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Distal tibial metaphyseal fractures: the role of fibular fixation

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Abstract Distal tibial extra-articular fractures are often a result of complex high-energy trauma, which commonly involves associated fibular fractures and soft tissue injury. The goal of tibial fixation is to maximise fracture stability without increasing soft tissue morbidity from surgical intervention. The role of adjunctive fibular fixation in distal tibial metaphyseal fractures has been controversial; although fibular fixation has been shown to improve stability of distal tibial fractures, there has been increased potential for soft tissue-related complications and a delay to tibial fracture healing. Adjunctive fixation of concomi-

tant fibular fractures without associated syndesmotic or ankle pathology is not necessary in surgically stabilised extra-articular metaphyseal fractures of the distal tibia.

Key words Distal tibial fractures • Fibular fixation • External fixation • Intramedullary nailing

Introduction

Epidemiology

Distal tibial metaphyseal fractures are often caused by high-energy axial compressive, direct bending or low-energy rotational forces [1–3]. These fractures represent less than 7% of all tibial fractures [4, 5] and less than 10% of all lower extremity fractures [6]. Specifically, metaphyseal fractures of the distal tibia comprise 15% of all fractures of the distal third of the tibia [7]. This injury commonly occurs in males 35–40 years of age and is the result of motor vehicle accidents, falls from heights or twisting injuries [2, 3, 8, 9].

Soft tissue injury

Soft tissue injury with distal tibial fractures is common, as the soft tissue envelope of the tibia is limited. When the threshold of impact absorption in the distal tibia is exceeded, as in a fracture, there is rapid transmission of the residual destructive forces to the thin cover of adjacent soft tissues. Consequently, the incidence of open fractures is high (Fig. 1), at 16%–47% of all distal tibial fractures [2, 9–13]. Closed tibial fractures are often accompanied by extensive contusions, fracture blisters (Fig. 2) or significant muscular damage [2]. An increased rate of complications in open tibial fractures is also associated with the degree of soft

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Fig. 1 Open fractures of the distal tibia are common in high-energy trauma. The soft tissue deficit exposes bone, thereby increasing the risk of osteomyelitis



Fig. 2 Closed distal tibial fractures are often accompanied by formation of fracture blisters indicating the level of soft tissue injury. Extensive surgery to these compromised areas frequently leads to soft tissue necrosis and should be avoided

tissue injury [14–16]. Infection rates at fracture sites of 16% and delayed unions of 14% are common sequelae encountered in severe open tibial fractures [15].

Concomitant fibular fractures

High-energy distal tibial injuries involve concomitant fibular fractures in 80% of cases [17]. The presence of ipsilateral fibular fractures in distal tibial fractures has been correlated with a higher severity of injury than those without fibular fractures [18].

Debating the need for fibular fixation

The need for fibular fixation in such fractures is controversial. Many agree that fibular fractures associated with syn-

desmotic or ankle mortise instability should be stabilised as malreduction of the ankle mortise has been shown to be a factor in poor functional outcomes, but there is no consensus over the role of fibular fixation in extra-articular fractures of the distal tibial metaphysis.

Load-bearing function of fibula

Lambert [19] demonstrated that the fibula has weightbearing function, carrying 1/6 of the load applied to the knee joint. With ankle in neutral position, load distribution to the fibula has been shown to average between 6% and 7% of the total load transmitted through both the tibia and fibula [20, 21].

Fibular biomechanics

The fibula has also been shown to contribute to the biomechanical stability of the ankle mortise during gait. From plantarflexion to dorsiflexion of the ankle, Close [22] reported an increase in intermalleolar distance of 1.5 mm and lateral rotation of the fibular by 2.5°. This motion is in part due to the trochlear shape of the talar dome being wide anteriorly and narrow posteriorly. Scranton et al [23] demonstrated that the fibula descends approximately 2.4 mm during stance phase of gait. This deepening of the mortise during dorsiflexion of the ankle acts to create a close-pack stable position of the ankle in preparation for the toe-off phase of gait.

Significance of the interosseous membrane

The interosseous membrane between the tibia and fibula has been shown to function as a conduit for stress transmission, creating a load sharing function of the fibula. In a holographic investigation of cadaveric limbs, complete sectioning of the interosseous membrane decreased fibular load transference by 30% [24]. In another study, complete transection of the interosseous membrane decreased fibular strains to near zero [25]. These findings suggest that the tibia will bear most of the weightbearing stress in the presence of interosseous membrane disruption.

