STABILITY OF UNION AFTER TIBIAL SHAFT FRACTURE

ANALYSIS BY A NON-INVASIVE TECHNIQUE

RICHARD HAMMER, PAUL EDHOLM, BERNT LINDHOLM

From University Hospital, Linköping

The stability of union following the conservative treatment of tibial shaft fractures has been examined in 157 patients by a non-invasive method. With this technique it is possible to ascertain when the fragments are united and whether the strength of union is sufficient for full weight-bearing without protection. The mean time required for union was 14.0 ± 9.2 weeks, with a range of 4 to 48 weeks. In 31 cases union was judged to be delayed; in 22 of these, intended operations were avoided because repeated stability determinations indicated progressive union. Of nine fracture variables examined, the only ones which significantly affected the time required to achieve union were the age and the weight of the patient. Irrelevant factors were the type and level of the fracture, the energy of trauma, soft-tissue injury and the presence of multiple injuries.

It is often difficult to decide by conventional methods at what point union of a tibial shaft fracture is stable enough to allow unprotected loading (Jones 1912; Watson-Jones and Coltart 1943; Edwards and Nilsson 1965; Matthews, Kaufer and Sonstegard 1974). In the search for a solution to this problem a number of methods, designed to provide an objective criterion of the stage of union, have been used (Lippmann 1932; Jernberger 1970; Jørgensen 1972; Markey and Jurist 1974; Puranen and Kaski 1974; Brown and Mayor 1976; Sekiguchi and Hirayama 1979). We have used a non-invasive method, referred to as "shift comparison", by means of which it is possible to obtain a quantitative measure of the stability of union of the tibial fragments, and to follow the variation of this stability during repair (Edholm *et al.* 1983; Edholm *et al.* 1984). At a certain defined value of stability union is considered to have progressed to a stage where the leg may be loaded during walking, with no external fixation or support.

In this present study the progress of union and the time required to achieve complete repair were examined in a series of conservatively treated tibial shaft fractures.

MATERIAL

Over the period 1972 to 1981 measurements of stability were performed on 207 tibial shaft fractures in the same number of patients. Measurements were not performed on every fracture seen, because treatment was carried

out in two departments of the hospital between which there was some difference in the principles applied. In addition, the apparatus used for measurement was not always available throughout the period. This situation has resulted in a tendency to measure those patients in whom clinical and conventional radiographic examinations did not furnish definitive evaluation.

In 13 patients the primary treatment was open reduction and osteosynthesis, in 28 it was external fixation by the method of Hoffmann-Vidal-Adrey, and in 166 cast immobilisation was used. Impairment of union judged to be serious enough to need surgery was found in 26 patients (12.6%). Operative procedures to stimulate union were carried out in five patients after osteosynthesis, in 12 patients after external fixation and in nine patients treated in a plaster cast.

In order to obtain a homogenous series consisting only of conservatively treated fractures, the following cases were excluded: those treated by open reduction and osteosynthesis; those treated by external fixation; and those treated in plaster but in whom secondary surgical measures had been taken to promote union. Of the remaining 157 patients, 105 were male with a mean age of 29.8 ± 16.9 years (range 6 to 79 years); the 52 female patients had a mean age of 37.9 ± 22.3 years (range 6 to 90 years).

Classification of the fractures. Fractures were classified as transverse or oblique, according to whether the angle the fracture gap made with the axis of the tibia was greater or less than 135° . Fractures with an intermediate fragment whose width was at least one half that of the diaphysis were regarded as comminuted. Fractures caused by a direct blow from a heavy object or by a fall from a height of more than three metres, and fractures sustained in road accidents, were considered to be due to high-energy trauma.

R. Hammer, MD, PhD, Department of Orthopaedic Surgery
P. Edholm, Professor, Department of Diagnostic Radiology
B. Lindholm, Engineer, Department of Diagnostic Radiology
University Hospital, S-581 85 Linköping, Sweden.
Requests for reprints should be sent to Dr R. Hammer.

