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TRAUMA SURGERY

Treatment of type IIIA open fractures of tibial shaft with Ilizarov external fixator versus unreamed tibial nailing

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Abstract
Introduction The aim of this study was to compare the radiographic results and clinical outcome of unreamed tibial nailing (UTN) and Ilizarov external fixation (IEF) for the treatment of type IIIA open fractures of the tibia.
Materials and Methods Sixty-one patients with open type IIIA tibial shaft fractures were treated with an IEF ($n = 32$) or UTN ($n = 29$). Both groups were compared for union time, secondary outcomes of nonunion, infections, mechanical failure of the implant, and malunion.
Results The average time-to-bone healing was 19 weeks (range 14–23 weeks) for IEF and 21 weeks (range 16–36 weeks) for UTN; it was significantly shorter in the IEF group ($P = 0.039$). One patient had refracture in the IEF group. Malunion occurred in four patients for each group. Posttraumatic osteomyelitis occurred in two patients in the IEF group and in three patients in the UTN group. In the IEF group, additional surgical procedures were indicated in three cases including sequestrectomy ($n = 1$), and pin replacement ($n = 2$). In the UTN group, seven patients needed additional surgery including bone grafting ($n = 3$), nail exchanged ($n = 1$), and posttraumatic osteomyelitis ($n = 3$).
Conclusion The results of the current study showed that IEF technique had a notable incidence of pin-tract infection, joint contracture, and shortening related to treatment of the delayed union. The UTN technique had the disadvantage of a posttraumatic osteomyelitis and delayed union requiring additional surgery. We believe that the decision to use IEF or UTN should be made on a case-by-case basis.

Keywords Tibia · Open fractures · External fixator · Intramedullary nailing

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Introduction

The optimal treatment of severe open fractures of the tibia remains controversial although external fixators and unreamed tibial nailing (UTN) have been used as treatments of choice for these fractures [1–14]. However, studies to date have been limited by retrospective study designs, heterogeneity of groups compared, and the mechanical disadvantages of using an external fixator. The current study was planned prospective and included only patients with type IIIA open tibial fractures to obtain homogeneity between groups. To avoid mechanical insufficiency of the external fixator, Ilizarov external fixation (IEF) was used, which is reported to be more stable than the monolateral fixator system [15]. The purpose of this study was to prospectively compare the clinical and radiological results of two common fixation methods (UTN vs. IEF) in patients with Type IIIA open fractures of the tibial shaft.

Materials and methods

Seventy-one patients with Type IIIA open tibial shaft fractures were treated in the authors' institution from March 1997 to May 2000. This study was planned prospectively and data reviewed retrospectively. Two patients died within 5 days after injury due to associated injuries; eight patients were lost to follow up less than 2 years after surgery. The remaining 61 patients who had a Type IIIA open fracture of the tibial shaft, presented to the hospital within 24 h of injury included this study. Of 61 patients, 32 (52.5%) were treated with IEF and 29 (47.5%) with UTN. These patients were randomized based on even/odd patient numbers. Odd-numbered patients received IEF; even-numbered patients received UTN. Patient characteristics (mean age, gender, mechanism of injuries, and associated injuries) are listed in Table 1. Exclusions included any fractures associated with an arterial injury (whether it was repaired or not), bilateral fractures, those within 5 cm of the ankle or proximal to the tibial tubercle, and intraarticular extensions. Also, patients were excluded if the type of the open fracture changed after debridement.

Soft tissue injuries were graded according to the criteria of Gustilo et al. [16]. In type IIIA, soft-tissue coverage of the fractured bone is adequate, despite extensive laceration, flaps, or high-energy trauma. All fractures were classified according to the Orthopedic Trauma Association (OTA) classification of tibial fracture configurations [17], We followed a standard treatment protocol for both groups; all wounds were irrigated with normal saline solution, and then all devitalized tissues were debrided. Antibiotic treatment was started in the emergency room with 2 g of Cefazolin, continued for 3 days at a dose of 1 g every 8 h, then discontinued and reinstated for 48 h after each additional operation.

