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Long-Term Outcome After Tibial Shaft Fracture: Is Malunion Important?

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Background: Fractures of the shaft of the tibia often heal with some angulation. Although there is biomechanical evidence that such angulation alters load transmission through the joints of the lower limb, it is not clear whether it can eventually lead to osteoarthritis.

Methods: One hundred and sixty-four individuals who had sustained a tibial shaft fracture were assessed in a research clinic thirty to forty-three years after the injury. The subjects were evaluated with regard to self-reported lower limb joint pain, stiffness, and disability (assessed with the Western Ontario and McMaster Universities [WOMAC] osteoarthritis questionnaire); clinical signs of osteoarthritis; and radiographic evidence of osteophytes and joint-space narrowing in the knees, ankles, and subtalar joints.

Results: Twenty-two (15%) of the 151 subjects who reported no other knee injury reported at least moderate knee pain, and eight (6%) of the 145 subjects who reported no other ankle injury reported at least moderate ankle pain. Seventeen (13%) of the 135 subjects who reported no other knee or ankle injury reported at least moderate disability. The ipsilateral side demonstrated a higher prevalence than the contralateral side in terms of pain with passive ankle movement (nineteen versus nine subjects, $p = 0.02$), pain with passive subtalar movement (fifteen versus four subjects, $p = 0.01$), and radiographic signs of ankle joint space narrowing (twelve subjects versus one subject, $p = 0.0055$). Knee osteoarthritis was frequently bilateral. Forty-seven fractures (29%) healed with coronal angulation of ≥5°. Apart from an association between shortening of ≥10 mm and self-reported knee pain ($p = 0.016$), there were no significant univariate associations between these malunions and the development of osteoarthritis. Seventeen (15%) of 114 eligible subjects had overall malalignment of the lower limb, defined as a hip-knee-ankle angle outside the normal range of 6.25° of varus to 4.75° of valgus. This malalignment was due to the fracture malunion in nine subjects and predated the fracture in eight. In limbs with varus or valgus malalignment, there was an excess of subtalar stiffness ($p = 0.04$) and a nonsignificant trend toward more frequent knee pain. In limbs with varus malalignment, there was a nonsignificant trend toward more frequent radiographic evidence of osteoarthritis in the medial compartment of the knee joint. Most of the subjects in whom osteoarthritis was observed had normal overall alignment of the lower limb.

Conclusions: The thirty-year outcome after a tibial shaft fracture is usually good, although mild osteoarthritis is common. Fracture malunion is not the cause of the higher prevalence of symptomatic ankle and subtalar osteoarthritis on the side of the fracture. Although varus malalignment of the lower limb occurs occasionally and may cause osteoarthritis in the medial compartment of the knee, other factors are more important in causing osteoarthritis after a tibial shaft fracture.

Fracture of the shaft of the tibia is a common long-bone injury, with an annual incidence of approximately 1 in 2000[1]. In the past, such fractures usually were treated with a cast, with good intermediate-term results in the majority of patients[2]. Fracture union often occurs with some angulation after such treatment, and it has been suggested that this may predispose the patient to osteoarthritis by altering load transmission through the knee and ankle joints[3]. There has been a trend in recent years toward operative treatment of tibial shaft fractures, and such treatment has been associated with a lower incidence of angular malunion[4]. Although Wu et al. reported that experimentally produced 30° tibial malunions in rabbits resulted in histological changes that were consistent with osteoarthritis in the overloaded compartment of the knee[5], several clinical studies of patients with healed tibial shaft fractures have shown no association between malunion and osteoarthritis of the knee and ankle[6-9]. Those studies were too small to rule out the possibility of a type-II statistical error. Van der Schoot et al., in a study of eighty-eight patients who had sustained a tibial fracture, showed a higher prevalence of ankle osteoarthritis on the side of the fracture compared with the contralateral side and a significant association between angular malunion of ≥5° and radiographic changes indicative of osteoarthritis ($p = 0.02$)[10]. In an earlier study in which 398 patients who had previously sustained a tibial fracture were compared with 1573 age and sex-matched controls with use of a mailed questionnaire[11], we found that the patients who had had a fracture reported knee pain, lower limb osteoarthritis (as diagnosed by a general practitioner), and physical disability more frequently than the controls did. In the present clinical study, we evaluated a subset of the same group of patients in order to determine the long-term effects of fracture malunion.

Materials and Methods

Subjects

With Ethics Committee approval, the names of 1400 individuals who had been treated between 1954 and 1967 at a single hospital for a unilateral fracture of the tibial shaft were obtained from the original cast-room ledgers. All subjects had been at least sixteen years old at the time of the injury. Eight hundred and forty-nine subjects were successfully traced with use of the computer databases of the hospital, the local Family Health Services Authority, and the National Health Service Central Register. Six hundred and ten of these subjects were still alive, and 398 returned the questionnaire from our initial survey. Three hundred and forty-seven of these subjects were still living locally, and all were invited by mail to attend a special research clinic for clinical assessment. Those who did not respond were mailed one reminder. All 206 subjects who were enrolled and evaluated gave written informed consent.

Interview

All subjects were asked to recall as much as possible about the treatment of the tibial shaft fracture. This information was supplemented by copies of the entries from the cast-room ledger detailing changes of the cast and by a set of calendars for the years 1954 to 1968 as an aide-mémoire. The subjects also were asked to recall other lower limb injuries and any operations performed for the treatment of lower limb osteoarthritis.