© 1984 British Editorial Society of Bone and Joint Surgery
0301-620X/84/4103 \$2.00

Table I. Types and characteristics of the 166 conservatively treated tibial shaft fractures as related to the cause of fracture. The figures in parentheses relate to the fractures that were excluded because defective union developed that called for surgical treatment

Aetiology	Transverse	Oblique	Comminuted	Fibular fracture	Male	Female	Soft-tissue injury	Multiple injury
Road accidents	16 (3)	6 (1)	11	24	29 (4)	4	13 (2)	6 (1)
Crush injury	1	3 (1)	3	6 (1)	7	0	4 (1)	1
Soccer	19 (1)	7	6	17 (1)	28 (1)	4	1	0
Skiing (downhill)	8	15 (1)	4	9	13	14 (1)	1	0
Fall: <1 metre	7	29 (1)	15	41 (1)	28 (1)	23	3	1
1-3 metres	1	0	1	1	1	1	0	0
>3 metres	1	1	0	2	1	1	0	1
Miscellaneous	1 (1)	7	4	3	3	9 (1)	0	0
TOTAL	54 (5)	68 (4)	44	103 (3)	110	56	22	9

Where there were one or more other major fractures, or damage to other vital areas such as the chest, pelvis, abdomen and cranium, multiple injury was recorded. Soft-tissue damage was considered to be present if there was a skin lesion in direct communication with the fracture, or if there was severe contusion.

The distance of the fracture gap from the tip of the lateral malleolus, the patient's weight and any simultaneous fracture of the fibula were also recorded. The fracture variables, sex distribution and complicating injuries in the respective aetiological groups for all 166 conservatively treated fracture patients are presented in Table I.

METHOD

Measurement of stability of union. The method, described in a previously published study (Edholm *et al.* 1983), is shown in Figure 1. The patient is placed in the supine position on an examination couch. The proximal fragment of the tibia is stabilised by a sling attached to the lateral edge of the table. From a carriage which supports the foot and the distal fragment, a rope passes in the medial direction over a pulley-wheel and from its end is suspended a weight-holder. With this arrangement a bending moment, directed perpendicular to the longitudinal axis of the tibia and in the horizontal plane, can be applied to the site of the fracture. Two anteroposterior x-ray films are exposed, one without a load in the weight-holder and the other with a load varying from 2 to 8 kg. The deflection of the distal fragment in relation to the proximal fragment is then measured by the aid of the so-called shift-comparator. With this shift-comparison technique it is possible to measure the induced deflection with an accuracy of 0.19° (Edholm *et al.* 1984).

The quotient of the deflection by the bending moment is assumed to be inversely proportional to the stability of fracture union. This quotient is corrected for the patient's weight (W) by multiplying by the factor $W/75$ (see Edholm *et al.* 1984) and is then referred to as

Fig. 1

Drawing of the method used for inducing deflection of the tibial shaft. Two films are exposed, one before and one during application of the bending moment to the site of fracture. (Reproduced by kind permission of *Acta Radiologica; Diagnosis*.)

the deflection ratio (DR). When DR is less than 0.08 the strength of union is sufficient for the plaster cast to be removed and for full unprotected loading of the leg during walking to be permitted.

Stability curves. The graph representing the development of stability contains three lines indicating three levels of stability (Fig. 2). One line corresponds to DR 0.08, the adopted lower limit for considering union to have been achieved. Another line (dashed) is at DR 0.3; values above this represent extremely unstable fractures. As the variation between repeated measurement is large, these values are unreliable. The third line (dashed) is at DR 0.03; values below this are unreliable because the deflection at this high level of stability is small in relation to the error of the method.

With each fracture for which two or more measurements were performed a stability curve showing the change in stability during the course of union was drawn.

When all these curves were plotted in a single graph they appeared to follow essentially straight lines—at least the segments of the curves located between the deflection ratio values 0.3 and 0.03 are almost straight (Fig. 2).

By interpolation in a stability curve the point where the curve intersects the line for DR 0.08 was determined. It was then possible to estimate the time at which the fracture became stable enough for unprotected loading.

Fig. 2

Stability curves of fractures for which the deflection ratio was determined on three occasions during union. Within the range $0.03 < DR < 0.3$ the curve for a fracture conforms approximately to the function; $\log(DR) = k \log(t) + a$, where k is the slope coefficient and t is the period since the fracture was sustained.

When all the measurement points were above this stability level, or when only one measurement was performed during the course of repair, the time for achieving stable union could be estimated by extrapolation; this, however, requires a value for the mean slope of the stability curves in the various segments.

