



Tibial pilon fractures : A review of incidence, diagnosis, treatment, and complications

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Tibial pilon fractures are challenging to treat, as they are typically intra-articular and associated with extensive soft tissue damage. We briefly review the anatomy of the distal tibia, as well as the pathophysiology of pilon fractures. The treatment of tibial pilon fractures is still controversial in the literature, and we present some of the available options. Consideration is also given to peri-operative complications, such as preoperative oedema and blistering and late post-operative traumatic arthritis. Finally, we propose a treatment algorithm (used in our institution), taking into account the level of associated soft tissue injuries. The use of a 2-phase treatment protocol is recommended ; however, to date, no absolute treatment protocol exists for these injuries.

Keywords : pilon fracture ; distal tibia fracture ; fracture management.

INTRODUCTION

Distal tibial fractures often present a challenge to the orthopaedic surgeon. Destot first used the term in 1911, likening the pilon to a pestle (23). The tibial pilon comprises anatomically the distal end of the tibia including the articular surface. Its proximal limit is found approximately 8-10 cm from the ankle articular surface, where the triangular section of the tibial diaphysis, with its anterior crest, changes direction forming the metaphysis. The three-dimensional configuration of this region appears to be designed to increase the area of the

articular surface, reducing the stress on the ankle joint (53,66,68).

Tibial pilon fractures represent 5-7% of all tibial fractures (1,28,58). The treatment of this type of fracture is of current research interest (49,64), since there is no universally agreed treatment method. The choice of treatment must take into account not only the stabilisation of the fracture, but also the management of the soft tissue injury which is a frequent cause of subsequent complications (13,42). The timing of definitive surgery is crucial with respect to the soft tissues (5,52). The principal aim is to avoid the development of arthritis of the ankle joint, which often results in a serious functional impairment with significant implications for employment

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following this type of fracture (15,21,43). Great attention must be given to the accurate reconstruction of the articular surface. By convention, all fractures of the tibia involving the distal articular surface should be classified as tibial pilon fractures, except for medial or lateral malleolar fractures and trimalleolar fractures where the posterior malleolar fracture involves less than 1/3 of the articular surface (21,39,56). However, included in the definition are isolated fractures of the posterior malleolus (Volkman triangle), which alone account for 5% of the tibial pilon fractures (4,32,63).

Pathophysiology

There are a wide variety of pilon fractures observed, dictated by the mechanism and energy involved. Low-energy fractures result in minimal soft tissue injuries, less comminution, and are often minimally displaced or undisplaced. In contrast high-energy injuries such as those following road traffic accidents and axial loading mechanisms can result in significant soft tissue insults, highly comminuted fracture configurations and displaced fracture patterns (34).

Disruption of the articular surface of the distal tibia occurs in varying degrees with fragments of the articular surface being driven proximally into the metaphysis of the tibia by the impact (38).

Classification and Aetiology

There are several classifications of this type of fracture, some with mere historical interest (64) and others which are more commonly used (47,64). The AO / OTA classifies pilon fractures in three main subgroups : extra-articular (43-A), partial articular (43-B) and complete articular fractures (43-C), divided into subgroups depending on the comminution. Most type B fractures have traumatic torsion mechanisms, while the C-type usually have high energy compression mechanisms (68). Although the AO / OTA Weber classification (64) is the most comprehensive, the most utilized is the Ruedi and Algöwer (45,46,47,48) classification that divides tibial pilon fractures into three types on the basis of size and displacement of articular fragments : type I

(AO / OTA 43B1), with no displacement of the articular surface, type II (AO / OTA 43C1) with displacement of the articular surface but without metaphyseal comminution, and type III (AO / OTA 43C2-43C3), with comminution of both the articular surface and the metaphysis.

The degree of soft tissue injury insult must also be considered in the classification as well as directing definitive management strategies. Open fractures are classified according to Gustilo and Anderson (19,20). Prevalence of open wounds has been reported to be approximately 20% (2,3). The Tscherné classification can be utilised for soft tissues associated with closed tibial fractures (54,61). The majority of tibial pilon fractures present a great risk of instability in the sagittal plane, whilst malleolar fractures often result in instability in the coronal plane.

