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MORPHOLOGICAL OBSERVATIONS OF TORSIONAL FRACTURES OF THE ADULT TIBIAL SHAFT

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The present study is an analysis of the radiographic morphology of 250 consecutive clinical torsional fractures of the adult tibial shaft. The site, extent, degree of comminution and orientation of the principal fracture plane were determined, with special attention paid to the initial lateral displacement as an estimate of injury to the interosseous membrane.

The predilection site of the torsional fractures was at the junction of the middle and distal thirds of the tibia. An additional moment of axial compression in the causative violence seemed to result in a more distal fracture. The orientation of the principal fracture plane did not occur at random. The centre of the actual spiral component of the fracture line was located in the anterolateral and the vertical element of the fracture in the posteromedial quadrant of the tibial circumference in 78 per cent of cases. A latero-medial orientation of the fracture, approaching the sagittal plane and perpendicular to the interosseous membrane, showed increased frequency of severe initial lateral displacement as compared with postero-anterior fractures, lying in the coronal plane ($P < 0.01$). Tibial fractures with intact fibulae were seen only in the young, with a mean age of 25 years for these patients, but no other age-associated fracture characteristics were found.

Key words: biomechanics; computerised tomography diaphyseal bone; stress, mechanical

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The mechanical properties of bone can be investigated at different levels of organisation, from molecular to whole body level. The torsional strength of human tibial whole bone specimens has been tested in experimental studies by Asang (1976) and Martens et al. (1981). The human lower leg, however, is a complex musculo-ligamento-skeletal functional unit. Its biomechanical behaviour under rotation load leading to failure can scarcely be fully explained by means of experimental investigations made on the tibia alone. The important role of the soft tissues, especially the interosseous membrane, in the stability, blood supply and healing of tibial shaft fractures has been pointed out by Sarmiento et al. (1974) and Trueta (1974).

Torsional moments, leading to rotation stress, are often involved in the types of force that cause clinical tibial shaft fractures (Alms 1961, Frankel & Burstein 1965). The present study is a morphological analysis of spiral fractures of the adult tibial shaft. The purpose was to examine the variation and permanence in the radiographic appearance of these fractures and to analyse the influence of the mechanism of injury on the fracture morphology, with reference to previous experimental findings reported in the literature.

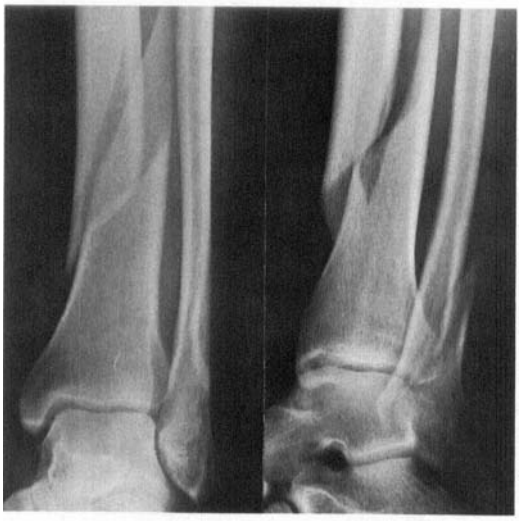

Figure 1. A long latero-medial fracture of the distal third of the tibial shaft with a malleolar associated fibular fracture. The apparently oblique fracture line on the anteroposterior radiogram proved to be indisputably helical in another view.

PATIENTS AND METHODS

The series consisted of 250 consecutive torsional fractures of the tibial shaft in patients over 15 years of age, admitted to the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital during the years 1972–80. There was a total of 1149 patients with tibial shaft fractures under review during this period.

The fracture was considered torsional when the fracture line showed a helical configuration on some of the routine plain radiograms (Figure 1) and there was, in addition, a vertical element between the upper and lower ends of the fracture (Alms 1961). Fractures located within the distal 15 per cent of the tibial length were regarded as metaphyseo-malleolar and were excluded.

