Displaced tibial shaft fractures

A prospective randomized study of closed intramedullary nailing versus cast treatment in 53 patients

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ABSTRACT — Of 53 patients with unilateral, displaced and closed or grade 1 open tibial shaft fractures, 27 patients (group I) were randomized to treatment with an intramedullary nail and 26 patients (group II) to treatment with a plaster cast. 12 fractures in the latter group were considered stable enough for treatment with only a cast (group IIa), while 14 fractures in group II showed redisplacement during reduction under anesthesia or at 1 week follow-up. Therefore, these fractures were stabilized with cerclage or screws (group IIb), which was a prerequisite for continuing cast treatment. The mean time-to-union was 19 weeks for group I, and 25 weeks for group II. 6 patients in group I and 16 in group II had delayed union. The Nottingham Health Profile index scores on physical mobility, social isolation, work ability, and sexual life were significantly better in group I than in group II at 3 months after injury. Delayed union, malunion, and restricted range of motion at the ankle joint were common complications when these fractures were treated with a cast. We recommend intramedullary nailing for these fractures.

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In our center, stable closed and grade 1 open fractures of the tibial shaft, displaced or not, have traditionally been treated with closed means. Unstable closed and grade 1 open fractures have been treated with minimal internal fixation and a cast (Goetze 1933, Rhinelander 1975, Habernek et al. 1989). However, closed intramedullary nailing has gained popularity during the last decade.

In the literature, the results after different types of treatment have often focused on time-to-union and complications. Few studies have included questions about general function (Bone et al. 1997). The combination of general function, quality of life and morbidity during fracture healing has not been studied in a prospective study.

We compared treatment with closed intramedullary nailing with a cast in patients having displaced fractures of the tibial shaft, emphasizing the patient's general function and morbidity.

Patients and methods

All patients with a closed or grade I open fracture of the tibial diaphysis, occurring between February 1994 and June 1997, were evaluated for inclusion in the present study. Inclusion criteria were displaced closed or grade I open fractures, according to the Gustilo classification system (Gustilo and Anderson 1976). The fractures of type A and B, according to the AO-classification system, were considered suitable for the study (Müller et al. 1990). The following exclusion criteria were used: 1) patients who had other major injuries which could influence the final functional result, 2) patients with cardiopulmunary, rheumatological, neurological, or metabolic disease, 3) patients with previous injuries which influenced their general function, and 4) patients with fractures within 5 cm distal to the tibial tuberosity or proximal to the ankle joint, and those with open growth plates. 56 patients (37 men) having a mean age of 38 (17–78) years fulfilled the criteria and entered the study.

Table 1. Distribution by gender, smoker, age, and details of soft-tissue damage in the treatment groups

Treatment group	n	Gender		Smoker	Age	Trauma type		Soft-tissue damage		
		Male	Female		Mean (range)	Low	High	C0 [a]	C1 [a]	Gustilo I
Group I	27	18	9	8	36 (17–76)	21	6	20	7	0
Group IIa	12	10	2	4	38 (18–53)	8	4	9	1	2
Group IIb	14	8	6	7	49 (20–73)	14	0	10	2	2
Group II	26	18	8	11	41 (18–73)	22	4	19	3	4
Total	53	36	17	19	39 (17–76)	43	10	39	10	4