Historic rationale for fibular fixation in distal tibial fractures

Ruedi and Allgower [1], in 1969, described the principles and classic technique for open reduction with internal fixation of the distal tibial intra-articular fracture:

- re-establish fibular length;
- reconstruct the articular surface of the distal tibia;
- utilise autogenous cancellous bone to fill the tibial metaphyseal defect;
- stabilise the tibia with a medial plate.

These principles have continued to be a standard of care as they identified the importance of fibular reconstruction and accurate restoration of the articular surface of the distal tibia as important criteria for good functional outcome in these fractures [1, 4, 5, 26–33]. These clinical precepts corresponded with experimental studies that showed malreduction of fibular fractures at the level of ankle joint lead to abnormally increased focal pressure on the joint surface – a precursor to early degenerative arthritis [34, 35].

The need for fibular fixation is unclear in extra-articular fractures of the distal tibial metaphysis, especially if the concomitant fibular fracture occurs above the level of the distal tibio-fibular syndesmosis. Although some authors recommend stabilising all concomitant ipsilateral fibular fractures, most agree that fixation should be performed if the fracture involves the distal tibiofibular syndesmosis or ankle mortise [2, 3, 9, 36–38]. This practice reflects results from studies demonstrating that the stability of the syndesmosis has a direct correlation with good clinical outcomes in ankle fractures [39]. Other authors have reported that adjunctive fibular fixation aids to reduce distal tibial fractures [12, 40].

In general, adjunctive fibular fixation seems to lessen the risk of distal tibial malalignment, but only a few clinical reports have specifically evaluated this clinical impression. In a retrospective study, Egol et al. [13] evaluated the role of fibular fixation in maintaining alignment of distal tibial fractures stabilised with a statically locked intramedullary nail. Of the 72 cases, there was loss of tibial alignment in 1 of 25 (4%) patients who had the fibula stabilised as compared to 6 of 47 (13%) who did not. Late loss of distal tibial alignment was statistically associated with the lack of adjunctive fibular fixation. This contrasts to a report by Whittle et al. [37] where the absence of fibular fixation did not increase the incidence of malunion in distal tibial fractures stabilised with intramedullary nailing. In their series, fibular stabilisation was performed in 1 of 25 distal fourth tibial fractures.

Williams et al. [10] reported clinical outcomes of tibial plafond fractures with associated fibula fractures stabilised using monolateral external fixators spanning the ankle joint. They found no statistically significant difference in the incidence of late tibial malalignment between those who had the fibula plated and those who did not. Although the group treated with adjunctive fibular fixation were aligned better, there was a higher incidence of wound infections and nonunion at the site of fibula surgery. The investigators concluded that favourable clinical outcomes may be achieved without fibular fixation in such cases.

In Whorton and Henley's [38] retrospective review of 157 open tibial fractures with ipsilateral fibular injuries, there were no statistical differences in final fracture alignment, time to union or number of secondary procedures needed to achieve union between the groups defined by fibula stabilisation (all distal fibular fractures that involved the syndesmosis and ankle mortise were stabilised). They concluded that fibular fixation in the absence of syndesmotomic and mortise-related injuries did not affect outcomes of open tibial fractures.

Several experimental models of mid-shaft tibial and fibula fractures have suggested there is improved mechanical stability of the tibia with adjunctive fibular fixation [41–43]. Kumar et al. [43] studied the effect of fibular plating on rotational stability in experimental distal tibial fractures stabilised with intramedullary locked nails. Using fresh-frozen and embalmed cadaveric legs, 5-mm segmental defects were created at the same level in the tibia and fibula 7 cm proximal to the ankle joint. A 9-mm intramedullary nail, statically locked with two distal and two proximal screws, was used to stabilise the tibia. A biaxial mechanical testing unit was then used to apply torque to the tibia. Specimens with plate fixation of the fibula demonstrated significantly less displacement when compared to the specimens without fibular plating in both fresh-frozen and embalmed specimens; however, there was no difference in rotational stiffness as the torque was increased.