Functional Assessment

All subjects who attended the research clinic completed the Western Ontario and McMaster Universities (WOMAC) lower limb osteoarthritis questionnaire[12]. This self-administered questionnaire includes sections on activity-related joint pain (five questions), joint stiffness (two questions), and everyday physical activities such as walking, climbing stairs, and bathing and dressing (seventeen questions). For each question, the subject was asked to indicate the severity of pain, stiffness, or disability by checking one of five boxes labeled none, mild, moderate, severe, or extreme. These responses were scored as 0, 1, 2, 3, or 4 points, respectively. Points were summated to produce separate scores for pain (0 to 20 points), stiffness (0 to 8 points), and physical function (0 to 68 points). The questions pertaining to pain and stiffness were asked twice, once for the knee and once for the ankle. Subjects who had undergone surgical treatment of lower limb osteoarthritis were asked to complete the questionnaire to reflect their preoperative status.

Clinical Examination

Each subject's height and weight were recorded and were used to calculate the body-mass index (determined as the weight in kilograms divided by the square of the height in meters). Nodal osteoarthritis was recorded as present if there were two or more Heberden nodes on the distal interphalangeal joints of the fingers of both hands[13]. Joint mobility was assessed with use of the Beighton score[14]. This system allocates a total of up to 9 points for joint laxity at different sites in the body. Points are assigned for the ability to hyperextend the elbow by ≥10° (1 point for each side), to hyperextend the knee by ≥10° (1 point for each side), to hyperextend the metacarpophalangeal joint of the little finger by ≥90° (1 point each side), to flex the wrist and abduct the thumb so that the thumb is parallel to or touching the flexor aspect of the distal part of the forearm (1 point for each side), and to bend forward from standing position to touch the floor with the palms of the hands while keeping the knees straight (1 point). A score of ≥6 points is considered to represent abnormal joint laxity. The level of pain during passive joint movement through the normal range was recorded for the knees, ankles, and subtalar joints on a self-reported scale of grade 0 (absent), 1 (mild), 2 (moderate), or 3 (severe). Clinical osteoarthritis was defined as present if the pain during passive movement was rated as grade 2 or 3. The range of joint movement was scored by the examiner on a scale of 0 (normal range of movement for the subject's age and sex), 1 (mild restriction compared with the uninjured side), 2 (moderate stiffness, with restriction of the range of movement to approximately half of that on the uninjured side), or 3 (severe stiffness, with only a small arc of movement present). Objective joint stiffness was defined as present if the limitation of joint movement was grade 1, 2, or 3. The subjects were examined for evidence of scars related to an open wound associated with the fracture, operative treatment of the fracture, subsequent procedures for the treatment of osteoarthritis, and other operations such as meniscectomy. No attempt was made to grade the severity of any open fracture.

Measurement of Malunion

With use of a special positioning board and consistent radiographic technique, standing anteroposterior and lateral radiographs of each tibia were made. The fracture angulation in the coronal and sagittal planes was measured to the nearest 0.5° with use of a template method[15]. The mechanical axis of the tibia, defined as a straight line passing from the midpoint between the tibial spines to the midpoint of the distal tibial articular surface, was marked on the anteroposterior radiograph of the contralateral tibia. This radiograph was turned over and was used as a template. By matching the osseous outlines first of the proximal and then of the distal portions of the tibiae, two straight lines representing the proximal and distal segments of the prefracture mechanical axis were traced onto the radiograph of the previously fractured tibia. The coronal malunion angle was the angle between these two lines. The sagittal malunion angle was measured on the lateral radiographs with use of the same method but with the center of the ankle defined as the most superior point of the distal tibial articular surface. Shortening was calculated from the difference between the lengths of the mechanical axes of the ipsilateral and contralateral tibiae on the anteroposterior radiographs. Rotational malunion was measured clinically with use of protractors printed on the positioning board to indicate the position of the second toe with the patella facing directly forward; the rotational malunion angle was the difference between the angles for the two sides.

Measurement of Lower Limb Alignment

The coronal plane alignment of the lower limb (the hip-knee-ankle angle) was calculated by measuring the horizontal displacement of the center of the knee (the midpoint between the tibial spines) from the load-bearing axis of the lower limb (a vertical line passing from the hip center to the ankle center, defined as the midpoint of the distal tibial articular surface) (Fig. 1). In subjects without joint-space narrowing in the medial or lateral compartment of the contralateral knee, the alignment of the contralateral lower limb was used as an estimate of the alignment of the ipsilateral knee prior to the fracture. This value and the malunion angle were used to estimate lower limb alignment at the time of fracture-healing, prior to any further change in joint alignment due to osteoarthritis of the knee. No subject had altered lower limb alignment due to ligamentous laxity of the knee.