[a] Oestern & Tscherne

The patients gave their informed written consent before inclusion in the study, which was approved by the hospital's ethics committee. Patients who agreed to participate in the study were randomized using the technique of stratified randomization by minimization (Pocock 1983). This method ensures that the treatment groups are similar as regards the percentage of patient factors that are considered of major prognostic importance. The aim is to balance the marginal treatment totals for each level of each patient factor. Using a computer minimization program, each patient was allocated according to high-energy, soft-tissue injury (open or closed), age (under or over 50 years), smoking (yes or no), alcoholism (yes or no), and occupation (sedentary, mobile, heavy, unemployed). Fractures caused by traffic accident or a fall from a height of at least 3 meters were classified as high-energy trauma (Önnerfält 1978). Patients in each stratum were randomly allocated for treatment by unreamed intramedullary nailing or plaster cast with or without minimal internal fixation. In 5 cases, the surgeon had no access to the allocating program. The date of the injury day (even or odd) was used to randomize these patients. The allocating program was upgraded by the respective variables, afterwards. 27 patients were randomized to have an intramedullary nail (group I), and 29 patients were randomized to have a plaster cast (group II). 12 patients in the latter group had a fracture stable enough for cast treatment only (group IIa) and 14 patients needed additional minimal internal fixation (lag-screw or cerclage wire) to obtain acceptable alignment in a cast (group IIb). 3 fractures in group II were excluded because they required fixation of their fractures by intramedullary nailing. Thus, there were a total of 53 patients with 27 in group I, 12 patients in group IIa and 14 in group IIb. All fractures were unilateral. 34 involved the right leg. 29 patients were injured by falling accidents. Traffic accidents caused the injuries in 7 patients, 5 of them were pedestrians, 1 was an automobile driver, and 1 was a motorcycle driver. 14 patients were injured in sporting accidents and 3 others were injured at work. The severity of the closed and open injuries was classified according to Oestern and Tscherne (1984), and Gustilo and Anderson (1976) (Table 1). 43 fractures were caused by low-energy trauma, while 10 fractures were caused by high-energy trauma (Table 1). The type of fracture was classified according to the AO system (Table 2). 2 fractures involved the proximal third of the tibia, 37 the middle third, and 14 the distal third. 35 patients had an associated fibula fracture, 17 at the same level as the tibia fracture and 18 at a different one (Table 2).

The median time of delay to operation was 1 day for group I and no days for group II. Gender, smoking habits, age, type of trauma, severity of soft-tissue damage, and degrees of comminution of the fractures were similar in the 2 groups. Type of trauma, soft-tissue condition, location of the tibial shaft fractures and whether or not the fibula was fractured were similar in groups IIa and IIb (Tables 1 and 2). However, 3 fractures in group IIa and 13 fractures in group IIb were of type A1 (spiral).

Closed tibial nailing was performed with the patient lying supine. A calcaneal pin was used if traction was required. We used a longitudinal medial parapatellar incision and approach to the proximal tibial cortex 1–1.5 cm below the joint line, just beneath the patellar tendon. The nail di-

Table 2. Distribution of the fractures according to the AO-classification system and fracture localization

Treatment group	AO-classification						Location of tibia fractures			Fibula [a]		
	A1	A2	A3	B1	B2	B3	Proximal	Middle	Distal	1	2	3
Group I	8	7	4	4	1	3	1	20	6	6	11	10
Group IIa	3	4	3	1	1	0	1	8	3	6	4	2
Group IIb	13	0	0	1	0	0	0	9	5	6	3	5
Group II	16	4	3	2	1	0	1	17	8	12	7	7
Total	24	11	7	6	2	3	2	37	14	18	18	17

[a] 1 intact, 2 fractured at a level different from the tibia fracture, and 3 fractured at the same level as the tibia fracture, according to AO-classification.

ameter was 8 mm in 11 patients, 9 mm in 12 and 10 mm in 4. In all patients except 6, the nail was inserted without reaming. These 6 patients had a narrow intramedullary canal at the isthmus, and a small nail could only be passed after reaming of the isthmus area. Static locking was performed in all patients. Weight bearing was allowed when the pain subsided.

Patients in group II were treated with a long leg plaster for the first 4–6 weeks. Thereafter, the cast was changed to a patellar tendon-bearing cast until the fracture was stable enough for treatment with a functional brace. Displaced fracture was defined as more than 5° of angulation in any direction, noticeable malrotation, shortening more than 5 mm, or displacement of more than half of the width of the tibia, on the radiograph. In group II, redisplacement of the fractures was seen in 12 patients during primary reduction under anesthesia, and in 2 patients at a 1-week follow-up. These fractures were assessed to be too unstable for treatment with a plaster cast alone. Therefore, adequate alignment was obtained by minimal internal fixation using either 2–3 cerclage wires or 2–3 lag-screws. All operations were carried out under antibiotic prophylaxis. Intramuscular pressure was measured in 2 patients with imminent acute compartment syndrome.

