Fracture in long bones stabilised by telescopic intramedullary rods in patients with osteogenesis imperfecta

We investigated the fracture-free survival of long bones stabilised by a telescopic intramedullary rod (TIMR) in patients with osteogenesis imperfecta with respect to the remodelling status of fracture or osteotomy sites and TIMR regions, in order to identify risk factors for fracture. A total of 44 femora and 28 tibiae in 25 patients with a mean age of 5.0 years (1.9 to 10.5) at presentation were studied. There were six patients with Sillence type I, five with type II, 13 with type IV and one with type V osteogenesis imperfecta. All received bisphosphonate treatment at the same stage during the mean follow-up of 7.3 years (0.5 to 18.1). The fracture-free survival was estimated at 6.2 years (95% confidence interval 5.1 to 7.3) by Kaplan-Meier analysis. More than half the fracture or osteotomy sites remained in a less-remodelled state at the latest follow-up or time of fracture. Of the 33 fractures, 29 (87.9%) occurred in long bones containing a less-remodelled site, and these fractures were located at this site. The relative fracture risk at the rod tip was significantly greater than in any other TIMR region (p < 0.001), and this was higher in bone segments having a less-remodelled site.

This study shows a persistent fracture risk in TIMR-stabilised long bones, especially at less-remodelled fracture or osteotomy sites and at the rod tip.

The concept of multiple osteotomies and intramedullary rodding for children with osteogenesis imperfecta (OI) was introduced by Sofield and Millar in 1959.1 Because of growth, fixed-length rods require frequent revision2 and this prompted the introduction of the telescopic intramedullary rod (TIMR), by Bailey and Dubow.3 However, high complication rates have been reported using this device due to problems associated with its ‘floating’ T-piece,4,5 and the Sheffield modification (Downs Surgical, Sheffield, United Kingdom) was developed with a permanently fixed T-piece in an attempt to avoid these complications.6 However, the insertion of any rod with a T-piece through an articular surface is traumatic and its removal during revision surgery frequently more traumatic. In recent designs of TIMR, such as the Fassier-Duval7 (PeguMedical, Laval, Canada) and the interlocking telescopic rod8 (U & I Co., Uijeongbu-si, South Korea) the sleeve and obturator are introduced in an antegrade manner, minimising intra-articular injury.

Such improvements have reduced the revision and complication rates associated with a TIMR.9 Bisphosphonates also improve the general condition of patients with OI and reduce the frequency of fractures.10 However, long-bone fractures cannot be prevented completely, even with a TIMR in situ.

We are unaware of any study which has addressed the fracture pattern in long bones with a TIMR in situ. The purpose of our study, therefore, was to describe the fracture-free survival pattern of the long bones of patients with OI stabilised with a TIMR, and to identify the risk factors of fracture with a rod in situ.

Patients and Methods

This retrospective study was approved by our institutional review board. Between October 1988 and January 2009, 72 primary TIMR procedures were performed in 44 femora and 28 tibiae in 25 patients. There were 11 boys and 14 girls. The implants were Bailey-Dubow rods4 in three cases, Sheffield rods7 in 30, and interlocking telescoping rods8 in 39. According to the Sillence classification11 there were six children with type I, five with type III, 13 with type IV, and one with type V OI. Their mean age at the first TIMR procedure was 5.0 years (1.9 to 10.5) and the mean follow-up was 7.3 years (0.5 to 18.1). All patients received intravenous or oral bisphosphonates during follow-up. A total of 12 received cyclic intravenous pamidronate, six
oral alendronate, and two both alternatively for a mean of 61.9 months (0.9 to 112). The mean accumulated dose of cyclic intravenous bisphosphonate was 46.3 mg/kg (12 to 81) and oral alendronate was administered for a mean of 18.3 months (0.23 to 52). The remaining five patients received bisphosphonate at another hospital.

Radiological and medical records were reviewed retrospectively by two authors (TJC, JBK).

We calculated the fracture-free survival of the stabilised long-bone segments using Kaplan-Meier survival analysis for the 72 procedures. A fracture in a long-bone segment with a TIMR in situ, whether treated operatively or conservatively, was considered a fracture endpoint. Corrective osteotomy not associated with fracture was considered a fracture-free endpoint. The exchange of an outgrown rod was not counted as an event affecting the status of the long-bone segment.

We analysed the effects of two parameters on the risk of fracture after TIMR, namely the remodelling status of the fracture or osteotomy site and the TIMR region. Serial radiographs were reviewed to determine the status of remodelling. Following clinical union, the radiological remodelling at these sites was classified as well- or less-remodelled. The former was defined by the absence of a radiolucent line or fusiform callus, and the latter by persistence of a radiolucent line at the fracture/osteotomy site or fusiform callus (Fig. 1). We analysed 112 fracture/osteotomy sites in the 72 cases and the remodelling processes at these sites were followed. The number of fractures in bone segments containing a less-remodelled site was counted. Also, we investigated whether these fractures were located at less-remodelled sites or elsewhere.

The TIMR region was divided into four areas, namely sleeve-only, obturator-only, overlapping, and the rod-tip (Fig. 2). The obturator-only and sleeve-tip regions were well identified on plain radiographs. However, the obturator-tip, sleeve-only and overlapping regions were sometimes difficult to determine. In such cases they were estimated from the lengths of the sleeve and obturator implanted. The locations of the 33 fractures among the 72 primary TIMR cases were grouped according to the TIMR regions described above, and the proportional lengths of rod regions were measured in every case. The expected number of fractures at each TIMR region were calculated by assuming that the probability of a fracture at
each area was proportional to its length. The relative risks of fracture at each region were calculated by dividing the observed by the expected number of fractures. The fracture cases were then grouped into those at a less-remodelled (29 cases) and those at a well-remodelled site (four cases). The relative risks of fracture at each TIMR region were calculated separately in the two groups and the fracture risks among TIMR regions were compared using the chi-squared goodness-of-fit test.