Evaluation of Joint Radiographs

A set of standardized joint radiographs comprising a weight-bearing posteroanterior radiograph of each knee in 30° of flexion[16], a 45° skyline radiograph of each patellofemoral joint[17], a weight-bearing mortise radiograph of each ankle, and an oblique radiograph of each subtalar joint was made for each subject[18]. The radiographs were trimmed as necessary to blind the observer to the presence of an adjacent fracture. The radiographs were evaluated separately in random order for the presence of osteophytes and joint-space narrowing on a scale of 0 (absent), 1 (mild), 2 (moderate), or 3 (severe). For the medial, lateral, and patellofemoral compartments of the knee, this scoring was performed by comparing the radiographs with a standard atlas of osteoarthritis produced specifically for this purpose[19]. As no such atlas exists for the ankle and subtalar joints, a set of radiographs compiled from the study group was used for comparison. Osteophytes and joint-space narrowing were deemed to be present if they had received a score of 2 (moderate) or 3 (severe). For subjects who had undergone joint replacement surgery, preoperative radiographs were used. All radiographs were scored by one observer (S.A.M.). For each joint, thirty radiographs were reread in random order to calculate the unweighted Kappa coefficient for intraobserver repeatability for the grading of severity of radiographic changes[20]. Repeatability was rated as moderate for Kappa values of 0.41 to 0.60, good for Kappa values of 0.61 to 0.80, and very good for Kappa values of 0.81 to 1.00.

Analysis of the Data

Any subject who reported a separate injury of a particular joint was excluded from the analysis for that joint. For the knee, fractures into the joint, meniscectomy, anterior cruciate ligament rupture, and patellar dislocation led to exclusion; for the ankle and the subtalar joint, fractures of the ankle, talus, or calcaneus and severe ankle "sprains" that had been treated with a cast for two weeks or more led to exclusion. The prevalence of clinical osteoarthritis and that of radiographic signs of osteophytes and joint-space narrowing on the ipsilateral and contralateral sides were compared with use of the McNemar test. Ninety-five percent confidence intervals for the odds ratios for paired data were calculated with use of the appropriate binomial tables. Subjects were split into two subgroups for analysis of each component of fracture malunion with use of cutoff points of 5° or 10° for angulation, 10° or 20° for rotation, and 10 or 20 mm for shortening. WOMAC questionnaire scores were compared between subgroups of subjects with different degrees of malunion and malalignment with use of the Mann-Whitney U test, with correction for ties. The prevalences of ipsilateral clinical osteoarthritis, objective joint stiffness, and radiographic signs of osteophytes and joint-space narrowing were compared between subgroups of subjects with different degrees of malunion and malalignment with use of the chi-square test with Yates' continuity correction or with use of the Fisher exact test for a 2×2 table where appropriate. Lower limb alignment in the coronal plane was categorized as normal (between 6.25° of varus and 4.75° of valgus) or abnormal (>6.25° of varus or >4.75° valgus). These values were obtained by combining the results of three published studies of lower limb alignment in normal young adults[21-23]. The effect of fracture location was examined by comparing the prevalence of knee osteoarthritis in subjects with fractures involving the proximal third of the tibia with the prevalence in subjects with fractures involving the middle or distal third of the tibia. Similarly, the prevalence of ankle and subtalar osteoarthritis in subjects with fractures involving the distal third of the tibia was compared with the prevalence in subjects with fractures involving the proximal or middle third of the tibia. Stepwise logistic regression was used to correct for known risk factors for osteoarthritis (namely, age, sex, weight, nodal osteoarthritis, joint hypermobility, and other joint injury) and to investigate whether any fracture-related factors independently affected outcome. The factors that were investigated included a high-energy mechanism of injury, type of fracture (open or closed), type of treatment (operation or cast), duration of immobilization, and joint-surface orientation to the horizontal. Statistical analysis was performed on a personal computer running SPSS software (SPSS, Chicago, Illinois). Post hoc statistical power calculations were performed using G*Power software[24] assuming a standardized difference of $d = 0.5$,

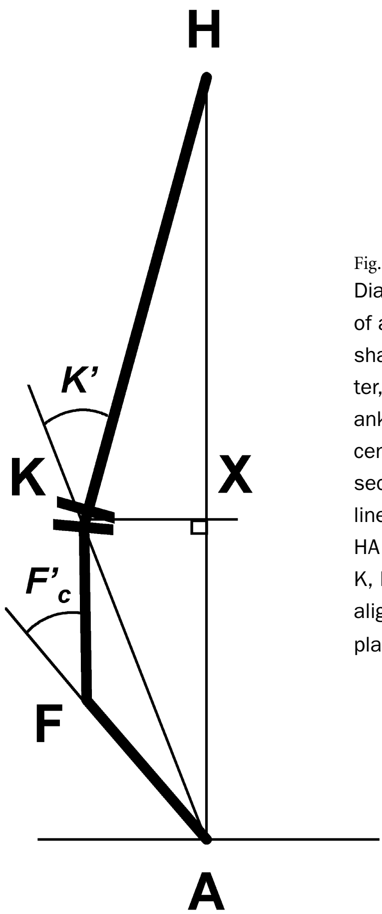

Fig. 1
Diagrammatic illustration of a malunion of a tibial shaft fracture. H = hip center, K = knee center, A = ankle center, F = fracture center of rotation, X = intersection of line HA and a line perpendicular to line HA passing through point K, K' = angle of lower limb alignment, F'_c = coronal plane malunion angle.

which equates approximately to the detection of a 20% difference between the groups in the prevalence of osteoarthritis.