All fractures were assessed clinically and radiographically, every 4 weeks until fracture union and at 12 months. Once a week during this time, when they had pain, all patients assessed their pain intensity at rest and during walking, on a 10 cm visual analogue scale (VAS).

The Nottingham Health Profile (NHP) questionnaire is a generic questionnaire designed for the patient's assessment of success after medical intervention (Hunt et al. 1981a). Its reliability and validity have been tested in the UK (Hunt et al. 1980, 1981b) and in Sweden (Wiklund et al. 1988) using a translated version. It consists of 2 parts. The first contains 38 questions requiring a 'yes' or 'no' answer, dealing with 6 aspects of health, namely pain, energy, sleep, mobility, emotional reaction and social isolation. The items are weighted and each yields a value between 0 and 100, with the worst state being 100. The answers can be compared with the average scores in a population matched for gender and age. The value of all 6 items in part one are added and the total divided by 6 to give the global score. The second part has 7 sections, which reflect the frequency of problems with occupation, housework, social life, family, sexual function, hobbies and holidays. All patients completed the NHP considering their situation before injury on the first day of admission to the hospital. NHP was also answered at 3 months and 1 year after injury. Preinjury activity level was recorded with the Tegner activity score system (Tegner and Lysholm 1985). This activity scale is graded from 0 to 10 points and covers activities of daily life, recreational activities and competitive sports. The median activity scores were 2 (1–9) for group I, and 2 (1–10) for group II. Complications, including compartment syndrome, fat embolism, pulmonary embolism, wound infection and restriction of knee and ankle motion were documented.

Healing was defined as bridging callus across at least 3 of 4 cortices on the anteroposterior and lateral radiographs (Sharrard 1990), with no pain by stressing the fracture or on walking. Delayed union was diagnosed as consolidation after 20 weeks without further surgical procedures to promote healing. Nonunion was reported when union did not occur unless an intramedullary reaming and fixation with a nail or bone graft was done. Nonunion patients were excluded from the groups when time-to-union was assessed. Malunion was defined as of more than 5° angular deformity (Collins et al. 1990), more than 10° rotational deformity (Johner and Wruhs 1983), or more than 10 mm shortening or lengthening (Collins et al. 1990). Infection was defined as a purulent discharge from which pathogenic organisms were cultured.

Statistics

Statistical analyses were performed using Fisher's exact test to assess differences in the rates of complications and part 2 in NHP between the 2 groups. The 95% confidence intervals (95% CI) were calculated for mean differences in time-to-union and time-to-full weight-bearing. The Mann-Whitney test was used to compare differences between the 2 groups with respect to part 1 in NHP, total NHP score, and VAS scores. Results are also given as mean values and one standard deviation (SD). The SPSS program was used to perform the statistical analyses. Significance was set at $p < 0.05$.

Results

14 of 26 fractures in the cast group were unstable for fixation with only cast treatment. The mean time-to-union was 25 weeks (SD 11) for group IIa and 26 weeks (SD 8.3) for group IIb (95% CI: -4.9–17.6). 3 of 12 patients in group IIa and 4 of 14 patients in group IIb showed malunion. 8 fractures in each group were classified as delayed unions. There were no statistically significant differences between groups IIa and IIb regarding time-to-union and complications (Table 3). For this reason, these 2 subgroups will be considered as 1, group II (non-nailed group). The mean time-to-union in group II was 25 weeks (SD 9.4), compared to 19 weeks (SD 8.2) in group I (nailed group) (95% CI: 2.5-12).

The functional brace was applied after a mean of 15 weeks (SD 3.5). The time-to-full weight-bearing was 14 weeks (SD 4.6) in group I and 22 weeks (SD 11) in group II (95% CI: 5–17). 6 patients in group I and 16 patients in group II had delayed union ($p = 0.005$). 1 patient in group I and 2 patients in group II developed nonunion. 1 patient with nonunion in group II had a deep infection (Table 3). No superficial infection was noted.