Mean slope of the stability curves. Before this calculation was performed measurement points were excluded that might be thought to introduce an element of unreliability or error in the estimation of the mean slope of the curves. All the points for which DR was more than 0.3 were excluded as being unreliable. All the points where DR was less than 0.03 were assigned the value 0.03. In addition, curves were excluded that did not have at least one point above and one point below the 0.08 level. If there were several points where DR was less than 0.08 only the first of them was used, the others being excluded for the following reason. When the stability of union had reached the level $DR < 0.08$ the cast was removed and full unprotected loading of the leg was allowed. In subsequent checks fluctuations of the deflection ratio were observed within the stable region ($0.03 < DR < 0.08$). In a number of cases the ratio stopped decreasing and in some it even rose again slightly. Though such fluctuations in the stable region often occur, they have been found to have no bearing on the process of union.

When the fractures with these criteria had been excluded there remained a selected group of 55 fractures. To the measurement points for each of these a line was fitted by linear regression analysis (Fig. 3). The slopes of these 55 regression lines were plotted against the logarithm of the period which had elapsed since the fracture (Fig. 4). The exponential function so obtained was used to estimate by extrapolation the time required for the rest of the series to achieve stable union.

For the 79 patients with only one measurement point the time to union was calculated by drawing a line from that point to intersect the stability level, with a slope identical to the mean slope associated with this time for

Fig. 3

Regression lines for the measurement points relating to 55 tibial shaft fractures showing the variation of the mean slope of the stability curve when $DR = 0.08$ with the period since the fracture was sustained. The period required to achieve stable union is defined as the time at which the regression line intersects the line for a deflection ratio of 0.08.

Fig. 4

Mean slope for the 55 tibial shaft fracture stability curves when $DR = 0.08$, plotted against the period since the fracture was sustained. By means of regression analysis (Snedecor's F -test) a curve has been fitted to the points which is considered to represent the variation of the mean slope of a fracture stability curve with the time since the fracture was sustained ($F = 8.957$; regression coefficient = 0.38; $P < 0.01$).

achieving stable union. As the time until union and the mean slope, so defined, were initially unknown, the line was calculated by Newton's method (Courant 1937).

For the cases where all the measurement points were located above the level of DR 0.08, points were excluded on the same basis as that applied in the calculation of the mean slope of the curve. For each such fracture the centroid of the remaining points was calculated. This point was considered to represent the whole curve, and the time to achieve stability was then estimated in the same way as for the cases where there was only one measurement point.

Statistical methods. In the calculations the Kolmogorov-Smirnov two-sample test and multiple regression analysis were used. Where appropriate, the chi-squared test, the *t*-test, the 2k contingency table and Snedecor's *F*-test were also used. All the graphs and curves were drawn with a computer-steered plotter.

RESULTS

On the 157 fractures a total of 342 measurements of stability were performed; 79 of the patients had one measurement, the remainder had two or more. The selected group of 55 fractures was comparable with the whole material as regards the fracture variables recorded.

If the time to union was less than five months this was regarded as normal; longer times were considered to indicate delayed union as long as repeated measurements showed an increase in stability. Of the 157 fractures 38 (24.2%) were caused by high-energy trauma. In seven cases (4.5%) there were multiple injuries and in 18 cases (11.5%) there were soft-tissue lesions (Table II).

Fig. 5

Distribution of the 157 tibial shaft fractures for which conservative treatment was given against the time required to achieve stable union. Union at DR 0.08 or below was achieved in 126 cases (80.3%) within five months of the fracture being sustained. Delayed union occurred in 39 cases (19.7%). The 13 patients for whom a stable union was recorded at one month were all children aged from 6 to 10 years.

period of union 29.5 ± 18.6 years ($P < 0.001$). In 22 cases of delayed union, operation would have been performed but for the fact that repeated determination of the deflection ratio indicated progressive union (Fig. 6).

In those cases in which the period of union was prolonged, the time to union was correlated with a concomitant fibular fracture ($P < 0.001$), with high-energy trauma ($P < 0.05$) or with the weight of the patient ($P < 0.001$). Union took place more slowly in women than in men ($P < 0.05$). From an analysis of the influence of the patient's age on the time required to obtain union it became evident that the series consisted of two distinct age groups, one of 48 patients aged between 6 and 20

Table II. Types and characteristics of the 157 tibial shaft fractures related to the energy of the cause

Energy	Transverse	Oblique	Comminuted	Fibular fracture	Male	Female	Soft-tissue injury	Multiple injury	Total
High	15	9	14	29	35	3	14	7	38
Low	34	55	30	68	70	49	4	0	119
TOTAL	49	64	44	97	105	52	18	7	157

Fibular fractures ($P < 0.05$), soft-tissue lesions ($P < 0.001$) and multiple injuries ($P < 0.001$) were significantly more common in the high-energy than in the low-energy trauma group, but no such difference was found in respect of transverse and comminuted fractures. Oblique fractures, however, were significantly more common in the low-energy trauma group ($P < 0.01$).