Results

Subjects

Two hundred and six subjects were enrolled. Thirty-nine subjects were excluded because the fracture had been incorrectly documented in the cast-room ledger as involving the tibial shaft, one was excluded because of severe congenital bowing of both tibiae, one was excluded because a below-the-knee amputation had been performed as a result of vascular complications related to the fracture, and one did not wish to have radiographs made. The remaining 164 subjects (147 men and seventeen women) were evaluated at a mean age of sixty-one years (range, forty-seven to eighty-two years) after a mean duration of follow-up of thirty-six years (range, thirty to forty-three years). Thirty-four subjects (21%) had a body-mass index of ≥30 kg/m^2. Three subjects (2%) had a Beighton joint-mobility score of ≥6. Forty-five subjects (27%) had nodal osteoarthritis in the fingers. One hundred and fifty-three subjects reported no injury of the ipsilateral knee, and 151 reported no injury of either knee. One hundred and fifty-two subjects reported no injury of the ipsilateral ankle, and 145 reported no injury of either ankle. One hundred and thirty-five subjects reported no injury of either knee or either ankle.

Fracture Characteristics

Sixty-four fractures had involved the left tibia, and 100 had involved the right tibia. Seventy-seven subjects (47%) had sustained a high-energy injury, mostly as the result of motor-vehicle and industrial accidents. Fifty-nine fractures (36%) had been open injuries. Forty-five fractures (27%) had been treated with open reduction and internal fixation, either primarily or as a delayed procedure. Fixation had been achieved with use of a plate in all subjects except one, in whom a single lag screw had been placed across the fracture site. All subjects had been treated with a plaster cast; most subjects initially had been treated with a long leg cast, although some subsequently had conversion to a short leg walking cast. The median period of immobilization in a cast as recalled by the subjects was seventeen weeks (range, six to 160 weeks).

Functional Outcome (WOMAC Questionnaire)

The median knee pain score was 2 (of 20) points (interquartile range, 0 to 7 points), and the median knee stiffness score was 1 (of 8) points (interquartile range, 0 to 4 points). The median ankle pain score was 0 (of 20) points (interquartile range, 0 to 5 points), and the median ankle stiffness score was 1 (of 8) points (interquartile range, 0 to 3 points). However, twenty-two (15%) of 151 subjects had a knee pain score of >10 (of 20) points, and thirty-nine (26%) had a knee stiffness score of >4 (of 8) points. Eight (6%) of 145 subjects had an ankle pain score of >10 (of 20) points, and twenty-seven (19%) had an ankle stiffness score of >4 (of 8) points. The median physical function score was 7 (of 68) points (interquartile range, 0 to 22 points), and seventeen (13%) of 135 subjects had a physical function score of >34 (of 68) points. Thus, the majority of subjects reported little joint pain or stiffness and minimal disability. However, there was a subset of subjects with more severe joint symptoms and consequent physical limitation. The distribution of the physical function scores is shown in Figure 2.

Prevalence of Osteoarthritis

The prevalences of clinical signs of osteoarthritis of the knee, ankle, and subtalar joints are given in Table I. There was an excess of pain with passive movement and objective stiffness on the side of the fracture for all joints, and the differences were significant for both the ankle and the subtalar joint ($p \leq 0.04$). Overall, four subjects (2%) had undergone one or more surgical procedures for the treatment of osteoarthritis of the knee: one subject had undergone an ipsilateral high tibial osteotomy for the treatment of osteoarthritis of the medial compartment of the knee twenty-five years after the fracture, one had undergone an ipsilateral total knee arthroplasty forty-three years after the fracture, one had undergone a bilateral total knee arthroplasty thirty-six years after the fracture, and one had undergone a bilateral high tibial osteotomy twenty-one years after the fracture and a subsequent bilateral total knee replacement eight years later. No subject had had an operation for the treatment of ankle osteoarthritis.

The Kappa coefficients for the grading of osteophytes and joint-space narrowing were 0.60 (moderate) and 0.87

TABLE I Prevalences of Clinical Signs of Osteoarthritis in the Ipsilateral and Contralateral Knee, Ankle, and Subtalar Joints

	Ipsilateral Limb Only*	Contralateral Limb Only*	Bilateral*	Odds Ratio (95% Confidence Interval)	P Value (McNemar Test)
Knee pain with passive movement (n = 151)	12 (7.9%)	6 (4.0%)	10 (6.6%)	2.0 (0.69 to 6.5)	0.24
Ankle pain with passive movement (n = 145)	13 (9.0%)	3 (2.1%)	6 (4.1%)	4.3 (1.2 to 23)	0.02
Objective ankle stiffness (n = 145)	10 (6.9%)	2 (1.4%)	0	5.0 (1.1 to 47)	0.04
Subtalar pain with passive movement (n = 145)	13 (9.0%)	2 (1.4%)	2 (1.4%)	6.5 (1.5 to 59)	0.01
Objective subtalar stiffness (n = 145)	35 (24.1%)	5 (3.4%)	11 (7.6%)	7.0 (2.7 to 23)	<0.001

*The data are given as the number of subjects, with the percentage in parentheses.

(very good), respectively, for the patellofemoral joint; 0.59 (moderate) and 0.74 (good) for the medial compartment of the knee; 0.74 (good) and 0.63 (good) for the lateral compartment of the knee; 0.65 (good) and 0.88 (very good) for the ankle; and 0.70 (good) and 0.81 (very good) for the subtalar joint. The prevalences of osteophytes and joint-space narrowing on radiographs are shown in Table II. The prevalence of radiographic signs of osteoarthritis was higher on the side of the fracture for all joints, and the difference was significant for osteophytes in the lateral compartment of the knee and for osteophytes and joint-space narrowing in the ankle ($p \leq 0.026$).