The role of fibular fixation was also studied by Weber et al. [42]. An external fixator or locked unreamed intramedullary nail was used to stabilise a 2-cm segmental defect of tibial midshaft. Fixation of an oblique fibula fracture was accomplished with either plate and screws or an Enders intramedullary nail. Motion at the tibial defect was measured in compression and bending loads. The study demonstrated that additional stability of tibia conferred by fibular fixation depended on the method of both tibial and fibular fixation. The investigators concluded that the maximal reduction of tibial motion resulted from fibular plating coupled to tibial external fixation. Little benefit was accomplished by fibular plating or Enders nailing if the tibia was stabilised by a locked intramedullary nail.

In a cadaveric study by Morrison et al. [41], a 2-cm mid-diaphyseal tibial defect with a 1-cm fibula defect at the same level was stabilised with a Vidal-Hoffman external fixator. The fibula was fixed with a standard 6-hole AO tubular plate in some specimens and the various constructs placed under axial and torsional loads. The study demonstrated that plated specimens had a 2.2 times increase in stiffness to axial loads but did not add resistance to torsion. The study proposed that fibular plating can add sufficient rigidity to tibial fractures for early weightbearing and concomitantly decrease the stress in the external fixation device and prevent loosening of half-pins.

Disadvantages of adjunctive fibular fixation in distal tibial fractures

Increased soft tissue envelope morbidity

Prior studies have suggested fibular fixation may influence outcomes of distal tibial fractures favourably but significant complications have also been reported with this adjunctive stabilisation. High-energy fractures of the distal tibia are associated with a high incidence of soft tissue trauma compromising the soft tissue envelope; traditional methods of open reduction and internal fixation of the distal tibia are reported to be associated with a high incidence of wound infections and necrosis (Fig. 3a) [1, 29, 44, 45]. This high incidence of complications around wound compromise suggests a more limited open approach should be utilised to manage these injuries [33, 46, 47]. Correspondingly,



Fig. 3 Wound complication of soft tissue necrosis and exposed internal fixation is seen at the site of surgical exposure of a distal tibial metaphyseal fracture (a). A distal tibial fracture with fibular wound complication is seen at the site of adjunctive fibular fixation (b). The condition often requires a second procedure for debridement and removal of exposed internal fixation. Infection of the underlying bone is a concern

ingly, open reduction internal fixation of the fibula has also shown an increased rate of wound complications (Fig. 3b) [10, 48]. Williams et al. [10] demonstrated a 23% incidence of wound infection at the fibular fixation site. In addition, the incidence of fibular nonunions was 9% with fibular fixation (possibly from further devascularisation on open surgical approach) in contrast to zero without fibular fixation. Marsh et al. [48,49] demonstrated that the only wound complications encountered in distal tibial fractures stabilised with monolateral articulated external fixator were at sites of fibular fixation. Advocates of routine fixation of all concomitant fibular fractures to reduce the risk of distal tibial malalignment disregard a crucial point of avoiding additional soft tissue injury [9, 10, 48].

Dynamisation of the distal tibia

Dynamisation of long bone fractures has been shown to accelerate periosteal callus formation and increase mechanical stiffness during early stages of bone healing [50, 51]. In addition, a more uniform callus formation is seen as a result of this controlled reduction of the fracture gap. Although the clinical benefit of dynamisation in fresh tibial fractures is debated, the technique is generally accepted as an essential method of stimulating fracture healing in delayed and nonunions [52–56]. Delayed and nonunion rates of the distal tibial fractures are reported at 13%–19% with intramedullary nailing with and without fibular fixation [11–13]. Mosheiff et al. [3] reported 42% of distal tibial fractures stabilised with intramedullary nailing required dynamisation after 6 weeks to accelerate bone healing; other studies have reported 11%–13% of distal tibial fractures needing the same [11, 12].

Effects of an intact fibula

There are no studies that elucidate the effect of fibular fixation on union rates of tibial fractures. However, several clinical reports have demonstrated that fracture stability of the distal tibia with an intact or stabilised fibula does not ensure successful healing. Teitz et al. [17] examined the effects of an intact fibula associated with a tibial fracture. They found that distal tibial fractures in patients aged 20 years or older with an intact fibula had a 61% complication rate including 22% delayed union, 4% nonunion and 26% varus malunion. Other reports of delayed tibial fracture healing with an intact or healed fibula have suggested that an intact fibula may prevent cyclic compression of the fractured tibia necessary for physiologic bone healing. DeLee et al. [57] reported results of partial fibulectomy in 48 patients with ununited tibial fractures of at least 5

months; a 2.5-cm resection of the fibula at the level of the tibial fracture was performed allowing dynamisation of the tibia within a patellar tendon brace. Seventy-seven percent achieved union after an average of 25 weeks. Their findings were consistent with other reports of delayed unions of tibial fractures successfully treated with fibulectomy [58] or fibular osteotomy [59].