The mean period for achieving union for the whole series was 14.0 ± 9.2 weeks, range 4 to 48 weeks (Fig. 5). Of the 31 fractures with delayed union 12 were caused by high-energy and 19 by low-energy trauma ($P < 0.05$). The mean age of the patients in the group with delayed union was 44.5 ± 16.7 years and in the group with a normal

years and the other of 109 patients aged over 20 (Fig. 7). The time for union was not correlated with the presence of skin lesions, the level of the fracture, the presence of multiple injuries, or the type of fracture. Since a significant correlation between the individual fracture variables and the time to achieve union may have been due to differences in age distribution in the various aetiological groups (Table III), multiple regression analysis was performed to ascertain the degree of any interaction between the fracture variables. Positive correlations were found only in the respect of age ($P = 0.003$; $t = 3.028$) and weight ($P = 0.04$; $t = 2.015$); the multiple correlation coefficient was 0.59.

Fig. 6

Fig. 7

Figure 6—Stability curves of four of the fractures in which union was clinically judged to be delayed. Measurements of the deflection ratio (DR) indicated progressive union. Immobilisation in plaster could be continued and operation avoided in 22 of 31 patients. Figure 7—Time required to achieve stable union for the 157 patients given conservative treatment plotted against the age of the patients. The dependence of the time to achieve stable union was analysed after the material had been divided into two groups according to age (Snedecor's *F*-test). The correlation was significantly stronger for the 6 to 20 age group ($F = 15.026$; $P < 0.001$) than for the group aged over 20 years ($F = 6.505$; $P < 0.025$).

Table III. Age as related to the cause

Aetiology	Age distribution (years)				Total
	0-20	21-40	41-60	60+	
Road accident	8	15	4	3	30
Crush injury	0	1	0	3	4
Soccer	7	21	1	0	29
Skiing (downhill)	21	6	—	—	27
Fall: < 1 metre	5	14	16	16	51
1-3 metres	1	—	1	—	2
> 3 metres	1	—	1	—	2
Miscellaneous	8	3	1	—	12
TOTAL	51	60	24	22	157

DISCUSSION

In a number of investigations concerned with an evaluation of the influence of various fracture variables on the time required to achieve stable union, the classification of fractures proposed by Charnley (1961) and Nicoll (1964) has been used. Factors considered to have a bearing on the course of union are damage to the interosseous membrane, the extent of the initial displacement, comminution, and the presence of soft-tissue lesions; all these factors reflect the magnitude of the energy involved in the trauma. Other factors are the presence of infection, poor immobilisation, too short a period of immobilisation and distraction by excessive traction (Boyd, Lipinski and Wiley 1961). The validity of these associations has, however, been called into question (Dehne 1974).

One possible explanation of the contradictory nature of these views may lie in the difficulty of deciding when the fracture is united. This difficulty, the large variability of the time required for achieving stable union (Ellis 1958) and the high incidence of irregular union, all make it difficult to define the boundary between normal and delayed union and between delayed union and failure to unite at all.

Moreover, the classification of high-energy and low-energy trauma is fairly crude and has been questioned (van der Linden, Sunzel and Larsson 1975). Unfortunately no more accurate analysis of trauma with respect to the magnitude and direction of the force and the time factor is possible. It is generally accepted, however, that union is delayed by high-energy trauma, the presence of a skin lesion and primary instability. Such associations appeared in the present series when the individual fracture variables were analysed. However, in an extended statistical analysis in which account was taken of the possibility of interference between variables, none of these associations was found. Positive associations with the time required for union were found only for age and body weight—the older and the heavier the patient the slower the union of the fracture.

The time required for union calculated in the present series should be considered in the light of the fact that the material was selected in that measurements of stability were performed more often with fractures whose stage of union was difficult to determine by conventional methods than with those where union was rapid and treatment was easy.

For 79 fractures the first and *only* determination of the deflection ratio yielded low values in 68 ($0 < DR < 0.08$). Of these 68, 31 (46%) had values lower than 0.03 and these were assigned a value of 0.03. These fractures may have been stable for a time, and the

computed time for stable union indicates only an upper limit, the true period being less than or equal to this value. Both these circumstances would tend to result in a longer mean time for union than would apply to an ordinary unselected series. In some patients with multiple injuries and with comminuted open tibial fractures caused by high-energy trauma, the deflection ratio indicated stable union after only eight weeks. Even in such complicated cases, unexpectedly rapid union has been demonstrated by means of stability measurements. On the other hand, union was slow in the case of some closed fractures caused by low-energy trauma, with no appreciable displacement.