Effect of Fracture Malunion

Forty-seven fractures (29%) healed with coronal angulation of ≥5° (twenty-six healed in varus and twenty-one, in valgus), and six (4%) healed with coronal angulation of ≥10° (four healed in varus and two, in valgus). Fifty-six fractures (34%) healed with sagittal angulation of ≥5° (forty-three healed in recurvatum and thirteen, in antecurvatum), and fourteen (9%) healed with sagittal angulation of ≥10° (twelve healed in recurvatum and two, in antecurvatum). A scatterplot showing the distribution of angular malunion is given in Figure 3. Rotational malunion was ≥10° in thirty-nine (25%) of the 158 subjects in whom it could be measured, and it was ≥20° in five (3%). Shortening of ≥10 mm was noted in thirty-three (21%) of the 158 subjects in whom it could be measured, and shortening of ≥20 mm was noted in eight (5%). Apart from associations between self-reported knee pain and shortening of ≥10 mm ($U = 1405$, $p = 0.016$; Mann-Whitney U test) and of ≥20 mm ($U = 288$, $p = 0.025$), there were no other significant associations between self-reported joint pain, stiffness, or disabil-

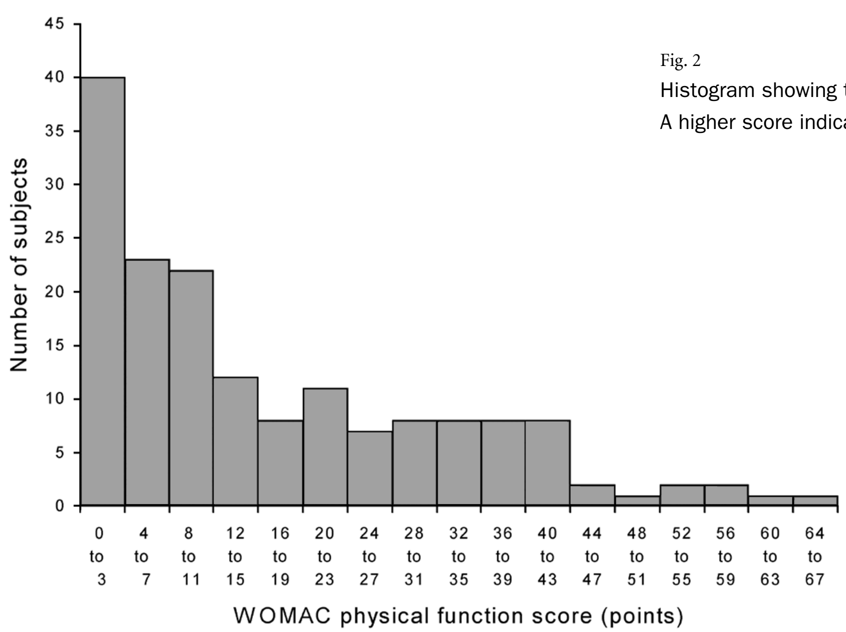

Fig. 2

Histogram showing the distribution of WOMAC physical function scores. A higher score indicates more severe disability.

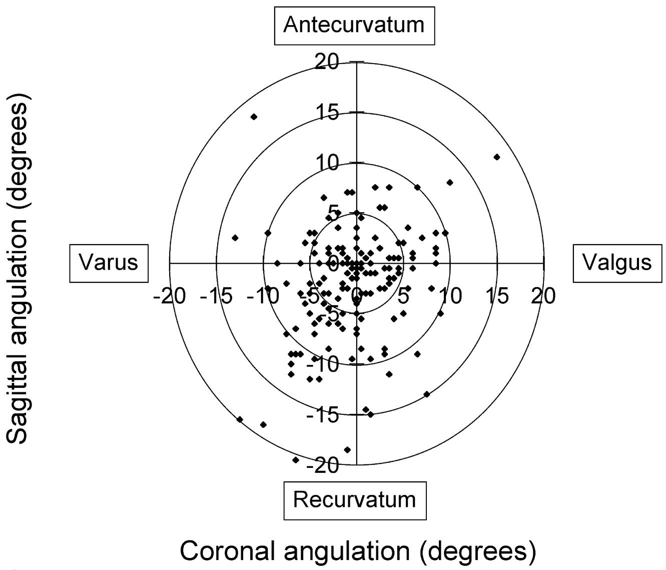

Fig. 3

Scatterplot of coronal angulation versus sagittal angulation. Each point represents one subject. The concentric circles indicate the true malunion angle, which is always greater than or equal to the coronal and sagittal angulations.

ity and angulation of ≥5° or ≥10°, rotation of ≥10° or ≥20°, or shortening of ≥10 or ≥20 mm (Mann-Whitney U test). There were no significant associations between clinical evidence of osteoarthritis (pain on passive joint movement), objective joint stiffness, or radiographic evidence of osteoarthritis and angulation of ≥5° or ≥10°, rotation of ≥10° or ≥20°, or axial shortening of ≥10 or ≥20 mm (chi square test, Fisher exact test). Post-hoc power calculations for these sample sizes (α = 0.05, standardized difference d = 0.5) gave power (1-β) values of 0.89 and 0.33 for ≥5° and ≥10° of coronal angulation, respectively; 0.92 and 0.55 for ≥5° and ≥10° of sagittal angulation, respectively; 0.83 and 0.25 for ≥10° and ≥20° of rotational malunion, respectively; and 0.80 and 0.36 for ≥10 and ≥20 mm of shortening, respectively.