Treatment

Intramedullary nailing

The intramedullary nailing technique for diaphyseal fractures of the tibia gained popularity for its minimally invasive approach, preservation of the extra-osseous blood supply and ability to restore axial alignment. However, as indications expanded to the distal tibial metaphysis, an increase of malalignment was seen [2, 3, 7, 60–62]. Several factors are attributed:

- comminuted fractures proximal or distal to the isthmus provide little guidance for distal tibial alignment [60];
- eccentric nail orientation in the medullary canal from an inappropriate entrance angle may result in difficulty centring the nail in the distal fragment;
- the use of a single distal locking screw.

Anatomic factors have also been attributed to malalignment problems. A widening of the tibia from the diaphysis to the metaphyseal segment distally decreases cortical contact and overall stability of the intramedullary nail (Fig. 4). Due to this mismatch in core diameter in the distal tibial metaphysis, the intramedullary nail cannot be used as an aid in fracture reduction as can be done in the diaphysis [12].

Distal locking screws have less cortical purchase in metaphyseal bone; as control of the intramedullary nail position in the distal tibial canal depends on these screws, there is increased stress at the screws to maintain fracture alignment. Consequently late complications, in particular loss of reduction, are attributed to implant failure at the distal locking sites of the intramedullary nail. This has been illustrated by a study showing a higher incidence of distal screw failure in unreamed intramedullary nails when used for distal metaphyseal tibial fractures [63]. Stresses are also increased in the presence of comminution or bone defects [37].

Dynamisation of tibial fractures stabilised with intramedullary nails is often needed to provide a mechanical stimulus for osteosynthesis in delayed unions [3, 7, 12, 60]. However, shortening of the tibia has been reported as a complication after conversion from static to dynamic locking [60]. Dogra et al. [11] reported shortening in 20% of the distal tibial fractures stabilised with static intramedullary nailing; this has also been documented by others [64–66]. In a series of distal metaphyseal fractures



Fig. 4 A spiral fracture of the distal fibular and distal tibial metaphysis (extra-articular) is shown to be medially displaced and shortened in both anterior–posterior (a) and lateral (b) views. Initial post-operative views (c and d) demonstrate fixation of the tibial fracture with an intramedullary nail with $>10^\circ$ valgus malalignment

treated with an unreamed nail, 40% of fractures without comminution required dynamisation of the intramedullary nail; of the comminuted types, 43% required second surgery, 64% healed with dynamisation and 36% required bone grafting [3].

External fixation

External fixation is widely used for high-energy tibial pilon fractures due to the ability to span across compromised soft tissues [49, 67–70]. These techniques have decreased complications by allowing a less invasive approach to fixation of the distal tibia. Tornetta et al. [71] reported the use of a femoral distractor spanning the ankle joint in a pilon fracture, demonstrating that an external fixator could restore tibial length without fixation of the fibula. Fibular fixation has not influenced the loss of reduction in extra-articular distal tibial fractures when stabilised with a spanning external fixator, suggesting the added surgery may not provide a signifi-

cant benefit over the risk of wound complications [10, 67]. Therefore, adequate stability may be accomplished by the external fixator alone such that those distal tibial fractures with fibular fractures above the level of the syndesmosis should not require adjunctive fixation (Fig. 5). Additionally spanning and articulated external fixators can restore fibular length, alignment and stability by ligamentotaxis and by virtue of half-pins inserted into the neck of the talus and calcaneum [48].

