Factors affecting fracture healing after intramedullary nailing of the tibial diaphysis for closed and grade I open fractures

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As there is little information on the factors that influence fracture union following intramedullary nailing of the tibia we retrospectively investigated patient-, injury- and treatment-related factors in 161 patients with closed or grade I open fractures of the tibial diaphysis. The patients were reviewed until clinical and radiological evidence of union at a mean of 13.3 months (4 to 60). Multivariate statistical analysis using a Cox proportional hazards model showed that the risk of failure of union increased by 2.38 times for highly comminuted fractures, by 3.14 times when nail dynamisation was applied, and by 1.65 times when the locking screws failed. In fractures with no or only minimal comminution the risk of nonunion increased if the post-reduction gap was ≥ 3 mm.

Closed intramedullary nailing is the preferred method of surgical treatment for closed and grade I open fractures (Gustilo and Anderson classification) of the tibial diaphysis as it produces satisfactory clinical results with a relatively low rate of complications. Although there have been descriptions of the factors which affect parameters of clinical outcome such as function, the risk of re-operation, and the incidence of complications, there is little current evidence on the factors that influence the time to union of fractures of the tibial shaft treated by closed intramedullary nailing. Moreover, the evidence available to date is based mainly on the results of studies using a variety of treatment methods. In order to identify the factors related to the patient, the injury and the method of treatment that might influence the time to union, we studied a cohort of patients with closed or grade I open fractures of the tibial shaft treated in one centre by closed reamed locked intramedullary nailing.

 Patients and Methods

Between 1991 and 1997, we treated 176 patients with closed or grade I open fractures of the tibial shaft by closed reamed intramedullary nailing. We used a closed cross-section stainless steel interlocking nail (Russell-Taylor tibial nail, Smith & Nephew Richards, Memphis, Tennessee). There were 161 fractures in 161 patients (119 men, 42 women) with a mean age of 34.4 years (14 to 87) who were available for follow-up until clinical and radiological union at a mean of 13.3 months (4 to 60). Fifteen patients (8.5%) were lost to follow-up.

Surgery was undertaken on the closed fractures at a mean of 3.5 days (1 to 20) after injury; and on the open fractures within six to eight hours of injury, with wound irrigation, debridement and stabilisation, followed by a second-look wound inspection under general anaesthesia 48 hours later. Post-operatively we allowed partial weight-bearing, progressing gradually to full weight-bearing once callus formation at the fracture site was seen on the radiographs. Clinical and radiological follow-up was performed six weeks post-operatively and at six- to eight-week intervals thereafter, until clinical and radiological union of the fracture had occurred.

The data obtained included the demographics (age, gender) the details of the injury (mechanism, associated injuries, fracture type, according to the AO and Winquist-Hansen classifications). We also obtained details of the method of treatment, including the diameter of the nail, the mode of locking, any post-operative fracture gap and the nature of any secondary interventions, such as dynamisation or other operative procedures. Tables I and II show the characteristics of the injury and of treatment. Finally, we gathered data on complications, including nonunion (defined as the need for further surgery to achieve union) and malunion (defined as an angular deformity > 5°, a rotational deformity of > 10°, and shortening of > 1 cm) and time to union defined...
both clinically (fully weight-bearing without pain) and radiologically (bridging callus in both anteroposterior and lateral radiographic views).

**Statistical analysis.** The differences between the time to union and the prognostic factors were tested by the chi-squared, Kruskal-Wallis or Wilcoxon tests. A further assessment was made using the log rank test in a Kaplan-Meier analysis for the time to union. In order to correct for possible confounding variables, the independent influence of prognostic factors was analysed by an unconditional maximum likelihood application of the Cox proportional hazards model, chosen as being the most suitable for the analysis of our data. Hazard in this context is defined as the probability (risk) of union not having been achieved when the fracture is examined at a given time. Statistical analysis was performed using SPSS statistical software version 13.0 (SPSS Inc., Chicago, Illinois). Fracture union was set as primary outcome. Values for $p < 0.05$ were regarded as significant.