Effect of Lower Limb Malalignment

Of the 123 subjects who had no contralateral knee osteoarthritis to prevent alignment calculations, 114 had had no other knee injury and 117 had had no other ankle injury. Seventeen eligible subjects (15%) had malalignment of the ipsilateral lower limb (twelve had varus malalignment and five, valgus malalignment). A post hoc power calculation for this sample size (α = 0.05, standardized difference d = 0.5) gave a power (1-β) of 0.60. For the subgroup with varus malalignment, the power (1-β) was 0.50. In nine subjects (six with varus and three with valgus malalignment) the malalignment of the lower limb was due to the fracture, and in the other eight subjects (six with varus and two with valgus malalignment) it predated the fracture. Although the WOMAC questionnaire scores for subjects with malaligned lower limbs were consistently slightly higher, comparison of the groups of subjects with and without lower limb malalignment showed no significant differences in the severity of self-reported knee pain (U = 818.0, p = 0.24; Mann-Whitney U test), knee stiffness (U = 896.5, p = 0.33), ankle pain (U = 803.5, p = 0.30), ankle stiffness (U = 812.5, p = 0.19),

TABLE II Prevalences of Radiographic Features of Osteoarthritis in the Ipsilateral and Contralateral Knee, Ankle, and Subtalar Joints

	Ipsilateral Limb Only*	Contralateral Limb Only*	Bilateral*	Odds Ratio (95% Confidence Interval)	P Value (McNemar Test)
Knee (n = 151)					
Patellofemoral compartment					
Osteophytes	25 (16.6%)	13 (8.6%)	11 (7.3%)	1.9 (0.95 to 4.1)	0.074
Joint-space narrowing	7 (4.6%)	6 (4.0%)	19 (12.6%)	1.2 (0.25 to 2.4)	1.0
Medial compartment					
Osteophytes	12 (7.9%)	4 (2.6%)	5 (3.3%)	3.0 (1.1 to 22)	0.080
Joint-space narrowing	10 (6.6%)	7 (4.6%)	8 (5.3%)	1.4 (0.49 to 4.4)	0.62
Lateral compartment					
Osteophytes	10 (6.6%)	0	3 (2.0%)	Cannot be calculated	0.0044
Joint-space narrowing	2 (1.3%)	1 (0.7%)	0	2.0 (0.1 to 118)	1.0
Ankle (n = 145)					
Osteophytes	11 (7.6%)	2 (1.4%)	3 (2.1%)	5.5 (1.2 to 51)	0.026
Joint-space narrowing	12 (8.3%)	1 (0.7%)	0	12 (1.8 to 525)	0.0055
Subtalar joint (n = 145)					
Osteophytes	8 (5.5%)	2 (1.4%)	0	4.0 (0.80 to 39)	0.11
Joint-space narrowing	1 (0.7%)	0	0	Cannot be calculated	1.0

*The data are given as the number of subjects, with the percentage in parentheses.

TABLE III Prevalences of Clinical and Radiographic Signs of Osteoarthritis in the Ipsilateral Knee, Ankle, and Subtalar Joints in Patients with Normal and Abnormal Lower Limb Alignment

	Lower Limb Alignment*		Odds Ratio (95% Confidence Interval)	P Value (Fisher Exact Test)
Knee (n = 114)				
	Normal or Valgus (N = 102)	*Varus (N = 12)*		
Medial osteophytes	6 (5.9%)	2 (16.7%)	3.2 (0.57 to 18)	0.20
Medial joint-space narrowing	5 (4.9%)	2 (16.7%)	3.9 (0.66 to 23)	0.16
	Normal or Varus (N = 109)	*Valgus (N = 5)*		
Lateral osteophytes	7 (6.4%)	0	0 (—)	1.0
Lateral joint-space narrowing	1 (0.9%)	0	0 (—)	1.0
	Normal (N = 97)	*Varus or Valgus (N = 17)*		
Clinical osteoarthritis	9 (9.3%)	3 (17.6%)	2.1 (0.50 to 8.7)	0.38
Patellofemoral osteophytes	14 (14.4%)	2 (11.8%)	0.79 (0.16 to 3.8)	1.0
Patellofemoral joint-space narrowing	14 (14.4%)	1 (5.9%)	0.37 (0.05 to 3.0)	0.46
Ankle (n = 117)				
	Normal (N = 100)	*Varus or Valgus (N = 17)*		
Clinical osteoarthritis	14 (14.0%)	4 (23.5%)	1.9 (0.54 to 6.6)	0.30
Clinical stiffness	7 (7.0%)	1 (5.9%)	0.83 (0.10 to 7.2)	1.0
Osteophytes	10 (10.0%)	2 (11.8%)	1.2 (0.24 to 6.0)	0.69
Joint-space narrowing	9 (9.0%)	0	0 (—)	0.35
Subtalar joint (n = 117)				
	Normal (N = 100)	*Varus or Valgus (N = 17)*		
Clinical osteoarthritis	10 (10.0%)	2 (11.8%)	1.2 (0.24 to 6.0)	0.69
Clinical stiffness	25 (25%)	9 (52.9%)	3.4 (1.2 to 9.7)	0.04
Osteophytes	5 (5.0%)	0	0 (—)	1.0
Joint-space narrowing	1 (1.0%)	0	0 (—)	1.0

*The data are given as the number of subjects, with the percentage in parentheses.

or disability (U = 870.5, p = 0.27).