Table 1 Demographics data of patients

	IEF ($n = 32$)	UTN ($n = 29$)
Male:female	28;4	24;5
Mean age (years; range)	32,3 (15–64)	31,7 (17–54
Mechanism		
Motor-vehicle vs. pedestrian	19	17
Motorcycle accident	4	5
Gunshot	4	3
Fall from high	5	4
Type of fracture		
Unstable	16	19
Stable	16	10
Fracture location		
1/3 Proximal	8	5
1/3 middle	19	14
1/3 distal	5	10
Associated injury		
Orthopedic injury	9	8
Head injury	2	1
Abdominal injury	1	2
Chest injury	3	1

Four surgeons were involved in the study. Two surgeons inserted only unreamed nails, and two other surgeons applied only external fixators. In the UTN group, Russell-Taylor nails (Smith Nephew Richards, Memphis, Tennessee, USA.) were used in 14 cases, Synthesnails in 3 cases, and Orthofixnails (Orthofix, Busselengo, Italy) in 12 cases. Intramedullary nails were placed through a portal medial to the patellar tendon with the leg draped free and without using a guide wire. Traction was applied to the extremity, and fluoroscopic image intensification was used to ensure that the tibia was restored to its proper length and the fracture was reduced. The UTN size (8 or 9 mm) was determined by measuring the width of the medullary canal under the image intensifier. A hybrid IEF described by Catagni[18] (Tıpsan, Izmir, Turkey), which combined half pins and transosseous wires (TW), was used for stabilization of fractures in the IEF group. A ring of proper size for the leg was selected. Four or five ring configurations were used. The 5/8 (C shape) ring was used in the proximal tibia so as to achieve full range of motion of the knee. The type, number, position, and direction of TW and half pins were selected according to the level and type of fracture.

Postoperative mobilization was largely dictated by the nature and extent of any associated injuries in both group. In patients with an isolated tibial fracture, active and passive ankle and knee movements were started on the first postoperative day. Crutch walking with partial weight bearing was allowed on the third postoperative day; full weight bearing was initiated as soon as patients could tolerate it. In unstable fractures treated with a UTN, however, only partial weight bearing was permitted until the fracture site had healed. The ranges of motion of the knee and ankle were recorded for each patient.

After discharge, we examined the patients clinically and radiographically at monthly intervals until bone union was seen. Union was defined clinically when the patient was fully weight bearing with no pain at the fracture site, and radiographically when callus bridged at least three cortexes. Early bone grafting was performed within the first 12 weeks if the surgeons assessed that union would be delayed based on radiographic findings consisting of insufficient or absence of callus, osteoporosis or gap at the bony end.

The pin sites were cared for daily by the resident and nursing staff until the patients demonstrated competence in their own care. Complications and Pin-tract infection was classified according to Paley as Grade 1, superficial soft tissue inflammation; Grade 2, deep soft tissue infection; Grade 3, osteomyelitis [19].

Minor complications were defined as those not requiring surgery [20]. They included pin-tract infection treated by medication or isolated pin removal, delayed union treated with dynamization or compression used by an external fixator, or locking screw failure. Major complications required the patient to be admitted to the hospital for additional surgery. These included sequestrum formation, nonunion, malunion (>7°), shortening (>1 cm), refractures, joint contractures resistant to physical therapy and the need for pin or TW replacement.

Two independent observers at the last follow-up performed clinical examination and radiographic review

For statistical analysis, Type I Error Rate (alpha); %5, actual power for Required N: %80 was defined by using Statistica (Ver. 6.0) program. According to this analysis**,** the number of patients included in the study was sufficient for comparing two groups. Also, two groups were similar according to age ($P = 0.831$), fracture site ($P = 0.156$), and fracture configuration ($P = 0.221$). Functional and radiographic results were compared between groups with the Kruskal–Wallis test, and union times were compared using the paired t test. $P < 0.05$ was considered statistically significant.

Results

The average interval from the time of the injury to the surgical procedure was 12 h (range 4–22 h) for IEF and 13.5 h (range 3–27 h) for UTN. The mean follow-up time was 46.5 months (range 33–67 months) for IEF and 43.3 months (range 30–61 months) for UTN. The average time to bone healing was 19 weeks (range 14–23 weeks) for IEF and 21 weeks (range 16–36 weeks) for UTN ($P = 0.039$).

Complications listed in Table 2. Delayed union developed in four patients (12.5%)in IEF group. All of these were treated with gradual compression (0.25 mm qid, total 1 mm/day) at the fracture site, continued until bony contact was seen on radiograms (mean 18 days, range 14–22 days). Following bony contact, compression was continued at a rate of 0.25 mm/week until bone union occurred. There were no nonunions in the IEF group. In the UTN group, three patients had delayed union. They were treated with early autogenous iliac bone grafting and all healed with the secondary operation**.** Nonunion occurred in one patient in UTN group and was treated by exchanging the unreamed nail. Bone healing was obtained in 3 months.