The radiograms were analysed for the location and extent of the fracture, the initial shortening, the degree of comminution, the initial lateral displacement in the coronal plane and the orientation of the principal fracture plane. When the middle point of the tibial fracture was located within the region 60–75 per cent distal along the tibial length the fracture was considered a junctional middle-distal third fracture and when within

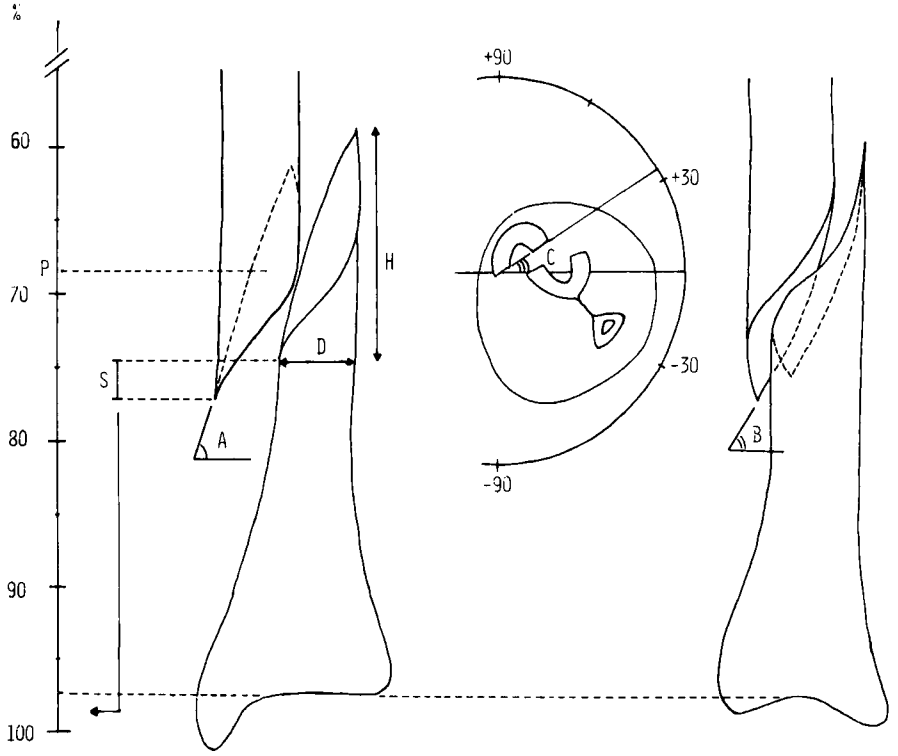

Figure 2. Anteroposterior and lateral views of distal tibia and a cross section at the fracture level. P represents the site of the middle point of the fracture (per cent distal along the tibial length), S the shortening (mm) and H/D the extent of the fracture. The orientation of the principal fracture plane in the cross section (angle C) was calculated with the aid of the angles A and B, determined on conventional anteroposterior and lateral radiograms with the formula: C = arc cot (tanAcosB).

Table 1. Morphology of tibial fracture and initial lateral displacement in the coronal plane as an estimate of injury to the interosseous membrane

Morphological characteristic	Initial lateral displacement		Significance	Total
	Not more than	More than		
	One half of the diaphyseal diameter			
Site				
Middle-distal third junction	140 (63)	81 (37)	N.S.	221
Distal third	21 (72)	8 (28)		29
Extent				
Short fracture line	74 (68)	35 (32)		109
Long fracture line	87 (62)	54 (38)	N.S.	141
Comminution				
Simple fracture line	77 (59)	54 (41)	$P < 0.05$	131
Additional fissures	47 (69)	21 (31)		68
Displaced butterfly fragment	37 (73)	14 (27)		51
Fracture plane orientation				
Posterior-anterior	102 (73)	37 (27)		139
Latero-medial or medio-lateral	59 (13)	52 (47)	$P < 0.01$	111
Total	161 (64)	89 (36)		250

( ) per cent.