Table 3. Complications

Treatment group	Group I	Group II	
		IIa	IIb
Delayed union	6	8	8
Nonunion	1	0	2
Malunion	1	3	4
Deep infection	0	0	1
Knee pain	12	0	0
Deep venous thrombosis	0	1	2
Pulmonary emboli	0	0	1
Compartment syndrome	2	0	0

In group I, 2 patients who developed acute compartment syndrome postoperatively, were operated on by fasciotomy of all 4 compartments. In group II, deep venous thrombosis was verified by phlebography in 3 patients, 1 of whom developed non-fatal pulmonary emboli. 11 patients in group I required removal of the nail because of anterior knee pain, while 3 patients in group II underwent removal of lag-screws ($p = 0.02$). 2 patients who were operated on with intramedullary nailing had failure of the interlocking screws. These fractures healed without any further operation. At the final follow-up, 12 patients in group I and no patients in group II suffered from anterior knee pain ($p < 0.001$).

At the time of fracture union, all patients had normal knee extension. In group I, 1 patient had restricted knee flexion, 2 patients had restricted dorsal flexion of the ankle joint, and 1 patient had restricted dorsal and plantar flexion of the ankle joint. In group II, 7 patients had restricted knee flexion and 14 patients had restricted range of motion of the ankle joint. 3 of these patients had restriction in both plantar- and dorsiflexion (Table 4).

At final follow-up, 1 patient in group I had restricted knee flexion and 1 patient had restricted dorsiflexion of the ankle joint. In group II, 5 patients had restricted knee flexion and 9 patients

Table 4. Restricted range of motion at knee and ankle joints at the time of fracture union and the final follow-up

		Time of fracture union				Final follow-up			
		Group I		Group II		Group I		Group II	
		5°–15°	16°–40°	5°–15°	16°–40°	5°–15°	16°–40°	5°–15°	16°–40°
Knee	Extension	0	0	0	0	0	0	0	0
	Flexion	0	1	5	2	0	0	3	2
Ankle	Dorsiflexion	3	0	5	2	1	0	3	1
	Plantar flexion	1	0	3	7	0	0	3	4

Table 5. Nottingham Health Profile Parts I and II and global, 3 months after injury. Values between 0 and 100, with the worst state being 100

NHP index	Ref. value	Group I	Group II	P-value
Pain	2	37	36	0.7
Energy	8	23	33	0.4
Sleep	8	23	27	0.3
Mobility	1	28	46	0.02
Emotion	13	15	19	0.6
Social isolation	4	6	17	0.02
Global NHP	6	22	27	0.2
Work	13	52	88	0.008
Housework	8	70	85	0.4
Social life	8	37	58	0.2
Family life	11	15	35	0.2
Sexual function	10	22	58	0.02
Hobbies	8	74	81	1
Holidays	4	48	73	0.1

Table 6. Mean (SD) pain intensity on VAS during first 5 months and at 12-month follow-up

Follow-up months	Group I	Group II	P-value
1	48 (22)	30 (25)	0.02
2	23 (19)	12 (18)	0.01
3	14 (14)	15 (24)	0.4
4	12 (16)	10 (20)	0.2
5	9 (20)	11 (23)	0.6
12	2 (5)	2 (6)	0.4

had restricted range of motion of the ankle joint ($p < 0.001$). 2 of these had restriction in both plantar- and dorsiflexion (Table 4). In group I, 1 patient had angular deformity of 7° and recurvatum of 15°. This fracture was located 7 cm from the knee joint. In group II, 6 patients had isolated angular deformity (7° in 2 cases, and 8°, 10°, 12°, 14°, each in 1 case) and 1 patient had angular deformity of 7° in both lateral and frontal planes and shortening of 10 mm ($p = 0.02$).