The prevalences of clinical and radiographic signs of osteoarthritis for lower limbs with normal and abnormal post-fracture alignment are summarized in Table III. Radiographic changes were present in the medial compartment of the knee of two of the six subjects with varus malalignment of the lower limb prior to the fracture and in one of the six subjects with varus malalignment secondary to fracture malunion. In each case, there were also mild radiographic changes in the lateral compartment. No subject with valgus malalignment had radiographic signs of osteoarthritis in the lateral or medial compartment of the knee. There was a trend toward a higher prevalence of clinical signs of osteoarthritis of the knee and radiographic signs of osteoarthritis of the medial compartment of the knee in subjects with malalignment, but the differences were not significant. Objective subtalar stiffness was significantly more common in malaligned lower limbs (p = 0.04).

Effect of Proximal and Distal Fractures

Seven fractures (4%) involved the proximal third of the tibia, seventy-six (46%) involved the middle third, and eighty-one (49%) involved the distal third. There was no significant association between clinical or radiographic signs of knee osteoarthritis and a fracture involving the proximal third of the tibia, although the power for this analysis was low (power = 0.36). There was no significant association between clinical or radiographic signs of ankle or subtalar osteoarthritis and a fracture of the distal third of the tibia (power = 0.94). However, subjects with fractures involving the distal third of the tibia were more likely to report ankle stiffness on the WOMAC questionnaire (χ^2 = 4.04, p = 0.044).

Effect of Other Factors—Multivariate Analysis

Logistic regression analysis confirmed the multifactorial etiology of osteoarthritis. Obesity was associated with joint-space narrowing in the medial compartment of the knee (p = 0.036), and nodal osteoarthritis of the fingers was associated with patellofemoral joint-space narrowing (p = 0.002). Previous injury of the ankle was associated with self-reported ankle pain (p = 0.023) and the presence of subtalar osteophytes (p = 0.022). The results after adjustment for these factors were very similar to the unadjusted results. Apart from an isolated association between self-reported knee pain and shortening ($p = 0.046$), there was no association between fracture malunion and symptoms or radiographic signs of osteoarthritis. However, there was a significant association between malalignment of the lower limb and self-reported knee pain ($p = 0.026$), and the associations between malalignment and clinical evidence of knee osteoarthritis ($p = 0.077$) and medial compartment joint-space narrowing ($p = 0.088$) approached conventional significance. Joint hypermobility, high-energy injury, open fracture, mode of treatment, prolonged immobilization, and joint-surface malorientation were not independently associated with an adverse outcome. For each regression model, the overall fit to the observed data was poor, indicating that the considered factors are not the main cause of the observed osteoarthritis.

Discussion

The present study demonstrates the difficulty of performing a long-term retrospective study of patients who have sustained a fracture. From an original cohort of 1400 patients with a documented fracture, only 164 (12%) were included in the final analysis. In our previous investigation, we found that 239 subjects from the original cohort had died; however, all of these patients had died of either cancer or ischemic heart disease, with the exception of one patient whose death was related to a connective-tissue disease[11]. We were not as successful as we had hoped in tracing subjects who were still alive, perhaps because of inaccurate documentation of their personal details in the cast-room ledgers. It is possible that the untraced subjects were the most mobile, but the long time-interval suggests that they are probably missing at random as most people would be expected to relocate at least once in thirty years. Of the 398 subjects who returned questionnaires, forty-one were not asked to participate in the study as they no longer lived locally and the facilities and funding necessary to arrange examinations and radiographs at their local hospitals were unfortunately not available. Another 151 subjects who had taken part in the questionnaire study did not wish to participate further. The low rate of follow-up means that, although our sample was large enough to examine the effect of modest malunions of ≥5° of angulation, ≥10° of rotation, or ≥10 mm of shortening with satisfactory statistical power, the number of subjects was insufficient for us to draw firm conclusions about the effect of malunions of ≥10° of angulation, ≥20° of rotation, or ≥20 mm of shortening. However, malunions of such severity do not occur commonly in routine clinical practice.

The retrospective design of our study is open to criticism. Most of the information about the treatment of the fracture and other lower limb injuries was obtained by questioning the subjects, as the original hospital notes had been destroyed. More than thirty years after the original injury, subjects' recollection of details may not be accurate or complete, although copies of the entries from the original cast-room ledgers, a set of calendars, and careful clinical examination of the previously fractured leg for relevant scars made it possible to reconstruct an account of the management of the fracture in a large majority of the subjects. The duration of immobilization in a cast was determined partly on the basis of the subjects' recollection and may in some cases be inaccurate, although the median duration of immobilization (seventeen weeks) is consistent with that given in the literature[2]. Most of the assessments and outcome measures used in this study have been previously validated. Clinical measurement of rotational malunion, however, is known to be relatively inaccurate. Unfortunately, we were not able to perform a computed tomographic assessment of tibial torsion.