In the 79 fractures in which only one stability measurement was performed during the course of union, this measurement was, in all cases, performed because the conventional clinical assessment of union had proved unreliable. In 68 (86%) of these cases deflection ratio values of less than 0.08 were obtained. By extrapolation it can be calculated that in these 68 patients union was

stable enough to allow unprotected loading, and the cast could be removed, on average four weeks earlier (range 2 to 12 weeks).

The weight-standardised value of the deflection ratio (0.08) chosen by us as a criterion for union stable enough to allow full unprotected weight-bearing, probably cannot be raised without increasing the risk of complications such as re-fracture. Our experience suggests that the method we use furnishes good prognostic information regarding the progress of union, and is superior to conventional clinical methods; it also provides a more reliable basis for calculating the time required for union with respect to different fracture variables.

Since 1981, when the present series ended, more than 150 tibial fractures have been measured at regular intervals during the process of union. So far no complications have been registered, and the superiority of this technique to conventional methods has been confirmed. The results obtained from this prospective series will be published in due course.

REFERENCES

- Boyd HB, Lipinski SW, Wiley JH. Observations on non-union of the shafts of the long bones, with a statistical analysis of 842 patients. *J Bone Joint Surg [Am]* 1961; **43-A**: 159-68.
- Brown SA, Mayor MB. Ultrasonic assessment of early callus formation. *Biomed Eng* 1976; **11**(4): 124-7, 136.
- Charnley J. *The closed treatment of common fractures*. 3rd ed. London: Livingstone, 1961.
- Courant R. *Differential and integral calculus*. 2nd ed. London and Glasgow: Blackie & Son Ltd, 1937; **1**: 355-60.
- Dehne E. Ambulatory treatment of the fractured tibia. *Clin Orthop* 1974; **105**: 192-201.
- Edholm P, Hammer R, Hammerby S, Lindholm B. Comparison of radiographic images: a new method for analysis of very small movements. *Acta Radiol [Diagn] (Stockh)* 1983; **24**: 267-72.
- Edholm P, Hammer R, Hammerby S, Lindholm B. The stability of union in tibial shaft fracture: its measurement by a non-invasive method. *Arch Orthop Traumat Surg* 1984; **102**: 242-7.
- Edwards P, Nilsson BER. Graphic representation of healing time in fractures of the shaft of the tibia. *Acta Orthop Scand* 1965; **36**: 104-11.
- Ellis H. The speed of healing after fracture of the tibial shaft. *J Bone Joint Surg [Br]* 1958; **40-B**: 42-6.
- Jernberger A. Measurement of stability of tibial fractures: a mechanical method. *Acta Orthop Scand* 1970; Suppl 135.
- Jones R. Present position of treatment of fractures. *Br Med J* 1912; **ii**: 1589-94.
- Jørgensen TE. Measurements of stability of crural fractures treated with Hoffmann osteotaxis. *Acta Orthop Scand* 1972; **43**: 280-91.
- Lippmann RK. The use of auscultatory percussion for the examination of fractures. *J Bone Joint Surg* 1932; **14**: 118-26.
- Markey EL, Jurist JM. Tibial resonant frequency measurements as an index of the strength of fracture union. *Wis Med J* 1974; **73**: s62-5.
- Matthews LS, Kaufer H, Sonstegard DA. Manual sensing of fracture stability: a biomechanical study. *Acta Orthop Scand* 1974; **45**: 373-81.
- Nicoll EA. Fractures of the tibial shaft: a survey of 705 cases. *J Bone Joint Surg [Br]* 1964; **46-B**: 373-87.
- Puranen J, Kaski P. The clinical significance of osteomedullography in fractures of the tibial shaft. *J Bone Joint Surg [Am]* 1974; **56-A**: 759-76.
- Sekiguchi T, Hirayama T. Assessment of fracture healing by vibration. *Acta Orthop Scand* 1979; **50**: 391-8.
- van der Linden W, Sunzel H, Larsson K. Fractures of the tibial shaft after skiing and other accidents. *J Bone Joint Surg [Am]* 1975; **57-A**: 321-7.
- Watson-Jones R, Coltart WD. Slow union of fractures with a study of 804 fractures of the shafts of the tibia and femur. *Br J Surg* 1943; **30**: 260-76.