There is a male predominance (57-65%) for these fractures following a bimodal distribution with peaks of frequency at 25 and 50 years (17). The aetiology of these fractures may be divided into two broad groups : high-energy trauma (including road accidents and skiing) and traumatic "benign" low-energy trauma (frequently women of older age with pre existing osteoporosis) (31). The aetiology of this type of fracture is particularly important for the treatment plan. High-energy compression trauma frequently causes severe comminution involving the articular surface and the soft tissues, while the low-energy trauma with a torsional component most frequently causes larger bony fragments and a less comminuted articular surface that, when involved, remains adherent to the large subchondral bone fragments (14,44,52,58). The two mechanisms of injury can then create two very specific types of fracture morphology and treatment choices (1,5,8,21,56).

Presentation

Patients involved in high-energy trauma should be treated according to advanced trauma life-support guidelines because they may have associated life- or limb-threatening injuries.

Oedema, pain, deformity and functional impairment are the classic clinical signs of most fractures



Fig. 1. — Soft tissue injury including oedema, contusion and blisters associated with pilon fractures.

(Fig. 1). The inability to sustain the weight of the body is particularly indicative. High-energy fractures are usually obvious on inspection, while tibial pilon fractures caused by a torsional mechanism often have less striking clinical signs. Extreme care should be taken in clinical examination to look for possible associated injuries, especially vascular or nerve injury and compartment syndrome, requiring urgent intervention (2,26,52,56).

The standard radiographic examination includes anteroposterior, mortise and lateral projections and must include the entire tibia and fibula and the foot. CT scanning, with 3D reconstruction, has now become routine in many centers for the study and operative planning of these high-energy fractures, proving especially useful to identify the precise path of sagittal and coronal fracture lines (58,59) (Fig. 2).

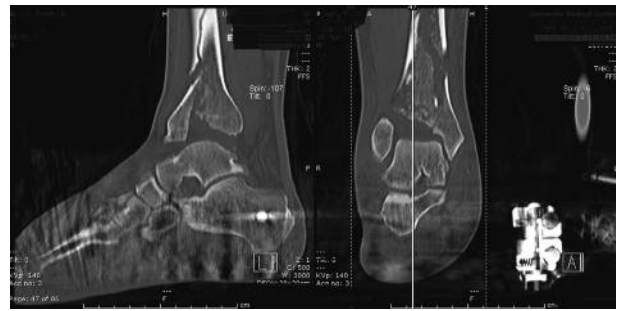


Fig. 2. — Computed Tomography (CT) images, including three dimensional reconstruction of a pilon fracture.

Treatment

The concept for the treatment of this type of fracture is management of the soft tissues, recreation of the joint surfaces and restoration of limb alignment. The treatment options for fractures of the tibial pilon include non surgical and surgical. Surgical options are internal fixation, external fixation with or without limited internal fixation and primary arthrodesis. The condition of the soft tissues guides the therapeutic choice. The non surgical treatment of tibial pilon fractures, based on prolonged transcaneal traction or casting has been superseded by modern surgical techniques and is limited to special cases only (8,35,41). Non surgical treatment is reserved for pilon fractures where there is minimal displacement and where the alignment of the limb can be maintained with a cast. Weight bearing is prohibited for at least 4-6 weeks. The prognosis is good.

The surgical treatment by means of open reduction and internal fixation is, like in all articular fractures, the most reliable way to obtain an anatomic reduction of the articular surface. However, this therapeutic option should be carefully weighted against not only the condition of the soft tissues (the vascularity may be affected by surgical approach if too early) but also by the comminution and the number of fragments. The first step is the fixation of the fibula, to regain the correct length of the tibia and to facilitate the three-dimensional orientation and reduction of the fracture. Several surgical approaches to the tibia have been described for the



Fig. 3. — Anatomically contoured distal tibial plates

treatment of these fractures (2,8,18,28,32). Whatever the surgical route chosen, the surgical approach should be centred on the larger bone fragment and care taken not to traumatise the skin with aggressive surgical technique. An arthrotomy is essential for the accurate reduction of articular fragments. At this stage the key concepts proposed by Ruedi and Allgöwer are still valid (45,46,47,48), aiming to keep a maximum of 2 mm of incongruity of the articular surface. The AO recommends the use of a temporary external stabilisation of the epiphyseal area, then moving to the meta-epiphyseal area for definitive reconstruction and stabilisation with a plate (LCP). Other schools of thought include the direct use of a rigid anatomical plate, fixed proximally to impose the reconstruction of the distal anatomy onto the plate (Fig. 3).