**Results**

**Fracture union.** We found that 157 fractures (97.5% of total fractures) united without an additional major operation.
The mean time to union was 25.8 weeks (8 to 130) with 121 (75.2%) of the fractures being healed in less than six months, 20 (12.4%) between six and nine months, ten (6.2%) between nine and 12 months, and ten (6.2%) in more than 12 months.

Complications. There was one case (0.6%) of deep infection, which was treated with intravenous antibiotics and exchange nailing. Three patients (1.8%) developed superficial infection; two resolved with antibiotics, the third required removal of the nail and wound debridement. Three patients (1.8%) developed a compartment syndrome, which was treated by fasciotomy, and two others (1.2%) developed late sequelae following an unrecognised deep posterior compartment syndrome. Deep-vein thrombosis was diagnosed by phlebography in one patient (0.6%) and fat embolism was diagnosed in another (0.6%). Failure of one or more locking screws occurred in 23 patients (14.3%). Nonunion occurred in four patients (2.4%) and was treated by exchange nailing in one patient and by fibular osteotomy and dynamisation of the nail in three. These patients were followed up until fracture union after their secondary procedure. Malunion was observed in two fractures (1.6%), including malrotation in one dynamically nailed fracture and 8° of valgus angulation in one statically nailed fracture following failure of the distal screws.

Patient and injury characteristics. The results of the statistical analysis of the mean and median times to fracture union according to the characteristics of both patient and injury are shown in Table III. Analysis for differences in the time to union between groups (age, gender, mechanism of injury and the presence of associated injuries) showed no significant differences. However, further analysis that took into account fracture union as outcome revealed a significant difference in the time to union between both age (log rank; chi-squared = 8.352; df = 3; p = 0.039) and mechanism of injury (log rank; chi-squared = 9.779; df = 3; p = 0.021).

Fracture characteristics. The results of the analysis of the time to union according to fracture characteristics are shown in Table IV. The time to union was significantly longer for grade I open fractures than for closed fractures (log rank; chi-squared = 4.197; df = 1; p = 0.041). Similarly, the time to union was significantly longer in unstable than...
which remained statically locked throughout the healing
a significantly longer time to union than were fractures
ation, or those with failure of a screw, were associated with
trations of the tibial diaphysis was not significantly different
the fibula was intact, although this was not significant (log rank; chi-squared = 1.690; df = 3; p = 0.639). In addition, the time to union was shorter when the fibula was
screw failure and delayed dynamisation. We found that the risk for failure of union was increased 1) when the fracture gap was ≥ 3 mm, 2) when dynamisation was used, and 3) when the locking screws failed (Table VI). Finally, we found no significant independent effect of any individual factor on the time to union for unstable fractures (n = 25).

Discussion
Our results have shown an overall union rate of 97.6%, which is comparable with previous reports. However, direct comparisons are difficult because of variations in the classification of the fractures and the outcome criteria used.\(^4\)

We found a significant difference in the mean and median time to union of the fractures between the age groups and for fractures caused by a road traffic accident. However, these two parameters may be related, as most of the fractures caused by road traffic accident occurred in this age group. This prolonged time to union may be consistent with previous observations showing a similar effect for high-energy tibial fractures,\(^5\) although this was not the case for all studies of tibial fractures treated by intramedullary nailing.\(^4,8\) Clearly, there are other patient-related factors that might influence the fracture-healing process, but these were not the major focus of our investigation.

We also found that the mean and median time to union was significantly longer in open rather than closed fractures. Although the degree of comminution has been regarded as an important prognostic factor in fractures of the tibial shaft,\(^16\) the results of previous studies of tibial intramedullary nailing failed to show significant differences in the time to union between comminuted and non-comminuted fractures,\(^17\) or between fractures with different degrees of comminution.\(^8\) It thus appears that comminution is a poor predictor of outcome for fractures treated by intramedullary nailing. Our results have for the first time shown a significant difference in the mean and median time to union between fractures with either no or only a low degree of comminution and highly comminuted fractures.