One patient had refracture in the IEF group. Union was obtained by using a cast in 7 weeks. No patients in the UTN group had a refracture.

In the IEF group, two malunions (10 and 12° valgus) developed following fixator removal; two malunions (8° valgus and 10° varus) occurred secondary to inadequate reduction. These malreductions could have been corrected immediately after operation by replacing the TWs under general anesthesia. However, the anesthetist disallowed general anesthesia for 3 weeks in these patients because of their associated head injuries. After this period, the deformity was accepted to avoid additional surgical risk.

In the UTN group, there were two malunions (7 and 11° of varus) and two malrotations (one external rotation of 10°, and the other internal rotation of 12°). Varus malunions developed secondary to breakage of distal locking screws. The first malrotation occurred because of a technical error at the beginning of the learning curve; this deformity was not corrected by further operation because 10° of external rotation would not seriously limit function. The second malrotation occurred in a multiply injured patient whose operation had to be completed immediately because of worsening patient condition on the operating table. Additional surgery to correct this malrotation was not allowed for 6 weeks because of a life-threatening head injury. Afterwards, bone healing occurred, and revision was cancelled after discussion with the patient's family.

In the IEF group, fractures healed with shortening more than 1 cm in three patients (1.7, 2.0, and 3.0 cm) treated with gradual compression for delayed union. In the UTN group, there were two patients who had tibial shortening (1.4 and 2.1 cm) secondary to distal screws breakage and one patient had 1.2 cm shortening because of initial reduction.

Posttraumatic osteomyelitis occurred in two patients in the IEF group; it was managed subsequently with wound debridement and sequestrectomy. A successful union was obtained in both patients; however, despite bone healing, active drainage continued in one patient at last control and he did not accept further operation. In the UTN group, posttraumatic osteomyelitis occurred in three patients. In the first patient, the intramedullary nail was removed and the endosteal canal was reamed. Despite bone healing, the tibia was stabilized with an Ilizarov external fixator for 6 weeks to avoid refracture. No active infection was seen 2.4 years after this procedure. A second patient experienced infection at the distal locking screw site, despite fracture healing. The nail and screw were removed, and the infected screw tract was cleaned by curettage and irrigation. There was no persistent infection at follow-up. In the third patient, a sequestrum developed in the fracture site. The UTN was removed, and after sequestrectomy, local antibiotic beads were applied. Suppressive oral antibiotic therapy was continued for 6 weeks; no signs of recurrent infection occurred during 2.7 years of follow-up.

In the IEF group, one patient who had a fracture of the proximal third of the tibia developed a 30° knee flexion

Table 2 Comparison of complications

OTA classification (patient number)	Delayed union	Nonunion	Contracture (patient number)	Posttraumatic osteomyelitis	Pin-tract infection	Varus (°)	Valgus (°)	Rotation (°)	LLD (cm)	Neural injury	Refracture
Ilizarov external fixator group											
IA (3)							8				
IB (9)							10				
IIA (2)	1			1	1				1,7		
IIB (3)			Knee flexion contarcture (1)		2	10					
IIC(2)											
IID (10)	2		Equin deformity (2)	1	1[a]		12		3.0	1	
IIIA(3)	1				1				2.0		1
Total (32)	4		3	2		1	3		3	1	1
Unreamed tibial nailing group											
IA (6)	1										
IB(10)	2										
IC(2)								10			
IIA(1)				1							
IIB(3)											
IID(6)		1		2		7 and 11		12	1.2, 1.4, and 2.1 cm		
IIIA(1)											
Total (29)	3	1	No	3		2		2	3	no	no

LLD limb length discrepancy

[a] Sequestrectomy was performed

contracture. This patient refused an intensive physical therapy program at the hospital and further surgery to prevent joint contracture. Two patients who had tibial fractures of the distal third had 10° equinus contractures of the ankle. One of them also had a peroneal nerve injury secondary to the insertion of the transosseous wire. After fixator removal, these two patients were cured with intensive physical therapy; 5° passive ankle dorsiflexion was achieved 3 months after fixator removal. In the UTN group, no patient had a loss of range of motion of the ankle or knee. However, three patients had activity-related knee pain secondary to irritation from the proximal nail.