The role of external fixation as definitive treatment has been of interest in recent years (6,12,16,25,29,36,40), particularly for the benefits it provides with respect to minimal interference with the soft tissue (15,52,68). The principle of treatment with an external fixator is through ligamentotaxis, but while most fixators are constructed to provide a tibio-

talar-calcaneal bridge (Fig. 6), circular fixators allow a tibial only assemblage. Although not always possible, this can allow early mobilisation of the ankle and also, depending on the size and orientation of the wires, a juxta-epiphyseal assembly and partial control over the comminution of the fragments (6,29,42,44,68), which may be assembled under arthroscopic control (25) (Fig. 4). In any case, the assembly of the external fixator should not jeopardize the attainment of an eventual coverage flap (15) and should, as with internal fixation, be preceded by the fibular synthesis, where necessary, in order to restore the correct length. Several authors also combine this type of therapeutic choice with percutaneous osteosynthesis of epiphyseal fragments using free screws or wires (22,55) under C-arm control (Fig. 5).

The use of articulated external fixators may be an alternative for these fractures (11,50), as well as minimally invasive percutaneous plate osteosynthesis (22) or the combination of internal and external fixation (16,42,60). Arthrodesis is nowadays reserved only for severe articular comminution which is not otherwise reconstructable (3,23,33).

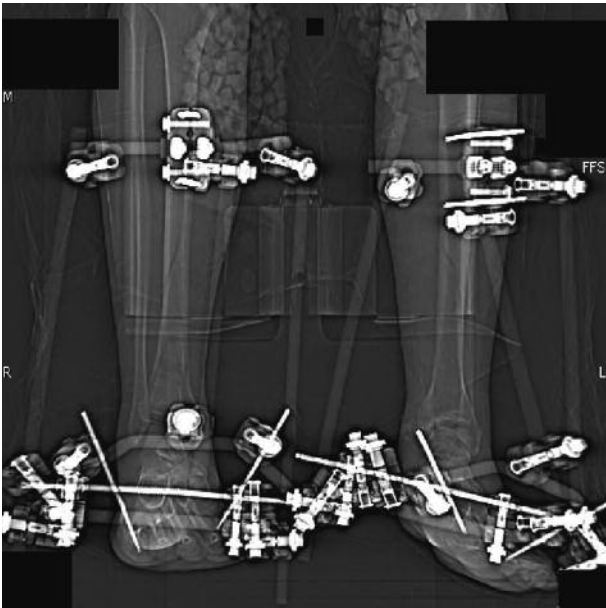


Fig. 4. — Bridging external fixation of bilateral pilon fractures.

DISCUSSION

The main objectives of the treatment of tibial pilon fractures are the maintenance of length, recreation of the joint surfaces and restoration of limb alignment. Open reduction provides the safest way of achieving fracture reduction and restoring joint congruity, considering also the possibility of external fixation to restore severe articular comminution in Type C fractures (AO / OTA) (21,48). However, this type of therapeutic choice must not come at the expense of the soft tissues, where severe injury could lead to failure of even the most anatomical reconstructions, with serious consequences such as surgical wound breakdown with exposure of hardware and infection (2,15,26,57).

As stated above, Tscherne *et al.* (61) have proposed a classification of soft tissue damage in this type of fracture as a guide for decision making. No matter how precisely these protocols are applied, the key concept, especially with high-energy fractures, is that early open surgery (less than a week) results in a significantly higher rate (2,7,15,26,38,51, 52,56,57,68) of complications compared to delayed surgery (usually 10-15 days or longer). It is necessary to wait for the reepithelialization of each



Fig. 5. — Circular frame (LIMA) external fixation of a pilon fracture.

blister locally and assess the status of the skin until the so-called *wrinkle sign* of the skin is positive.

Delayed surgical intervention is to be recommended in all those situations where there is even minimal evidence of soft tissue injury. There are indeed situations, such as low-energy fractures of AO / OTA type A or B with no significant soft tissue injury, where internal fixation may be undertaken without prolonged delay. The management of type C fractures remains a source of discussion. There seems to be consensus on protocols to prevent frequent complications especially regarding the soft tissues (30), which are not only the guide for surgical choice, but also the timing of treatment.