76–85 per cent a distal third fracture. The extent of the fracture was classified short when its height did not exceed the double diaphyseal diameter. The site of an associated fibular fracture, when present, was recorded. The fibular fracture was regarded as eccentric when located at a different level as compared with the tibial fracture, i.e. when subcapital, high diaphyseal, suprasyndesmal or malleolar.

The principal tibial fracture plane in the cross section was calculated with the aid of the angles of the fracture measured on conventional plain anteroposterior and lateral radiograms (Figure 2). The plane was named according to the location of the upper and lower ends of the fracture. Thus fractures approaching the coronal plane were called postero-anterior (Figure 3) or theoretically antero-posterior, if the upper end in any fracture had been located anteriorly. Consequently sagittal plane fractures were called latero-medial (Figure 4a) or respectively medio-lateral (Figure 4b).

The statistical evaluation of the results was performed using Student's *t*-test and the chi-square test. The level of significance was $P < 0.05$.

RESULTS

Site of the tibial fracture

The fracture was in the right lower leg in 68 per cent of the patients ($P < 0.001$). The location of the middle point of the fracture was 60–67 per cent distal along the tibial length in 78 patients and 68–75 per cent distal along the length in 143 patients. In only 29 cases (12 per cent) was there a strictly distal third fracture, with the middle point 76–85 per cent distal along the tibia (Table 1). The mean initial shortening at the fracture was 8.3 ± 3.9 mm. A separate fracture of the posterior tibial triangle was seen in 10 patients (4 per cent).

Extent of the fracture

The average extent of the tibial fracture (height/diaphyseal diameter) was 2.12 ± 0.27. It was significantly greater, 2.41, for the distal third fractures than for the junctional middle-distal third ones, 2.08 ($P < 0.02$). The extent of the fracture line did not show any correlation with the length of the tibia or with the width of the shaft.

Degree of comminution

The fracture had smooth surfaces and a simple fracture line in 53 per cent (Table 1). Continuation of the fracture line as a visible additional