We are aware of five previous follow-up studies on the effects of malunion in patients who have sustained a tibial shaft fracture[6-10]. Kettelkamp et al.[6], in a study of fourteen patients who had a malunited tibial shaft fracture, showed that the compartmental distribution of knee osteoarthritis was predicted by biomechanical calculations of load transmission through each compartment. Kristensen et al.[7] interviewed ninety-two patients in whom a tibial shaft fracture had been treated with immobilization in a plaster cast between twenty and thirty-nine years previously. Thirty-three subjects (36%) had an angular malunion of >5°, and six of these patients had mild or moderate ankle symptoms without radiographic evidence of osteoarthritis. Although Kristensen et al. concluded that malunion of a tibial fracture did not predispose to osteoarthritis of the ankle, further analysis of their data showed that ankle symptoms were significantly more common in subjects with fracture malunion ($p = 0.016$, Fisher exact test). In the study by Merchant and Dietz[8] , thirty-seven patients were evaluated clinically and radiographically at a mean of twenty-nine years (range, twenty to forty-nine years) after they had sustained a tibial shaft fracture. The clinical outcome was good or excellent for 92% of the knees and 78% of the ankles, and the radiographic outcome was good or excellent for 92% of the knees and 76% of the ankles. Fourteen subjects had an angular malunion of >10°; this was not associated with a worse clinical or radiographic outcome. Puno et al.[9] examined twenty-seven patients at an average of eight years (range, six to twelve years) after a tibial shaft fracture and calculated the change in the orientation of the knee and ankle joints due to the fracture malunion. Patients with greater malorientation of the ankle joint were shown to have a worse outcome as assessed with use of a multidimensional outcome score. However, because 30% of the outcome score was related to clinical or radiographic deformity, this finding does not prove that joint function is worse in subjects with fracture malunion. In the study by van der Schoot et al.[10], eighty-eight patients who had sustained a tibial fracture were evaluated clinically and radiographically between thirteen and seventeen years after the injury. Radiographic evidence of osteoarthritis of the knee and ankle were more common on the side of the fracture than on the uninjured side, although these changes usually were mild and often were not associated with symptoms. Patients with angular malunion of ≥5° were significantly more likely to have radiographic osteoarthritis of the knee or ankle ($p = 0.02$) but were no more likely to have joint symptoms. All patients had returned to their previous employment, and all but three had resumed their usual sporting activities.

Our findings are similar to those of previously published studies. The functional outcome was good in the majority of subjects, although mild knee pain and radiographic signs of osteoarthritis were common and frequently were bilateral. Clinical and radiographic evidence of osteoarthritis of the knee was more prevalent on the side of the fracture than on the contralateral side, but the difference only reached significance with regard to the presence of osteophytes in the lateral compartment of the knee. In comparison, there was a significant increase in clinical and radiographic evidence of osteoarthritis in the ipsilateral ankle and a significant increase in clinical evidence of osteoarthritis in the ipsilateral subtalar joint. We thought that it was important not to overdiagnose the radiographic signs of osteoarthritis because subjects with small osteophytes or mild joint-space narrowing are often asymptomatic[25]. Therefore, for the data analysis, subjects were required to have grade-2 or 3 radiographic changes in order to be considered to have osteoarthritis. The prevalence of severe (grade-3) radiographic tibiofemoral joint-space narrowing has been estimated to be 2.2% among men between fifty and fifty-four years old, with an increase to 8.5% among men between seventy-five and seventy-nine years old[26]. In our group, the prevalence of severe radiographic tibiofemoral osteoarthritis of the ipsilateral knee was somewhat higher (11.6%; nineteen of 164), in agreement with the findings of our previous study[11]. The estimated prevalence of severe radiographic tibiofemoral osteoarthritis of the contralateral knee in our cohort, calculated with use of the age, sex, and side-specific prevalence data from the Zoetermeer survey[26], was 4.3% (seven of 164), which was very close to the actual prevalence of 5.5% (nine of 164). This finding suggests that use of the contralateral knee as a comparator is valid. Our methodology also has the advantage that results are less likely to be confounded by constitutional risk factors for osteoarthritis, such as obesity, which may vary with time but which act similarly on each lower limb.

Although coronal plane malunion of ≥5° was common in our group, only a small minority of subjects had abnormal lower limb alignment as a result. We have shown a trend toward a greater prevalence of osteoarthritis in the medial compartment of the knee in patients with varus malalignment of the lower limb. A malunion of a proximal tibial fracture will cause a greater alteration in the overall lower limb alignment, and therefore in the load distribution in the knee joint, than a distal malunion will. Nomograms to calculate the effects of angulation at different levels of the tibia have been published previously[27].

In summary, the long-term clinical outcome after a tibial shaft fracture was found to be good in the majority of subjects, although mild joint symptoms and mild disability were common. Osteoarthritis was more common on the side of the fracture. While malalignment of the lower limb was possibly associated with osteoarthritis of the medial compartment of the knee in a small number of subjects, most of the observed osteoarthritis was unrelated to malunion, malalignment, or any other factor related to the fracture or the subject. Changes in tibial shaft fracture management designed to decrease the prevalence of lower limb malalignment below that seen in the present study are therefore unlikely to result in a clinically substantial decrease in the prevalence of osteoarthritis thirty years later. Other, undefined factors are much more important in the causation of most of the osteoarthritis observed after this injury. ■

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