimally invasive reduction technique in split depression type tibial pilon fractures. J Foot Ankle Surg. 2012;51:254-7.
20. Tarkin IS, Clare MP, Marcantonio A, Pape HC. An update on the management of high-energy pilon fractures. Injury. 2008;39:142-54.
21. Riechelmann F, Kaiser P, Arora R. Primary soft tissue management in open fracture. Oper Orthop Traumatol. 2018;30:294-308.
22. Al-Hourani K, Fowler T, Whitehouse MR, Khan U, Kelly M. Two-stage combined ortho-plastic management of type IIIB open diaphyseal tibial fractures requiring flap coverag: is the timing of debridement and coverage associated with outcomes? J Orthop Trauma. 2019;33:591-7.
23. Wilmore DW. From cuthbertson to fast-track surgery: 70 years of progress in reducing stress in surgical patients. Ann Surg. 2002;236:643-8.
24. Bin Y, Xinbao W, Peifu T, Jun L, Yong L, Gang W, et al. Chinese guidelines for the diagnosis and treatment of open fractures. Chinese J Trauma Orthop. 2019;21:921-8.
25. Esposito JG, Van Der Vliet QM, Heng M, Potter J, Cronin PK, Harris MB, et al. Does surgical approach influence the risk of postoperative infection after surgical treatment of tibial pilon fractures? J Orthop Trauma. 2019;34:126-30.
26. Ferris FD, Al Khateib AA, Fromantin I, Hoplamazian L, Hurd T, Krasner DL, et al. Palliative wound care: managing chronic wounds across life's continuum: a consensus statement from the international palliative wound care initiative. J Palliat Med. 2007;10:37-9.
27. Fang LM, Zhang YJ, Zheng JY, Zhang J. Early treatment of large soft-tissue wounds with intermittent vacuum sealing drainage. Zhonghua Yi Xue Za Zhi. 2011;91:2329-32.
28. Egol KA, Bazzi J, McLaurin TM, Tejwani NC. The effect of knee-spanning external fixation on compartment pressures in the leg. J Orthop Trauma. 2008;22:680-5
29. Mathews JA, Ward J, Champman TW, Khan UM, Kelly MB. Single-stage orthoplastic reconstruction of gustilo-anderson grade III open tibial fractures greatly reduces infection rates. Injury. 2015;46:2263-6.