Table VI. Analysis of the independent influence of factors, using a Cox proportional hazards model, for all fractures (n = 161)

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Hazard ratio</th>
<th>95% confidence interval</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable fracture</td>
<td>2.38</td>
<td>1.48 to 3.81</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Dynamisation</td>
<td>3.14</td>
<td>1.97 to 5.01</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Screw failure</td>
<td>1.65</td>
<td>1.05 to 2.58</td>
<td>0.030</td>
</tr>
</tbody>
</table>

Table VII. Analysis of the independent influence of factors, using a Cox proportional hazards model, for stable fractures

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Hazard ratio</th>
<th>95% confidence interval</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture gap ≥ 3 mm</td>
<td>2.69</td>
<td>1.68 to 4.31</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Dynamisation</td>
<td>3.07</td>
<td>1.81 to 5.22</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Screw failure</td>
<td>1.86</td>
<td>1.11 to 3.11</td>
<td>0.020</td>
</tr>
</tbody>
</table>

in stable fractures (log rank, chi-squared = 6.306; df = 1; p = 0.012). Although we found that the time to union increased according to the AO classification, these differences were not significant (log rank; chi-squared = 4.902; df = 2; p = 0.086). Similarly, although we observed that the time to union increased with more distal or segmental fractures, the mean time to union for fractures at different locations of the tibial diaphysis was not significantly different (log rank; chi-squared = 1.690; df = 3; p = 0.639). In addition, the time to union was shorter when the fibula was intact, although this was not significant (log rank; chi-squared = 3.814; df = 1; p = 0.051).

**Treatement characteristics.** The results of the analysis of the time to union according to the treatment characteristics are shown in Table V. We found that a post-reduction fracture gap of ≥ 3 mm with a statically-locked nail was associated with significantly longer time to union than with a gap of < 3 mm (log rank; chi-squared = 34.687; df = 1; p < 0.001). Furthermore, a statically locked nail was associated with a significantly longer time to union than a dynamically locked nail (log rank; chi-squared = 8.468; df = 1; p = 0.004). There was no significant difference in the time to union between fractures treated by static and dynamic fixation when the post-reduction gap was < 3 mm (log rank; chi-squared = 1.952; df = 1; p = 0.162). Finally, fractures treated by static fixation which required dynamisation, or those with failure of a screw, were associated with a significantly longer time to union than were fractures which remained statically locked throughout the healing period (log rank; chi-squared = 27.599; df = 1; p < 0.001).

**Independent influence of all factors.** For this analysis we considered patient age and gender, mechanism of injury, the presence of associated injuries, AO classification, fracture level, open or closed types of fracture, the degree of comminution, residual post-reduction fracture gap, mode of locking, screw failure and delayed dynamisation. We found that the risk for failure of union was increased 1) in unstable fractures, 2) when dynamisation was used, and 3) when the locking screws failed (Table VI). Analysis of stable fractures (n = 136) showed that the risk for failure of union was increased 1) when the fracture gap was ≥ 3 mm, 2) when dynamisation was used, and 3) when the locking screws failed (Table VII). Finally, we found no significant independent effect of any individual factor on the time to union for unstable fractures (n = 25).
need for re-operation in surgically treated fractures of the tibial diaphysis.9 Our results show that a residual gap of ≥3 mm significantly prolongs the time to union in tibial fractures treated with a statically locked intramedullary nail. This also suggests that a residual fracture gap is more important in tibial fractures treated by statically locked intramedullary nailing than in similarly treated femoral fractures, where a gap of up to 5 mm does not influence the time to union.18

The reported rate of dynamisation of statically nailed tibial fractures in earlier studies ranged between 10% and 30%,4,6,17 whereas the timing of dynamisation ranged between six weeks and four months.4,6,12,17,19 The relatively low rate (14.9%), as well as longer time (17.8 weeks) for nail dynamisation compared to most other series,4,6,12,17,19 may partly explain the overall longer time to union, the low rate of malunion, and the high rate of locking screw failure in our series. Our results showed that fractures that required dynamisation had a mean and median times to union that was significantly longer than those that did not; this agrees with earlier work.4 Finally, we found screw failure to be associated with failure of union at that time, such failure perhaps representing an autodynamisation event.

Statistical analysis was initially undertaken by Ionnis Vlachonicholis, Professor of Biostatistics. Because of his serious (fatal) illness, subsequent analysis was undertaken by his associate, A. K. Alegakis.

No benefits in any form have been received or will be received from a com-

References