Designs of monolateral external fixators have been shown to provide different degrees of mechanical stability [72–76]. These properties are important in achieving sufficient control for early weightbearing and preventing late malalignment. In the study by Jaskulka et al. the Orthofix monolateral fixator retained the highest mechanical stability after dynamisation as compared with the Marin Monodynamix and AO tubular fixators (in a single-plane, double-



Fig. 5 A displaced and angulated spiral distal tibial metaphyseal (extra-articular) fracture with concomitant fibular fracture is shown in anterior posterior (a) and lateral (b) views. An Orthofix monolateral external fixator was applied restoring both distal tibial and fibular length and alignment (c and d). The fibular fracture did not involve the syndesmosis; therefore, adjunctive fixation was not needed. The distal tibial and fibular fracture at 2 months with osseous bridging, ready for dynamization (e and f)



Fig. 6 A comminuted, angulated and shortened distal tibial metaphyseal fracture with concomitant open fracture of the fibula shown in anterior posterior (a) and lateral (b) views. An Orthofix monolateral external fixator was applied restoring both distal tibial and fibular length and alignment (c and d). The fracture was dynamised at 2 months and union was achieved at approximately 4 months (e and f) when the external fixator was removed and the limb supported by a weightbearing cast

tube, unilateral configuration) [77]. Furthermore, the ability to reduce fracture gaps by adjusting the telescopic body (Fig. 6) in comminuted distal tibial fractures may be complemented by fracture callotaxis techniques, thereby restoring length and decreasing the need for bone grafting. Releasing a different axial constraint of the telescopic body also allows for controlled axial dynamisation, without loss of significant length – a property useful for distal tibial fractures demonstrating delayed healing.

Pin tract infections are the most common complication of external fixation, reported at between 0.9% and 60% [55, 78–81]. The large variation is likely due to the retrospective nature of the studies and a lack of a definition of infection or protocol for treatment. In addition there is little conformity of pin placement techniques, including atraumatic techniques to minimise soft tissue damage of pin insertion, abiding by the safe zones of pin placement or overall management of pin tract care – all of which are associated with pin tract complications [80]. De Bastiani et al. [55] reported the placement of 1525 half pins, of which only 14 pin tract infections (0.9%) were noted, but ‘infection’ was defined as persistent drainage and inflammation despite antibiotic therapy, followed by pin loosening.

Conclusions

The case for fibular fixation in extra-articular distal tibial fractures, when the fracture does not involve the syndesmosis or ankle mortise, has not been established. The additional trauma of internal fixation may induce greater morbidity. With such tibial fractures, stabilisation with intramedullary nailing or with an external fixator is sufficiently stable and carries little risk of soft tissue morbidity or late stage malalignment. Additionally, the use of a dynamic axial fixator would provide advantages of controlled dynamisation and closure of fracture gaps.