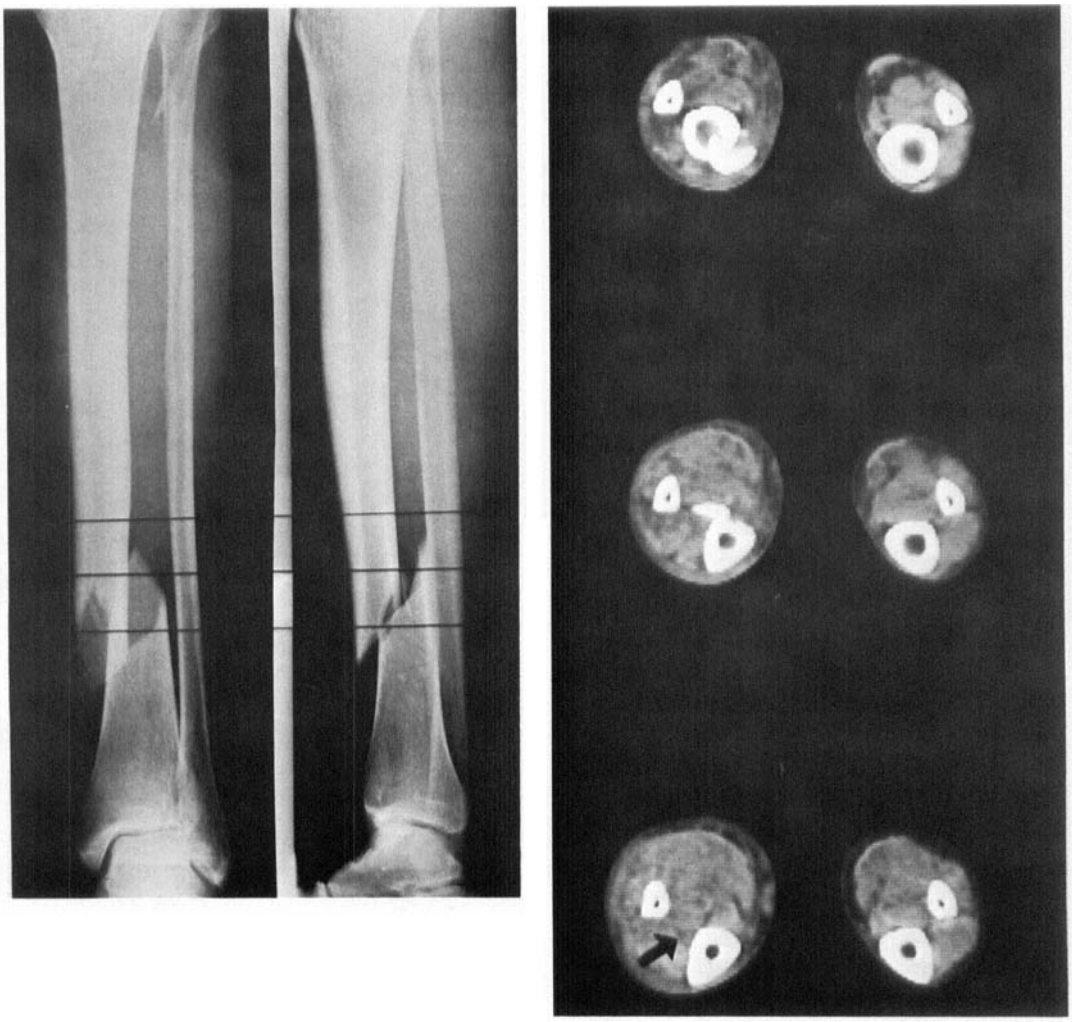

Figure 3. A short postero-anterior fracture with an additional distal fissure, a subcapital comminuted fibular fracture and a calculated fracture plane angle of −5° (a). In this individual case serial computerised tomography was made to demonstrate the damage to the interosseous membrane. Cuts at indicated levels of both the intact and the injured lower leg reveal the detachment of the interosseous membrane (arrow) off the proximal fragment, while the fibula has remained attached by the membrane to the distal tibial fragment. The principal fracture plane is seen in the lowest of the three cuts (b).

fissure was seen in 27 per cent. The additional fissure was distal to the principal fracture line in 55 patients (Figure 3) and proximal in 13 cases. A displaced butterfly fragment was present in 51 patients (20 per cent), the location being dorsolateral in 22 patients (Figure 4a), dorsomedial in 21 and ventral in 8 patients.

Principal fracture plane

The calculated orientation of the principal fracture plane (Figure 2) was postero-anterior (within ±45° of the coronal plane) in the majority, 56 per cent, and latero-medial or medio-lateral (beyond ±45° of the coronal plane) in 44 per cent. The mean orientation angle of the fracture plane was +37°. The detailed distribution was as follows:

−30° to	+30°	87 fractures (Figure 3)
+31° to	+60°	98 fractures
+61° to	+120°	62 fractures
+121° to	−30°	3 fractures

In 196 fractures (78 per cent) the orientation angle was between 0° and +90°, with the centre of the spiral component of the fracture line located in the anterolateral quadrant and the vertical element in the posteromedial quadrant of the tibial circumference. In another 51 fractures the angle was slightly beyond these limits, namely between −30° and 0° or between +90° and +120°. In only three patients was there a medio-lateral fracture pattern with an angle between +120° and −30°, diverging clearly from the others.

Initial lateral displacement

The displacement in the coronal plane was on an average 36 per cent of the diaphyseal diameter. Severe displacement, more than one half of the diaphyseal diameter was significantly more frequent among the latero-medial fractures as compared with the postero-anterior fractures, and among the simple fractures as compared with the fractures having additional fissures or a displaced butterfly fragment (Table 1). The direction of the displacement of the distal tibial fragment was latero-posterior (Figure 3) in all except in the three fractures with a medio-lateral orientation angle of the fracture plane (Figure 4b).