Since the studies by Helfet (21) in 1994, in which he first proposed a two-stage protocol for this type of fracture, several authors in recent years have highlighted the decision algorithms for the treatment of tibial pilon fractures (3,28,36,39,48). In

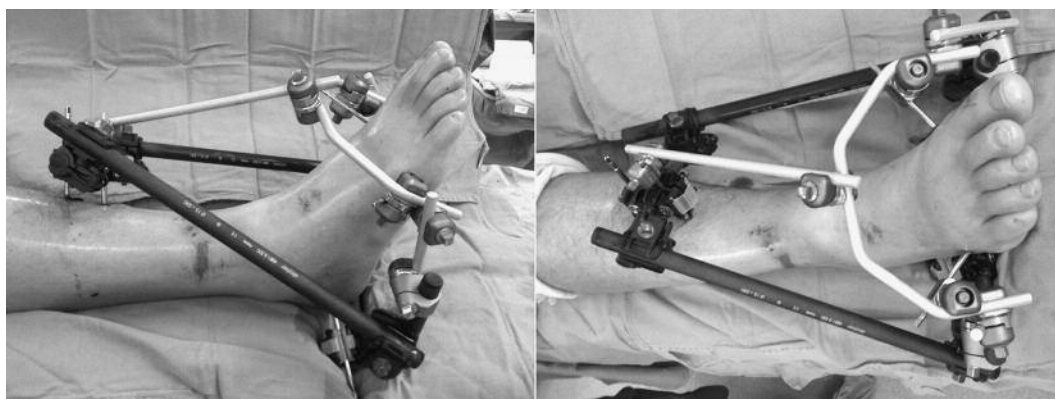


Fig. 6. — Portable traction

particular, two studies (37,52) in 1999 have shown how to obtain a good compromise between reduction of the fracture, infection rates and complications with a two-stage protocol. The first stage consists of using external fixation, a temporary trans-skeletal traction (portable traction) suitable to restore length, and alignment and rotation of the limb (Fig. 6). Particular care should be taken not to place the pins of the fixator along the course of a possible incision site for future surgical treatment. Open reduction and internal fixation of a fibular fracture, if present, may be done at this time if the soft tissue allows. In particular, the use of a radiolucent external fixator with a tibio-calcaneal assembly (Prefix® - Orthofix Inc.) has some advantages compared to other types of fixators in terms of obtaining further imaging of the fracture. Care of any associated skin damage must be undertaken. The observation of a positive wrinkle sign may take up to three weeks. In the case of fractures with significant tissue loss, surgical debridement may be required with the subsequent use of vacuum-assisted wound dressings (15,57).

During this waiting period, if not done before, it is useful to obtain a CT scan to accurately delineate the fracture pattern. The second stage of treatment is the definitive surgery, performed at a point when the soft tissues have recovered sufficiently to limit the likelihood of complications. The treatment protocol used in our institution can be summarised schematically as in Fig. 7. Osteosynthesis (ORIF)

of tibial pilon fractures is never a treatment to be performed under emergency conditions.

An interesting prospective randomized trial by Wyrsh (66) *et al* compared definitive treatment by means of open reduction and internal fixation with external fixation. In this study, postoperative infections were significantly more frequent with the open plate fixation with no statistically significant differences in functional results and complications (although the average clinical scores in the group treated with external fixation were higher than for patients treated with a plate).

For the treatment of type B and C fractures, Mitkovic (31) *et al*, using dynamic external fixation, found 71% subjectively and 67% objectively excellent results, despite a high frequency of infections (11%) and osteoarthritis (15%). The rate of amputation, arthritis, chronic osteomyelitis and dehiscence of the surgical wound stood at approximately 2% with the use of open reduction and internal fixation with a rate of skin necrosis of 13%.

With respect to outcomes, the multicenter review of SOFCOT (Société Française de Chirurgie Orthopédique et Traumatologique) in 1991, which considered more than 300 tibial pilon fractures treated surgically by various techniques, found only 38% objectively satisfactory clinical results with only 28% of patients walking without pain (10). More recent studies (36,38,68), using quality of life evaluation tools such as the 36-item Short Form Health Survey of the Medical Outcomes Study (SF-