References

- Ruedi TP, Allgower M (1969) Fractures of the lower end of the tibia into the ankle-joint. *Injury* 5:130
- Robinson CM, McLauchlan GJ, McLean IP, Court-Brown CM (1995) Distal metaphyseal fractures of the tibia with minimal involvement of the ankle. Classification and treatment by locked intramedullary nailing. *J Bone Joint Surg Br* 77:781–787
- Mosheiff R, Safran O, Segal D, Liebergall M (1999) The unreamed tibial nail in the treatment of distal metaphyseal fractures. *Injury* 30:83–90
- Bourne RB, Rorabeck CH, Macnab J (1983) Intra-articular fractures of the distal tibia: the pilon fracture. *J Trauma* 23:591–596
- Ovadia DN, Beals RK (1986) Fractures of the tibial plafond. *J Bone Joint Surg Am* 68:543–551
- Marsh JL, Saltzman CL (2001) Ankle fractures. In: Bucholz RW, Heckman JD (eds) *Rockwood and Green's fractures in adults*. Lippincott Williams & Wilkins, Philadelphia, pp 2001–2090
- Tyllianakis M, Megas P, Giannikas D, Lambiris E (2000) Interlocking intramedullary nailing in distal tibial fractures. *Orthopedics* 23:805–808
- Wu CC, Shih CH (1993) Complicated open fractures of the distal tibia treated by secondary interlocking nailing. *J Trauma* 34:792–796
- Fan CY, Chiang CC, Chuang TY, et al (2005) Interlocking nails for displaced metaphyseal fractures of the distal tibia. *Injury* 36:669–674
- Williams TM, Marsh JL, Nepola JV et al (1998) External fixation of tibial plafond fractures: is routine plating of the fibula necessary? *J Orthop Trauma* 12:16–20
- Dogra AS, Ruiz AL, Thompson NS, Nolan PC (2000) Diaphyseal distal tibial fractures – treatment with a shortened intramedullary nail: a review of 15 cases. *Injury* 31:799–804
- Nork SE, Schwartz AK, Agel J et al (2005) Intramedullary nailing of distal metaphyseal tibial fractures. *J Bone Joint Surg Am* 87:1213–1221
- Egol KA, Weisz R, Hiebert R et al (2006) Does fibular plating improve alignment after intramedullary nailing of distal metaphyseal tibia fractures? *J Orthop Trauma* 20:94–103
- Tornetta P 3rd, Bergman M, Watnik N et al (1994) Treatment of grade-IIIb open tibial fractures. A prospective randomised comparison of external fixation and non-reamed locked nailing. *J Bone Joint Surg Br* 76:13–19
- Henley MB, Chapman JR, Agel J et al (1998) Treatment of type II, IIIA, and IIIB open fractures of the tibial shaft: a prospective comparison of unreamed interlocking intramedullary nails and half-pin external fixators. *J Orthop Trauma* 12:1–7
- Alberts KA, Loochagen G, Einarsdottir H (1999) Open tibial fractures: faster union after unreamed nailing than external fixation. *Injury* 30:519–523
- Teitz CC, Carter DR, Frankel VH (1980) Problems associated with tibial fractures with intact fibulae. *J Bone Joint Surg Am* 62:770–776
- Barei DP, Nork SE, Bellabarba C, Sangeorzan BJ (2006) Is the absence of an ipsilateral fibular fracture predictive of increased radiographic tibial pilon fracture severity? *J Orthop Trauma* 20:6–10
- Lambert KL (1971) The weight-bearing function of the fibula. A strain gauge study. *J Bone Joint Surg Am* 53:507–513
- Takebe K, Nakagawa A, Minami H et al (1984) Role of the fibula in weight-bearing. *Clin Orthop Relat Res* 184:289–292
- Goh JC, Mech AM, Lee EH et al (1992) Biomechanical study on the load-bearing characteristics of the fibula and the effects of fibular resection. *Clin Orthop Relat Res* 279:223–228
- Close JR (1956) Some applications of the functional anatomy of the ankle joint. *J Bone Joint Surg Am* 38:761–781
- Scranton PE Jr, McMaster JG, Kelly E (1976) Dynamic fibular function: a new concept. *Clin Orthop Relat Res* 118:76–81
- Vukicevic S, Stern-Padovan R, Vukicevic D, Keros P (1980) Holographic investigations of the human tibiofibular interosseous membrane. *Clin Orthop Relat Res* 151:210–214
- Skraba JS, Greenwald AS (1984) The role of the interosseous membrane on tibiofibular weightbearing. *Foot Ankle* 4:301–304
- Ruedi T (1973) Fractures of the lower end of the tibia into the ankle joint: results 9 years after open reduction and internal fixation. *Injury* 5:130–134
- Kellam JF, Waddell JP (1979) Fractures of the distal tibial metaphysis with intra-articular extension – the distal tibial explosion fracture. *J Trauma* 19:593–601
- Pierce RO Jr, Heinrich JH (1979) Comminuted intra-articular fractures of the distal tibia. *J Trauma* 19:828–832
- Ruedi TP, Allgower M (1979) The operative treatment of intra-articular fractures of the lower end of the tibia. *Clin Orthop Relat Res* 138:105–110
- Steadman JR (1981) Rehabilitation of tibial plafond fractures after stable internal fixation. *Am J Sports Med* 9:71–72
- Ayeni JP (1988) Pilon fractures of the tibia: a study based on 19 cases. *Injury* 19:109–114
- Mast JW, Spiegel PG, Pappas JN (1988) Fractures of the tibial pilon. *Clin Orthop Relat Res* 230:68–82
- Teeny SM, Wiss DA (1993) Open reduction and internal fixation of tibial plafond fractures. Variables contributing to poor results and complications. *Clin Orthop Relat Res* 292:108–117
- Ramsey PL, Hamilton W (1976) Changes in tibiotalar area of contact caused by lateral talar shift. *J Bone Joint Surg Am* 58:356–357
- Thordarson DB, Motamed S, Hedman T et al (1997) The effect