In the IEF group, Grade 3 pin-tract infections were observed in 12 pin sites in 5 patients. Of these 12 pins, seven (two patients) were treated by removal of pins; three (two patients) were treated by removal of pins and insertion of new pins under general anesthesia. The surgeon decided whether to remove or to replace infected pins based on whether removal would affect stability of the external fixator. Two sequestrae (one patient) seen secondary to pin tract infection were treated by sequestrectomy. All infections were healed and there was no evidence of infection at last follow up.

One IEF patient sustained a peroneal nerve injury related to the insertion of the TW. The wire was removed immediately, and nerve function recovered in the sixth postoperative month.

Two distal screws broke in the UTN group and no other hardware failure, such as breakage of pins, wires, or nails, occurred in the study.

In the IEF group, additional surgical procedures were indicated in three cases including sequestrectomy ($n = 1$), and pin replacement ($n = 2$). In the UTN group, seven patients needed additional surgery: three patients required bone grafting, one patient had the nail exchanged, and three patients had posttraumatic osteomyelitis.

Discussion

External fixation and intramedullary nailing are well-accepted techniques for the treatment of open tibial fractures. Both techniques offer the advantages of minimum operative trauma and high union rates in the treatment of open tibial fractures. However, there is still no universal acceptance of either external fixation or intramedullary nailing.

Unreamed nailing in patients with open tibial fractures has been reported to result in lower delayed union rate than the Hoffman external fixation [21, 22]. Alberts et al. [21] and Tu et al. [22]. In both studies, the incidence of delayed union was twice as high in the external fixator group. Henley et al. [2] found no significant difference in the healing rates for the two methods; however, their series consisted of Type II, IIIA, and IIIB open tibial fractures and contained no specific data for Type IIIA fractures. We are aware of only one prospective randomized study comparing external fixation versus intramedullary nailing for Type II and III open tibial fractures, which was presented by Santoro et al. [23]. They reported a longer time to union in patients treated with a monolateral fixator, as compared with the UTN. Their healing rate was 76% for external fixation and 97% for UTN. In the current study, we found the bone-healing rate in the IEF group after initial surgery (87.5%) was similar to that in the UTN group (86.2%). Time to union was, however, shorter in IEF group.

Based on literature, reamed intramedullary nailing has been associated with a significantly lower rate of malunion than the external fixator or undreamed nailing [14, 24–26]. Nevertheless, unreamed nailing does not provide adequate stability for severely comminuted fractures. Malunion after UTN have been reported 0–27% [12, 13, 24, 27–29]. In this study, developing malunion in both groups was certainly comparable and associated with a technical error more than inadequate stability of fixation method. In the current study, two malunions in the IEF group and two malrotations in the UTN group occurred secondary to technical errors. Technical errors have not been reported in previous comparative studies. However, it seems that the technique of intramedullary nail insertion has a relatively short learning curve, and leads to fewer complications than does the technique of insertion for external fixators [12]. Also, Tornetta et al. [24] found that technical errors were slightly more common with unreamed nailing than with reamed nailing.

The IEF should be maintained on the fracture until bone bridge develops at least three cortex on the fracture site. If the frame is ended before maturation of callus, a malunion or refracture can occur, which will need future operation [30]. To avoid these complications, fracture site can be stabilized by cast or brace following external fixator removal. In our series, malunion developed in two patients because of early removal of external fixator and we suggest casting or bracing for 6 weeks after fixator removal.

Residual shortening more than 1 cm after treatment of open tibial fracture have been relatively rarely reported [4, 5, 11, 12]. The causing factors for both UTN and IEF methods are inadequate reduction of the fracture at the initial operation, hardware failure, and dynamization [1, 2, 9, 22, 25, 30, 31]. In our study, residual shortening occurred in UTN group secondary to hardware failure in two patients and inadequate initial reduction in one patient. In IEF group, despite an achieved bone healing, a performed gradual compression maneuver for treatment of delayed union led to shortening in three patients. In these patients, lengthening procedures (gradual distraction from the nonunion site or additional corticotomy) were not performed to avoid potential technical problems, more surgical procedures, and not to increase the treatment time.