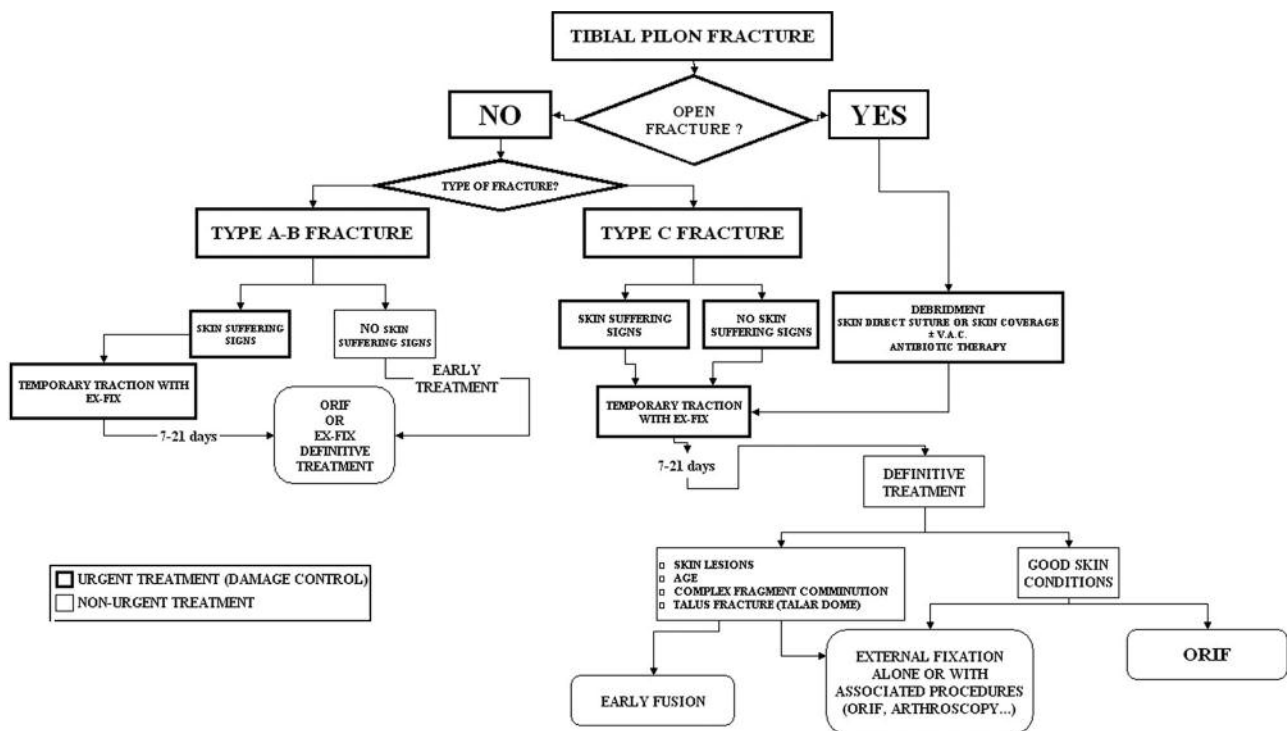


Fig. 7. — Decision making flowchart

36), saw the scores for the population of patients treated for type C fractures falling far below the average score for the normal population. The clinical results relate particularly to the type of fracture, associated soft tissue damage and the type of surgical treatment (36,38,56,68). However, it must be emphasized that unsatisfactory functional results can also occur despite optimal treatment and anatomical reduction of the fracture, stressing once again that post-traumatic arthritis is a risk for most patients following this type of fracture, regardless of treatment protocol (9,24,27).

To date, no one surgical treatment method has demonstrated superiority over others ; however, the authors recommend the use of a two-phase protocol for the management of the soft tissue. This review re-emphasizes the complexity of the treatment of tibial pilon fractures and the importance of further studies (including randomized controlled trials) directed at the formulation of evidence-based recommendations for treatment.

REFERENCES

1. Bedi A, Le TT, Karunakar MA. Surgical treatment of nonarticular distal tibia fractures. *J Am Acad Orthop Surg* 2006 ; 14 : 406-416.
2. Bhattacharyya T, Crichlow R, Gobeze R, Kim E, Vraha MS. Complications associated with the posterolateral approach for pilon fractures. *J Orthop Trauma* 2006 ; 20 : 104-107.
3. Blauth M, Bastian L, Krettek C, Knop C, Evans S. Surgical options for the treatment of severe tibial pilon fractures : a study of three techniques. *J Orthop Trauma* 2001 ; 15 : 153-160.
4. Boraiah S, Gardner MJ, Helfet DL, Lorich DG. High association of posterior malleolus fractures with spiral distal tibial fractures. *Clin Orthop Relat Res* 2008 ; 466 : 1692-1698.
5. Borrelli J Jr, Ellis E. Pilon fractures : assessment and treatment. *Orthop Clin North Am* 2002 ; 33 : 231-245.
6. Bottlang M., Marsh JL, Brown TD. Articulated external fixation of the ankle : minimizing motion resistance by accurate axis alignment. *J Biomech* 1999 ; 32 : 63-70.
7. Brumback RJ, McGarvey WC. Fractures of the tibial plafond. Evolving treatment concepts for the pilon fracture. *Orthop Clin North Am* 1995 ; 26 : 273-285.