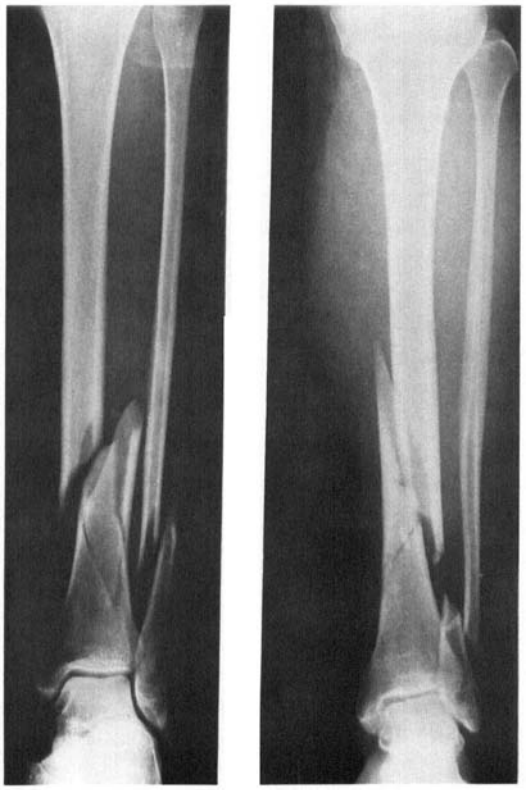

Figure 4. Two uncommon torsional fracture patterns. A latero-medial fracture with a displaced, dorsolateral butterfly fragment (a). A long, presumably internal rotation fracture with a 'reverse', medio-lateral orientation of the fracture plane, the interosseous membrane remaining exceptionally attached to the proximal tibial fragment (b).

Site of fibular fracture

An associated fibular fracture was present in 87 per cent of the patients (Table 2). The mean age of the 145 patients with an eccentric fibular fracture was 41 years, and of 33 patients with intact fibulae, 25 years. The subcapital and high diaphyseal fibular fractures themselves were comminuted (Figure 3) in 76 per cent whereas the suprasyndesmal and malleolar fibular fractures were comminuted in only 31 per cent. Severe initial lateral displacement was seen more often in tibial fractures with eccentric fibular fractures (69 cases) than in fractures with the fibular fracture on the same level with the tibial

Table 2. Site of associated fibular fracture

Site	No. of patients	
Intact fibula	33	(13)
Subcapital	57	(37)
High diaphyseal	34	
On a level with the tibial fracture	72	(29)
Suprasyndesmal	15	(17)
Malleolar	28	
Duplex (subcapital plus malleolar)	11	(4)
Total	250	(100)

( ) per cent.

fracture (20 cases) having severe displacement ($P < 0.02$).

Age and sex of the patients

The mean age of the patients was 36 years (range 16–76 years), 34 years for the male and 41 years for the female. The male:female ratio was 2.4:1. The younger patients had an increased frequency of isolated tibial fractures and the older had more often fractures with eccentrically located fibular fractures, as presented above, but no other age or sex associated differences were noted.

Mechanism of injury

Low energy trauma (stumbling or slipping at ground level, fall on stairs or from a chair or table) caused 79 per cent of the injuries, and high energy trauma (motor vehicle accident, fall from a height) 21 per cent. As for initial displacement no difference emerged between these groups. High energy trauma expectedly resulted more often in fractures with a displaced butterfly fragment ($P < 0.02$). A distinct additional axial compressive moment was present in the accidents of 36 patients. In 22 of these, the fracture was located in the distal third.