There were no significant differences between the 2 groups in all indices of the NHP scores, age- and gender-matched, on the first day of injury, and 1 year after injury. However, at 3 months after the injury, patients in group I had better scores on NHP including the physical mobility index ($p = 0.02$), social isolation ($p = 0.02$), work ability ($p = 0.008$), and sexual life ($p = 0.02$) than patients in group II (Table 5).

20 patients in group I and 22 patients in group II regularly completed a questionnaire on their intensity of pain once a week for a maximum of 20 weeks after the injury. Patients in group I had more pain on walking during the first 2 months ($p = 0.05$). During the remainder of the follow-up period, there was no significant difference in pain intensity between the 2 groups (Table 6). This result was confirmed by repeated measurement analysis. There were no significant differences between the 2 groups regarding NHP scores and pain intensity at the 1-year follow-up.

Discussion

We considered group IIa and group IIb as a cast group (group II) for the following reasons: 1) there were no significant differences between the subgroups regarding time-to-union and complications, 2) both subgroups were treated with a cast and functional brace according to the same protocol. To compare the results after intramedullary nailing and cast or functional brace in treatment of tibial shaft fractures is difficult. To justify such a comparison, both groups must contain comparable fractures. Displaced, unstable fractures cannot be treated with a cast or brace alone, which means that they should be excluded from this group. Therefore only stable fractures would be left in the cast group, which are no longer comparable with fractures in the nail group. We speculate that if all displaced tibial shaft fractures in this study had been treated with a cast alone, it would have resulted in a higher rate of complications in the cast group. With minimal internal fixation, it was ethically possible to use the cast treatment on all fractures that were randomized to the cast group, whether stable or not. This made the fractures in both groups homogeneous and in line with the inclusion criteria. On the other hand, the cast group contained 14 patients treated with a cast, using minimal internal fixation which could, throw doubt on the homogeneity of group II.

Patients in group I needed a shorter time to union and to full weight-bearing than those in group II. Bone et al. (1997) reported a retrospective study of 99 patients who had unilateral, displaced, isolated closed fractures of the tibial shaft. 47 patients were managed with closed intramedullary nailing and reaming. 52 were managed with closed reduction and a cast. The mean time to union was shorter in the patients who had been managed with intramedullary nailing (18 weeks) than in those who had been managed with a cast (26 weeks). In 25 matched pairs of patients, identified on the basis of age (within 10 years) and the location and type of the fracture, the mean time-to-union was 26 weeks after management with a cast and 20 weeks after management with nailing. Hooper et al. (1991) performed a prospective randomized study on displaced tibial shaft fractures. Patients treated with closed intramedullary nailing (n = 29) showed significantly more rapid union, less malunion, and less time off work than those treated non-operatively (n = 33). Court-Brown et al. (1990) presented the results of a reamed, interlocking nail in the management of 125 closed and type I open tibial fractures. The mean time-to-union was 17 weeks and no fracture required a bone graft. They concluded that intramedullary nailing of closed and grade I open fractures was a safe technique and it combined a high rate of union with a low complication rate. Sarmiento (1974) and Sarmiento et al. (1984) developed the functional below-knee cast and, later, the custom-made prefabricated functional brace, and suggested that of controlled motion contributed to fracture healing. Sarmiento et al. (1989) reported average time-to-union of 17 (6-39) weeks for 539 closed tibial fractures treated with a functional brace. The mean time-to-union in our study in both groups is in line with the results of Court-Brown et al. (1990), Hooper et al. (1991) and Bone et al. (1997).

12 of 27 patients in group I had anterior knee pain. This complication has been reported by others (Alho et al. 1990, Hooper et al. 1991, Orfaly et al. 1995, Haddad et al. 1996, Keating et al. 1997). Orfaly et al. (1995) showed that 33 of 65 fractures were associated with subsequent knee pain when a paratendinous insertion had been used. When nail insertion was through the tendon, 28 of 36 knees later developed pain. They found that the position of the nail in relation to the anterior cortex and tibial plateau had no influence on knee pain and the effect of nail removal was unpredictable. In our study, paratendinous insertion was used in all patients in group I. We suspect that dissection in the patellar region, trauma in the patellar tendon during nail insertion, and iatrogenic damage of the infrapatellar nerve may cause anterior knee pain. It is apparent that room for improvement exists in the operative technique of closed intramedullary nailing for tibial shaft fractures.