8. **Calori GM, Tagliabue L, Mazza E et al.** Tibial pilon fractures : which method of treatment ? *Injury* 2010 ; 41 : 1183-1190.
9. **Chen SH, Wu PH, Lee YS.** Long-term results of pilon fractures. *Arch Orthop Trauma Surg* 2007 ; 127 : 55-60.
10. **Copin G.** [Tibial pilon fractures in the adult] (in French). *Rev Chir Orthop Reparatrice Appar Mot* 1992 ; 78 suppl : 33-83.
11. **DiChristina D, Riemer BL, Butterfield SL, Burke CJ 3rd.** Pilon fractures treated with an articulated external fixator : a preliminary report. *Orthopedics* 1996 ; 19 : 1019-1024.
12. **Dunbar RP, Barej DP, Kubiak EN, Nork SE, Henley MB.** Early limited internal fixation of diaphyseal extensions in select pilon fractures : upgrading AO/OTA type C fractures to AO/OTA type B. *J Orthop Trauma* 2008 ; 22 : 426-429.
13. **Edwards P.** Fracture of the shaft of the tibia : 492 consecutive cases in adults. Importance of soft tissue injury. *Acta Orthop Scand Suppl* 1965 ; 76 suppl : 1-82.
14. **Egol KA, Wolinsky P, Koval KJ.** Open reduction and internal fixation of tibial pilon fractures. *Foot Ankle Clin* 2000 ; 5 : 873-885.
15. **Fischer MD, Gustilo RB, Varecka TF.** The timing of flap coverage, bone-grafting, and intramedullary nailing in patients who have a fracture of the tibial shaft with extensive soft-tissue injury. *J Bone Joint Surg* 1991 ; 73-A : 1316-1322.
16. **Gardner MJ, Mehta S, Barei DP, Nork SE.** Treatment protocol for open AO/OTA type C3 pilon fractures with segmental bone loss. *J Orthop Trauma* 2008 ; 22 : 451-457.
17. **Gay R, Evrard J.** [Recent fractures of the tibial pestle in adults]. *Rev Chir Orthop Reparatrice Appar Mot* 1963 ; 49 : 397-512.
18. **Grose A, Gardner MJ, Hettrich C et al.** Open reduction and internal fixation of tibial pilon fractures using a lateral approach. *J Orthop Trauma* 2007 ; 21 : 530-537.
19. **Gustilo RB.** Management of open fractures. An analysis of 673 cases. *Minn Med* 1971 ; 54 : 185-189.
20. **Gustilo RB, Merkow RL, Templeman D.** The management of open fractures. *J Bone Joint Surg* 1990 ; 72-A : 299-304.
21. **Helfet DL, Koval K, Pappas J, Sanders RW, DiPasquale T.** Intraarticular "pilon" fracture of the tibia. *Clin Orthop Relat Res* 1994 ; 298 : 221-228.
22. **Helfet DL, Suk M.** Minimally invasive percutaneous plate osteosynthesis of fractures of the distal tibia. *Instr Course Lect* 2004 ; 53 : 471-475.
23. **Hulscher JB, te Velde EA, Schuurman AH et al.** Arthrodesis after osteosynthesis and infection of the ankle joint. *Injury* 2001 ; 32 : 145-152.
24. **Kilian O, Bündner MS, Horas U, Heiss C, Schnettler R.** [Long-term results in the surgical treatment of pilon tibial fractures. A retrospective study.] (in German). *Chirurg* 2002 ; 73 : 65-72.