One of the basic goals in treatment of open tibial fractures is to prevent infection. In the literature, the overall infection rate in open tibial fractures have been reported as 0–21% with external fixation and 0–13% with UTN [2, 9, 22, 25, 29]. Baker et al. [29] compared the infection rate in experimental contaminated tibial fractures stabilized with UTN versus external fixation. As a result of this study, external fixation appeared to offer decreased infection rates as compared with unreamed intramedullary nailing. Nevertheless, some clinical studies have argued that the risk of infection is not increased in patients treated with UTN for open fractures (except Type IIIC). Velazco et al. [32] and Spiegel et al. [33] did not detect any significant difference in the prevalence of infection in Grade III open fractures treated with an external fixator or a Lottes nail. Recently, Henley et al. [2] compared the two methods prospectively and found no significant differences in the infection rate between external fixation and UTN. Our results regarding infection rate at the fracture site were similar to those of these three studies. However, if we include pin related infections rate as a complication of IEF, then UTN techniques have the advantage of a lower infection rate. Since pin-tract infection resulted a deep soft tissue infection in 12 pin sites (five patients) and required additional surgery.

Hardware failure remains the most reported complication with unreamed nails, with an incidence of up to 3–16% [30, 31, 34]. No broken nails occurred in our study group; however, two patients who had fractures of the distal third of the tibia experienced broken distal interlocking screws. Malunion and shortening developed after screw breakage. Pin and wire failure may be seen in some patients treated with IEF. However, this complication usually occurs during bone lengthening or transport, which transmit more stress to the pins or the wires. No broken pins or wires were observed in our series.

The advantages of both UTN and IEF include an early range of motion after surgical intervention; however, in the IEF technique, the wires and pins passing through muscles may lead to limitation of motion and joint contracture [5, 10, 19]. Our series included one knee flexion contracture and two ankle equinus contractures in the patients treated with IEF group. These patients refused ambulation with weight bearing and did not continue the physical therapy program regularly.

Bhandari et al. [24] reported that the use of locked intramedullary nailing results in lower reoperation rates than external fixation, particularly with respect to open fractures of grades I to IIIA. The results of the present study were not parallel with this study, because more additional operations were performed in UTN group. The limitations of our study include the use of different types of intramedullary nails. Unfortunately, the selection of intramedullary nail types to be used was done by our hospital as part of its policy regarding implants, and not by the authors. All nails used in this study were solid tibial nails; they differed only in their distal screw orientations. Greitbauer et al. [34] compared different types of solid tibial nails for treatment of closed and open tibial fractures and reported that all solid tibial nails gave successful results.

The results of current study showed that IEF technique had a notable incidence of pin-tract infection, joint contracture, and shortening related to treatment of the delayed union. The UTN technique had a disadvantage of a post-traumatic osteomyelitis and delayed union requiring additional surgery. We believe that the decision to use IEF or UTN should be made on a case-by-case basis. Additional prospective clinical studies are necessary to further explain risks and benefits of these treatment modalities.