- of fibular malreduction on contact pressures in an ankle fracture malunion model. *J Bone Joint Surg Am* 79:1809–1815
36. Im GI, Tae SK (2005) Distal metaphyseal fractures of tibia: a prospective randomized trial of closed reduction and intramedullary nail versus open reduction and plate and screws fixation. *J Trauma* 59:1219–1223; discussion 1223
 37. Whittle AP, Wester W, Russell TA (1995) Fatigue failure in small diameter tibial nails. *Clin Orthop Relat Res* 315:119–128
 38. Whorton AM, Henley MB (1998) The role of fixation of the fibula in open fractures of the tibial shaft with fractures of the ipsilateral fibula: indications and outcomes. *Orthopedics* 21:1101–1105
 39. Leeds HC, Ehrlich MG (1984) Instability of the distal tibiofibular syndesmosis after bimalleolar and trimalleolar ankle fractures. *J Bone Joint Surg Am* 66:490–503
 40. Obremsky WT, Medina M (2004) Comparison of intramedullary nailing of distal third tibial shaft fractures: before and after traumatologists. *Orthopedics* 27:1180–1184
 41. Morrison KM, Ebraheim NA, Southworth SR et al (1991) Plating of the fibula. Its potential value as an adjunct to external fixation of the tibia. *Clin Orthop Relat Res* 266:209–213
 42. Weber TG, Harrington RM, Henley MB, Tencer AF (1997) The role of fibular fixation in combined fractures of the tibia and fibula: a biomechanical investigation. *J Orthop Trauma* 11:206–211
 43. Kumar A, Charlebois SJ, Cain EL et al (2003) Effect of fibular plate fixation on rotational stability of simulated distal tibial fractures treated with intramedullary nailing. *J Bone Joint Surg Am* 85:604–608
 44. Bastian L, Blauth M, Thermann H, Tscherne H (1995) [Various therapy concepts in severe fractures of the tibial pilon (type C injuries). A comparative study]. *Unfallchirurg* 98:551–558
 45. McFerran MA, Smith SW, Boulas HJ, Schwartz HS (1992) Complications encountered in the treatment of pilon fractures. *J Orthop Trauma* 6:195–200
 46. Dillin L, Slabaugh P (1986) Delayed wound healing, infection, and nonunion following open reduction and internal fixation of tibial plafond fractures. *J Trauma* 26:1116–1119
 47. Wyrsh B, McFerran MA, McAndrew M et al (1996) Operative treatment of fractures of the tibial plafond. A randomized, prospective study. *J Bone Joint Surg Am* 78:1646–1657
 48. Marsh JL (2000) Distal tibial and plafond fractures. In: De Bastiani G, Apley AG, Golberg A (eds) *Orthofix external fixation in trauma and orthopaedics*. Springer, London, pp 286–298
 49. Marsh JL, Bonar S, Nepola JV et al (1995) Use of an articulated external fixator for fractures of the tibial plafond. *J Bone Joint Surg Am* 77:1498–1509
 50. Egger EL, Gottsauner-Wolf F, Palmer J et al (1993) Effects of axial dynamization on bone healing. *J Trauma* 34:185–192
 51. Larsson S, Kim W, Caja VL et al (2001) Effect of early axial dynamization on tibial bone healing: a study in dogs. *Clin Orthop Relat Res* 388:240–251
 52. Wiss DA, Stetson WB (1995) Unstable fractures of the tibia treated with a reamed intramedullary interlocking nail. *Clin Orthop Relat Res* 315:56–63
 53. Marsh JL, Nepola JV, Meffert R (1992) Dynamic external fixation for stabilization of nonunions. *Clin Orthop Relat Res* 278:200–206
 54. Moed BR, Watson JT, Goldschmidt P, van Holsbeeck M (1995) Ultrasound for the early diagnosis of fracture healing after interlocking nailing of the tibia without reaming. *Clin Orthop Relat Res* 310:137–144
 55. De Bastiani G, Aldegheri R, Renzi Brivio L (1984) The treatment of fractures with a dynamic axial fixator. *J Bone Joint Surg Br* 66:538–545
 56. De Bastiani G, Aldegheri R, Renzi Brivio L (1986) Dynamic axial fixation. A rational alternative for the external fixation of fractures. *Int Orthop* 10:95–99
 57. DeLee JC, Heckman JD, Lewis AG (1981) Partial fibulectomy for ununited fractures of the tibia. *J Bone Joint Surg Am* 63:1390–1395
 58. Fernandez-Palazzi F (1969) Fibular resection in delayed union of tibial fractures. *Acta Orthop Scand* 40:105–118
 59. Rankin EA, Metz CW Jr (1970) Management of delayed union in early weight-bearing treatment of the fractured tibia. *J Trauma* 10:751–759
 60. Koval KJ, Clapper MF, Brumback RJ et al (1991) Complications of reamed intramedullary nailing of the tibia. *J Orthop Trauma* 5:184–189
 61. Cole JD, Ansel LJ, Schwartzberg R (1995) A sequential protocol for management of severe open tibial fractures. *Clin Orthop Relat Res* 315:84–103
 62. Freedman EL, Johnson EE (1995) Radiographic analysis of tibial fracture malalignment following intramedullary nailing. *Clin Orthop Relat Res* 315:25–33
 63. Hutson JJ, Zych GA, Cole JD et al (1995) Mechanical failures of intramedullary tibial nails applied without reaming. *Clin Orthop Relat Res* 315:129–137
 64. Hamza KN, Dunkerley GE, Murray CM (1971) Fractures of the tibia. A report on fifty patients treated by intramedullary nailing. *J Bone Joint Surg Br* 53:696–700
 65. Sedlin ED, Zitner DT (1985) The Lottes nail in the closed treatment of tibia fractures. *Clin Orthop Relat Res* 192:185–192
 66. Bone LB, Johnson KD (1986) Treatment of tibial fractures by reaming and intramedullary nailing. *J Bone Joint Surg Am* 68:877–887
 67. Bonar SK, Marsh JL (1993) Unilateral external fixation for severe pilon fractures. *Foot Ankle* 14:57–64
 68. Bone L, Stegemann P, McNamara K, Seibel R (1993) External fixation of severely comminuted and open tibial pilon fractures. *Clin Orthop Relat Res* 292:101–107
 69. Sirkin M, Sanders R, DiPasquale T, Herscovici D Jr (1999) A staged protocol for soft tissue management in the treatment of complex pilon fractures. *J Orthop Trauma* 13:78–84
 70. Patterson MJ, Cole JD (1999) Two-staged delayed open reduction and internal fixation of severe pilon fractures. *J Orthop Trauma* 13:85–91
 71. Tornetta P 3rd, Weiner L, Bergman M et al (1993) Pilon fractures: treatment with combined internal and external fixation. *J Orthop Trauma* 7:489–496
 72. Chao EY, Hein TJ (1988) Mechanical performance of the standard Orthofix external fixator. *Orthopedics* 11:1057–1069
 73. Moroz TK, Finlay JB, Rorabeck CH, Bourne RB (1988) External skeletal fixation: choosing a system based on biomechanical stability. *J Orthop Trauma* 2:284–296
 74. Paley D, Fleming B, Catagni M et al (1990) Mechanical eval-