25. **Kim HS, Jahng JS, Kim SS, Chun CH, Han HJ.** Treatment of tibial pilon fractures using ring fixators and arthroscopy. *Clin Orthop Relat Res* 1997 ; 334 : 244-250.
26. **Kline AJ, Gruen GS, Pape HC et al.** Early complications following the operative treatment of pilon fractures with and without diabetes. *Foot Ankle Int* 2009 ; 30 : 1042-1047.
27. **Koulovaris P, Stafylas K, Mitsionis G et al.** Long-term results of various therapy concepts in severe pilon fractures. *Arch Orthop Trauma Surg* 2007 ; 127 : 313-320.
28. **Lee YS, Chen SH, Lin JC et al.** Surgical treatment of distal tibia fractures : a comparison of medial and lateral plating. *Orthopedics* 2009 ; 32 : 163.
29. **McDonald MG, Burgess RC, Bolano LE, Nicholls PJ.** Iliizarov treatment of pilon fractures. *Clin Orthop Relat Res* 1996 ; 325 : 232-238.
30. **Mehta S, Reilly MC, Rhorer AS, Liporace FA.** Current plating techniques and definitive treatment options for fractures of the tibial plafond and treatment of the late and failed pilon. In : *AAOS 2011 Annual Meeting Instructional Course* Edited 2011, San Diego Convention Center.
31. **Mitkovic MB, Bumbasirevic MZ, Lesic A, Golubovic Z.** Dynamic external fixation of comminuted intra-articular fractures of the distal tibia (type C pilon fractures). *Acta Orthop Belg* 2002 ; 68 : 508-514.
32. **Mizel MS, Temple HT.** Technique tip : revisit to a surgical approach to allow direct fixation of fractures of the posterior and medial malleolus. *Foot Ankle Int* 2004 ; 25 : 440-442.
33. **Morgan SJ, Thordarson DB, Shepherd LE.** Salvage of tibial pilon fractures using fusion of the ankle with a 90 degrees cannulated blade-plate : a preliminary report. *Foot Ankle Int* 1999 ; 20 : 375-378.
34. **Muller FJ, Nerlich M.** Tibial pilon fractures. *Acta Chir Orthop Traumatol Cech* 2010 ; 77 : 266-276.
35. **Othman M, Strzelczyk P.** Results of conservative treatment of "pilon" fractures. *Ortop Traumatol Rehabil* 2003 ; 5 : 787-794.
36. **Papadokostakis G, Kontakis G, Giannoudis P, Hadjipavlou A.** External fixation devices in the treatment of fractures of the tibial plafond : a systematic review of the literature. *J Bone Joint Surg* 2008 ; 90-B : 1-6.
37. **Patterson MJ, Cole JD.** Two-staged delayed open reduction and internal fixation of severe pilon fractures. *J Orthop Trauma* 1999 ; 13 : 85-91.
38. **Pollak AN, McCarthy ML, Bess RS, Agel J, Swiontkowski MF.** Outcomes after treatment of high-energy tibial plafond fractures. *J Bone Joint Surg* 2003 ; 85-A : 1893-1900.
39. **Pugh KJ, Wolinsky PR, McAndrew MP, Johnson KD.** Tibial pilon fractures : a comparison of treatment methods. *J Trauma* 1999 ; 47 : 937-941.
40. **Renzi Brivio L, Lavini F, Cavina Pratesi F, Corain M, Bartolozzi P.** The use of external fixation in fractures of the tibial pilon. *Chir Organi Mov* 2000 ; 85 : 205-214.