Significantly fewer patients in group I had malunion and restricted range of motion in the knee and ankle joints. Using a functional brace, Sarmiento et al. (1989) reported more than 5° of angular deformity in 27%, and more than 10 mm of shortening in 10%. Den Outer et al. (1990), Oni et al. (1988) and Haines et al. (1984) reported 35–40% malunion after closed management. Hooper et al. (1991) and Bone et al. (1997) reported significantly more malunion in patients who did not undergo surgery than in those who were treated with intramedullary nailing. Biomechanical analysis indicated that angular deformity of the tibia increased the force on the tibial plateau at the knee or ankle joint (Tarr et al. 1985, Kettelkamp 1988). Van Der Schoot et al. (1996) found a relationship between tibial malalignment and degenerative changes in the knee and ankle joints. Unfortunately there is no consensus on the limits of acceptable malalignment and until this exists, the surgeon should aim to obtain fracture union with as little angular deformity as possible.

The NHP index scores on physical mobility, social isolation, work ability, and sexual life were all significantly better in group I than in group II at 3 months after injury. These differences disappeared 1 year after injury. Any interference by comorbid factors on NHP scores was eliminated by using our exclusion criteria numbers 2 and 3, and the Tegner score. Bone et al. (1997) reported that the scores on the SF-36 questionnaire (Short Form, 36 questions) in the matched-pairs group at a mean of 4.4 years follow-up were significantly better after nailing than after management with a cast. The difference is probably due to the presence of comorbid factors that had a significant negative effect on the overall scores (Otsuka et al. 1998).

The main reasons why nailed patients had more pain during the first 2 months were that: 1) they were more mobile than the patients in the cast group, as shown by the mobility score on NHP, 2) they were encouraged by the surgeons to force the injured leg, and 3) they suffered from anterior knee pain.

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Alho A, Ekeland A, Strömsoe K, Follerås G, Thoresen B O. Locked intramedullary nailing for displaced tibial shaft fractures. J Bone Joint Surg (Br) 1990; 72: 805-9.

Bone L B, Sucato D, Stegemann P M, Rohrbacher B J. Displaced isolated fractures of the tibial shaft treated with either a cast or intramedullary nailing. An outcome analysis of matched pairs of patients. J Bone Joint Surg (Am) 1997; 79: 1336-41.

Collins D N, Pearce C E, McAndrew M P. Successful use of reaming and intramedullary nailing of the tibia. J Orthop Trauma 1990; 4: 315-22.

Court-Brown C M, Christie J, McQueen M M. Closed intramedullary tibial nailing. Its use in closed and type I open fractures. J Bone Joint Surg (Br) 1990; 72: 605-11.

Den Outer A J, Meeuwis J D, Hermans J, Zwaveling A. Conservative versus operative treatment of displaced noncomminuted tibial shaft fractures. A retrospective comparative study. Clin Orthop 1990; vol 252: 231-7.

Goetze O. Subcutane Drahtnaht bei Tibiaschrägfrakturen. Arch f Klin Chir 1933; 177: 445-9.

Gustilo R B, Anderson J T. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg (Am) 1976; 58: 453-8.

Habernek H, Walch G, Dengg C. Cerclage for torsional fractures of the tibia. J Bone Joint Surg (Br) 1989; 71: 311-3.

Haddad F S, Desai K, Sarkar J S, Dorrell J H. The ao unreamed nail: friend or foe. Injury 1996; 27: 261-3.

Haines J F, Williams E A, Hargadon E J, Davies D R. Is conservative treatment of displaced tibial shaft fractures justified? J Bone Joint Surg (Br) 1984; 66: 84-8.

Hooper G J, Keddell R G, Penny I D. Conservative management or closed nailing for tibial shaft fractures. A randomised prospective trial. J Bone Joint Surg (Br) 1991; 73: 83-5.