DISCUSSION

Torsional loading of a tubular whole bone specimen results in failure at the section where its polar moment of inertia reaches its minimum (Engesaeter et al. 1978). This minimum occurs in the region around 70 per cent distal along the length of the human tibia (Jernberger 1970, Minns et al. 1975, Martens et al. 1981). Although pure torsional violence is unlikely to exist except under experimental conditions, the results of those anatomical measurements agree with the location of the vast majority of the clinical fractures in this series. A component of axial compression in the mechanism of injury appeared to shift the fracture towards the distal metaphysis as previously demonstrated experimentally with rabbit whole bone specimens by Hirsch et al. (1955).

A bone under torsional loading can be expected to have maximum tensile stresses on planes 45° clockwise to the planes parallel to the long axis of the bone (Brooks et al. 1970, Paavolainen 1978). The fracture initiation itself probably occurs as a shear crack or multiple microcracks in the middle of the subsequent spiral (Reilly & Burstein 1974, Netz et al. 1980) and obviously could appear on any surface of a symmetrical tubular specimen. The fractures of this study, however, did not seem to occur at random but most were oriented with the centre of the spiral line located within the anterolateral quadrant of the tibial circumference. This fact presumably is due to, besides the asymmetry of the tibia, the interplay between tibia and fibula and to the role of the soft tissues in the biomechanics of the human lower leg.

As Alms (1961) has pointed out, the typical spiral tibial shaft fracture opens on its soft-tissue hinge when the foot rotates outward. Thus the predominating postero-anterior and latero-medial fractures of this series, with the interosseous membrane remaining attached to the distal tibial fragment while separating from the proximal, were probably external rotation injuries. The very infrequent reverse situation with a medio-lateral fracture plane could then have represented internal rotation injuries. The right lower leg was fractured more often than the left. In right-handed individuals, likely to have likewise a dominant right foot, a misapplication of the body-weight by stumbling or slipping perhaps is prone to occur with just the right leg in external rotation, trying to support the body and prevent the fall.

Severe initial lateral displacement was seen especially in the patients with a latero-medial fracture plane, perpendicular to the plane of the interosseous membrane. Severe displacement of the tibial fracture was also associated with eccentric location of the fibular fracture but, unexpectedly, not with the energy contents of the trauma. Marked displacement has been experimentally shown to be accompanied with extensive damage to the interosseous membrane particularly in a fracture pattern with the tibial and fibular fractures at different levels (Sarmiento et al. 1974). Interestingly the configuration of the fractures located at the junction of the middle and distal thirds of the tibia seemed to follow the distal

margin of the insertion area of the flexor digitorum longus muscle (Gardner et al. 1969). Together with the soleus and the tibialis posterior muscles this muscle brings about the shortening at the fracture but may even participate in the ultimate fracturing force. Asang (1976) has reported dynamic muscle forces at the heel, exceeding the calculated injury threshold of bone.

The ultimate torsional strength of bone is dependent upon the rate of loading, the energy to failure increasing with the rate of deformation (Sammarco et al. 1971, Panjabi et al. 1973). The clinical concept of high energy trauma obviously often signifies rapid loading, and these injuries, indeed, frequently had additional fissures or butterfly shear pieces at the tibial fracture. The fibular fracture, in contrast, when subcapital or high diaphyseal, was often comminuted in low energy traumata. In this type of injury the fibula, subjected to combined twisting and bending, possibly is fractured at a high rate of loading, the tibia itself having already failed. A malleolar fibular fracture, in turn, may occur simultaneously with the tibial fracture, the foot in external rotation analogous to injuries restricted to the ankle. Intact fibulae were seen only in younger patients with still elastic ligaments and flexible fibulae (Teitz et al. 1980). In agreement with the experimental findings of Burstein et al. (1976) no other age-associated differences in the morphology of the fractures were noted.

In conclusion the present results indicate that the injury to the interosseous membrane can be estimated with the aid of morphological observations of the tibial shaft fracture pattern. This allows practical therapeutic considerations as regards stability and vascular supply of the fracture.

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