41. **Resch H, Pechlaner S, Benedetto KP.** [Long-term results after conservative and surgical treatment of fractures of the distal end of the tibia.] (in German). *Aktuelle Traumatol* 1986 ; 16 : 117-123.
42. **Ries MD, Meinhard BP.** Medial external fixation with lateral plate internal fixation in metaphyseal tibia fractures. A report of eight cases associated with severe soft-tissue injury. *Clin Orthop Relat Res* 1990 ; 256 : 215-223.
43. **Ristiniemi J.** External fixation of tibial pilon fractures and fracture healing. *Acta Orthop Suppl* 2007 ; 78 : 3, 5-34.
44. **Rose R.** Treatment of pilon fractures using the Ilizarov technique. Case reports and review of the literature. *West Indian Med J* 2002 ; 51 : 176-178.
45. **Ruedi TP.** Fractures of the lower end of the tibia into the ankle joint : results 9 years after open reduction and internal fixation. *Injury* 1973 ; 5 : 130-134.
46. **Ruedi T.** The treatment of displaced metaphyseal fractures with screws and wiring systems. *Orthopedics* 1989 ; 12 : 55-59.
47. **Ruedi T, Matter P, Allgöwer M.** [Intra-articular fractures of the distal tibial end.] (in German). *Helv Chir Acta* 1968 ; 35 : 556-582.
48. **Ruedi TP, Allgower M.** The operative treatment of intra-articular fractures of the lower end of the tibia. *Clin Orthop Relat Res* 1979 ; 138 : 105-110.
49. **Ruwe PA, Randall RL, Baumgaertner MR.** Pilon fractures of the distal tibia. *Orthop Rev* 1993 ; 22 : 987-996.
50. **Saleh M, Shanahan MD, Fern ED.** Intra-articular fractures of the distal tibia : surgical management by limited internal fixation and articulated distraction. *Injury* 1993 ; 24 : 37-40.
51. **Sirkin M, Sanders R.** The treatment of pilon fractures. *Orthop Clin North Am* 2001 ; 32 : 91-102.
52. **Sirkin M, Sanders R, DiPasquale T, Herscovici D Jr.** A staged protocol for soft tissue management in the treatment of complex pilon fractures. *J Orthop Trauma* 1999 ; 13 : 78-84.
53. **Souza TR, Fonseca ST, Goncalves GG, Ocarino JM, Mancini MC.** Prestress revealed by passive co-tension at the ankle joint. *J Biomech* 2009 ; 42 : 2374-2380.
54. **Südkamp N, Haas N, Flory PJ, Tscherner H, Berger A.** [Criteria for amputation, reconstruction and replantation of extremities in multiple trauma patients.] (in German). *Chirurg* 1989 ; 60 : 774-781.
55. **Syed MA, Panchbhavi VK.** Fixation of tibial pilon fractures with percutaneous cannulated screws. *Injury* 2004 ; 35 : 284-289.
56. **Tarkin IS, Clare MP, Marcantonio A, Pape HC.** An update on the management of high-energy pilon fractures. *Injury* 2008 ; 39 : 142-154.
57. **Thordarson DB.** Complications after treatment of tibial pilon fractures : prevention and management strategies. *J Am Acad Orthop Surg* 2000 ; 8 : 253-265.
58. **Topliss CJ, Jackson M, Atkins RM.** Anatomy of pilon fractures of the distal tibia. *J Bone Joint Surg Br* 2005 ; 87 : 692-697.
59. **Tornetta P 3rd, Gorup J.** Axial computed tomography of pilon fractures. *Clin Orthop Relat Res* 1996 ; 323 : 273-276.
60. **Tornetta P 3rd, Weiner L, Bergman M et al.** Pilon fractures : treatment with combined internal and external fixation. *J Orthop Trauma* 1993 ; 7 : 489-496.
61. **Tscherner H, Lobenhoffer P.** Tibial plateau fractures. Management and expected results. *Clin Orthop Relat Res* 1993 ; 292 : 87-100.
62. **van der Werken C, Zeegers EV.** Fracture of the lower leg with involvement of the posterior malleolus ; a neglected combination ? *Injury* 1988 ; 19 : 241-243.
63. **Vander Griend R, Michelson JD, Bone LB.** Fractures of the ankle and the distal part of the tibia. *Instr Course Lect* 1997 ; 46 : 311-321.
64. **Weber BG.** [Treatment of compression fractures of the ankle from a biomechanical viewpoint.] (in German). *Hefte Unfallheilk* 1965 ; 81 : 176-179.
65. **Wehner T, Claes L, Simon U.** Internal loads in the human tibia during gait. *Clin Biomech (Bristol, Avon)* 2009 ; 24 : 299-302.
66. **Wyrsh B, McFerran MA, McAndrew M et al.** Operative treatment of fractures of the tibial plafond. A randomized, prospective study. *J Bone Joint Surg* 1996 ; 78-A : 1646-1657.
67. **Yeow CH, Lee PV, Goh JC.** Effect of landing height on frontal plane kinematics, kinetics and energy dissipation at lower extremity joints. *J Biomech* 2009 ; 42 : 1967-1973.
68. **Zelle BA, Bhandari M, Espiritu M, Koval KJ, Zlowodzki M.** Treatment of distal tibia fractures without articular involvement : a systematic review of 1125 fractures. *J Orthop Trauma* 2006 ; 20 : 76-79.