Hunt S M, McKenna S P, McEwen J, Backett E M, Williams J, Papp E. A quantitative approach to perceived health status: a validation study. J Epidemiol Community Health 1980; 34: 281-6.

Hunt S M, McKenna S P, Williams J. Reliability of a population survey tool for measuring perceived health problems: a study of patients with osteoarthrosis. J Epidemiol Community Health 1981a; 35: 297-300.

Hunt S M, McKenna S P, McEwen J, Williams J, Papp E. The Nottingham health profile: subjective health status and medical consultations. Soc Sci Med (A) 1981b; 15: 221-9.

Johner R, Wruhs O. Classification of tibial shaft fractures and correlation with results after rigid internal fixation. Clin Orthop 1983; 178: 7-25.

Keating J F, Orfaly R, O'Brien P J. Knee pain after tibial nailing. J Orthop Trauma 1997; 11: 10-3.

Kettelkamp D B, Hillberry B M, Murrish D E, Heck D A. Degenerative arthritis of the knee secondary to fracture malunion. Clin Orthop 1988; 234:159-69.

Müller M E, Nazarian S, Koch P, Schatzker J. The comprehensive classification of fractures of long bones. Springer-Verlag, Berlin 1990.

Oestern H J, Tscherne H. Pathophysiology and classification of soft tissue injury associated with fractures. In: Fractures with soft tissue injuries (Ed. Tscherne H G L). Springer-Verlag, Berlin 1984: 1-8.

Oni O O, Hui A, Gregg P J. The healing of closed tibial shaft fractures. The natural history of union with closed treatment. J Bone Joint Surg (Br) 1988; 70: 787-90.

Orfaly R, Keating J E, O'Brien P J. Knee pain after tibial nailing: does the entry point matter? J Bone Joint Surg (Br) 1995; 77: 976-7.

Otsuka N Y, McKee M D, Liew A, Richards R R, Waddell J P, Powell J N, et al. The effect of comorbidity and duration of nonunion on outcome after surgical treatment for nonunion of the humerus. J Shoulder Elbow Surg 1998; 7: 127-33.

Pocock S J. Methods of randomization. In: Clinical Trials (Ed. Pocock S J). John Wiley & Sons, New York 1983: 84-6.

Rhinelander F W. Minimal internal fixation of tibial fractures. Clin Orthop 1975; 166: 188-220.

Sarmiento A. Functional bracing of tibial fractures. Clin Orthop 1974; 105: 202-19.

Sarmiento A, Sobol P A, Sew Hoy A L, Ross S D, Racette W L, Tarr R R. Prefabricated functional braces for the treatment of fractures of the tibial diaphysis. J Bone Joint Surg (Am) 1984; 66: 1328-39.

Sarmiento A, Gersten L M, Sobol P A, Shankwiler J A, Vangsness C T. Tibial shaft fractures treated with functional braces. Experience with 780 fractures. J Bone Joint Surg (Br) 1989; 71: 602-9.

Sharrard W J. A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures. J Bone Joint Surg (Br) 1990; 72: 347-55.

Tarr R R, Resnick C T, Wagner K S, Sarmiento A. Changes in tibiotalar joint contact areas following experimentally-induced tibial angular deformities. Clin Orthop 1985; 199:72-80.

Tegner Y, Lysholm J. Rating system in the evaluation of knee ligament injuries. Clin Orthop 1985; 198: 43-9.

Van Der Schoot D K E, Den Outer A J, Bode P J, Obermann W R, Van Vugt A B. Degenerative changes at the knee and ankle related to malunion of tibial fractures. 15-year follow-up of 88 patients. J Bone Joint Surg (Br) 1996; 78: 722-5.

Wiklund I, Romanus B, Hunt S M. Self-assessed disability in patients with arthrosis of the hip joint. Reliability of the Swedish version of the Nottingham health profile. Int Disabil Stud 1988; 10: 159-63.

Önnerfält R. Fracture of the tibial shaft treated by primary operation and early weight-bearing. Acta Orthop Scand (Suppl 171) 1978: 1-63.