- uation of external fixators used in limb lengthening. *Clin Orthop Relat Res* 250:50–57
75. Price CT, Mann JW (1991) Experience with the Orthofix device for limb lengthening. *Orthop Clin North Am* 22:651–661
 76. Meffert RH, Tis JE, Lounici S et al (1999) Comparison of two systems for tibial external fixation in rabbits. *Lab Anim Sci* 49:650–654
 77. Jaskulka RA, Egkher E, Wielke B (1994) Comparison of the mechanical performance of three types of unilateral, dynamizable external fixators. An experimental study. *Arch Orthop Trauma Surg* 113:271–275
 78. Edge AJ, Denham RA (1981) External fixation for complicated tibial fractures. *J Bone Joint Surg Br* 63:92–97
 79. Benum P, Svenningsen S (1982) Tibial fractures treated with Hoffmann's external fixation: a comparative analysis of Hoffmann bilateral frames and the Vidal-Adrey double frame modification. *Acta Orthop Scand* 53:471–476
 80. Melendez EM, Colon C (1989) Treatment of open tibial fractures with the Orthofix fixator. *Clin Orthop Relat Res* 241:224–230
 81. Noordeen MH, Lavy CB, Shergill NS et al (1995) Cyclical micromovement and fracture healing. *J Bone Joint Surg Br* 77:645–648