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References

1. Atesalp AS, Yildiz C, Basbozkurt M, Gur E (2002) Treatment of type IIIa open fractures with Ilizarov fixation and delayed primary closure in high-velocity gunshot wounds. Mil Med 167:56–62
2. Henley MB, Chapman JR, Agel J, Harvey EJ, Whorton AM, Swiontkowski MF (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
3. Watson JT (1994) Treatment of unstable fractures of the shaft of the tibia. J Bone Joint Surg Am 76:1575–1584
4. Hosny G, Fadel M (2003) Ilizarov external fixator for open fractures of the tibial shaft. Int Orthop 27:303–306
5. Inan M, Tuncel M, Karaoglu S, Halici M (2002) Treatment of type II and III open tibial fractures with Ilizarov external fixation. Acta Orthop Traumatol Turc 36:390–396
6. Behrens F, Searls K (1986) External fixation of the tibia. Basic concepts and prospective evaluation J Bone Joint Surg Br 68:246–254
7. Caudle RJ, Stern PJ (1987) Severe open fractures of the tibia. J Bone Joint Surg Am 69:801–807
8. Edwards CC, Simmons SC, Browner BD, Weigel MC (1988) Severe open tibial fractures. Results treating 202 injuries with external fixation Clin Orthop 230:98–115
9. Marsh JL, Nepola JV, Wuest TK, Osteen D, Cox K, Oppenheim W (1991) Unilateral external fixation until healing with the dynamic axial fixator for severe open tibial fractures. J Orthop Trauma 5:341–348
10. Shtarker H, David R, Stolero J, Grimberg B, Soudry M (1997)Treatment of open tibial fractures with primary suture and Ilizarov fixation. Clin Orthop 335:268–274
11. Sanders R, Jersinovich I, Anglen J, DiPasquale T, Herscovici D Jr (1994) The treatment of open tibial shaft fractures using an interlocked intramedullary nail without reaming. J Orthop Trauma 8:504–510
12. Templeman DC, Gulli B, Tsukayama DT, Gustilo RB (1998) Update on the management of open fractures of the tibial shaft. Clin Orthop 350:18–25
13. Stegemann P, Lorio M, Soriano R, Bone L (1995) Management protocol for unreamed interlocking tibial nails for open tibial fractures. J Orthop Trauma 9:117–120
14. Finkemeier CG, Schmidt AH, Kyle RF, Templeman DC (2000) Varecka TF A prospective, randomized study of intramedullary nails inserted with and without reaming for the treatment of open and closed fractures of the tibial shaft. J Orthop Trauma 14:187–193
15. Podolsky A, Chao EY (1993) Mechanical performance of Ilizarov circular external fixators in comparison with other external fixators. Clin Orthop 293:61–70
16. Gustilo RB, Mendoza RM, Williams DN (1984) Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 24:742–746
17. Abramowitz A, Wetzler MJ, Levy AS, Whitelaw GP (1993) Treatment of open tibial fractures with Ender rods. Clin Orthop 293:246–255
18. Catagni MA MV, Kirienko A (1994) Fractures of the tibia-fibula. In: Maiocchi A (ed) Advanced in Ilizarov apparatus assembly. Il Quadratino, Milan, pp 48–58
19. Paley D (1990) Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. Clin Orthop 250:81–104
20. Paley D, Catagni MA, Argnani F, Villa A, Benedetti GB, Cattaneo R Ilizarov (1989) Treatment of tibial nonunions with bone loss. Clin Orthop 241:146–165
21. Alberts KA, Loohagen G, Einarsdottir H (1999) Open tibial fractures: faster union after unreamed nailing than external fixation. Injury 30:519–523
22. Tu YK, Lin CH, Su JI, Hsu DT, Chen RJ (1995) Unreamed interlocking nail versus external fixator for open type III tibia fractures. J Trauma 39:361–367
23. Santoro V HM, Benirschke S et al (1991) Prospective comparison of unreamed interlocking IM nails vs half pin external fixation and open tibial fractures. J. Orthop Trauma 5:238
24. Tornetta P 3rd, Bergman M, Watnik N, Berkowitz G, Steuer J (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
25. Koval KJ, Clapper MF, Brumback RJ, Ellison PS Jr, Poka A, Bathon GH, Burgess AR (1991) Complications of reamed intramedullary nailing of the tibia. J Orthop Trauma 5:184–189
26. Bhandari M, Guyatt GH, Tong D, Adili A, Shaughnessy SG (2000) Reamed versus nonreamed intramedullary nailing of lower extremity long bone fractures: a systematic overview and meta-analysis. J Orthop Trauma 14:2–9
27. Goodship AE, Kenwright J (1985) The influence of induced micromovement upon the healing of experimental tibial fractures. J Bone Joint Surg Br 67:650–655
28. Shannon FJ, Mullett H, O'Rourke K (2002) Unreamed intramedullary nail versus external fixation in grade III open tibial fractures. J Trauma 52:650–654
29. Baker JT ML, Costa AS, Nepola JV, Marsh LJ, Rodkey WA (1992) Comparison of infection rates in contaminated tibial

fractures stabilized with internal vs external skeletal fixation in rabbits. J Orthop Trauma 6:509
30. Hutson JJ, Zych GA, Cole JD, Johnson KD, Ostermann P, Milne EL, Latta L (1995) Mechanical failures of intramedullary tibial nails applied without reaming. Clin Orthop 315:129–137
31. Whittle AP, Wester W, Russell TA (1995) Fatigue failure in small diameter tibial nails. Clin Orthop 315:119–128
32. Velazco A, Whitesides TE Jr, Fleming LL (1983) Open fractures of the tibia treated with the Lottes nail. J Bone Joint Surg Am 65:879–885
33. Spiegel J BT, Chapman M, Swanson T (1988) The Lottes nail vs AO external fixation in open tibia fractures. Orthop Trans 12:656–663
34. Greitbauer M, Heinz T, Gaebler C, Stoik W, Vecsei V (1998) Unreamed nailing of tibial fractures with the solid tibial nail. Clin Orthop 350:105–114