**Statistical analysis.** All statistical analysis was performed using SPSS for Windows (version 12.0; SPSS Inc., Chicago, Illinois), and a p-value < 0.05 was considered statistically significant. When comparing remodelling between sites and TIMR among regions, we did not adjust the variations in severity of disease and age at surgery, because distribution of these parameters was balanced among the subgroups. However, as the durations of follow-up were not distributed evenly between less-remodelled and well-remodelled groups, association between the state of remodelling and the frequency of fracture was analysed using the Cochran-Mantel-Haenzel test with three strata (duration of follow-up less than two years, two to four years, and more than four years). The fracture-free survival was calculated using the Kaplan-Meier method with 95% confidence interval (CI).

**Results**
For the 72 procedures the Kaplan-Meier fracture-free survival was 6.2 years (95% CI 5.1 to 7.3). The fracture-free
cumulative survival probability reached 0.79 (95% CI 0.69 to 0.89) at three years post-TIMR, 0.65 (95% CI 0.52 to 0.77) at five years and 0.41 (95% CI 0.25 to 0.56) at eight years (Fig. 3).

The state of remodelling was followed at 112 fracture or osteotomy sites: 43 (38.4%) became well remodelled and 69 (61.6%) less remodelled at latest follow-up or at fracture. Of 33 fractures, 29 occurred at less-remodelled sites, and only four at well-remodelled sites (Cocharan-Mantel-Haenzel analysis, p = 0.0004). In bone segments containing a less-remodelled site(s), no fracture occurred elsewhere in the bone.

A total of 33 fractures occurred in 33 long-bone segments containing a TIMR in situ after 72 primary TIMR procedures. The mean proportional lengths, expected and observed number of fractures and relative fracture risks are listed in Table I. Although the rod-tip area comprised about 10% of the length of the TIMR and therefore was expected to have 3.3 of the 33 fractures, it was associated with 13 fractures, giving a relative fracture risk of 3.94. Conversely, the overlapping, obturator-only and sleeve-only areas had fewer fractures than expected based on their lengths, these differences were statistically significant (chi-squared test, p < 0.001), but there was no significant difference between the sleeve-only, obturator-only and overlapping areas (chi-squared, p = 0.330).

Long-bone segments containing a less-remodelled site presented a higher risk of fracture at the rod-tip area (chi-squared test, p < 0.001, Figs 4a and 5). Conversely, long-bone segments without a less-remodelled site presented an increased but not significantly higher relative risk of fracture at the rod-tip area (chi-squared test, p = 0.703, Fig. 4b) (Table II). However, the small number of cases in this subgroup (n = 4) did not provide enough power to detect significant differences according to the coincidence of a less-remodelled site and rod-tip area.

### Discussion

In this series, about one-third of patients undergoing primary TIMR sustained a fracture in the same long-bone segment within five years. Joseph, Rebello and B12 reported a mean survival time for a Sheffield telescoping rod of 52.0 months in femora and 42.7 months in tibiae. This is shorter than either the mean or the median survival times of our series, probably because they included all revision operations as endpoints, whereas we included only re-fractures. Considering that the mean age at TIMR was 5.0 years, and that the median fracture-free survival was 6.2 years, it is probable that a long-bone segment containing a primary TIMR will fracture before skeletal maturity. Although the fracture risk after TIMR in an individual patient should vary according to factors such as the severity of the disease, these data would be useful for explaining life-long prognosis to patients and their carers.

In the latter part of the study, we attempted to identify the risk factors for fractures in TIMR-implanted long-bone segments. We investigated fracture location with respect to remodelling status and TIMR regions in order to determine the weakest points.

Following clinical union of a fracture or osteotomy and recovery to pre-operative function, the fracture and osteotomy sites take time to acquire a normal cortical structure, or remain as gaps on plain radiographs. In this study, 61.6% of sites remained less-remodelled at the latest follow-up or fracture. Munns et al13 reported that 42 of 155 (27.1%) fractures and 97 of 162 (59.9%) osteotomies in cases receiving pamidronate showed delayed healing, defined as a persistent gap for one year. They suggested that osteotomy rather than fracture, elderly patients and tibial osteotomy were predictors for delayed healing when pamidronate was given. Our data suggest that this delayed healing or persistent gap represents a weak point in long bones and therefore probably increases the risk of fracture. Prolonged protection has been advised in this situation,14 but usually it is extremely difficult to persuade children who feel completely recovered to wear a brace. Additional surgery to achieve complete healing is a possibility, but no effective method has so far been reported.

TIMR comprises two rods that overlap, which, when implanted, have four regions with different mechanical characteristics, namely, the sleeve-only, the overlapping, the obturator-only, and the rod-tip regions (Fig. 2). It is noteworthy that the rod-tip area had the highest risk of fracture. It is well known that stress concentration occurs at the corners of metal plates,15 and, similarly, stress concentration should also occur at the rod-tip areas, where mechanical properties change abruptly. Owing to the telescopic nature of the TIMR, it is inevitable that there are two rod-tip areas. This study suggested that if the rod-tip area coincides with a less-remodelled fracture or osteotomy site, the risk of fracture would be higher than when it does not (Fig. 4). This provides some insight into the exchange of pre-existing TIMRs, which is usually considered when the long bone has outgrown the rod to a point where the rod is about to

| Table II. Number of fractures with reference to telescopic intramedullary rod regions |
|---------------------------------|--------|--------|--------|--------|
|                                 | Sleeve-only | Obturator-only | Overlapped | Rod-tip |
| Less-remoulded†                 | 5       | 2       | 10      | 12     |
| Well-remoulded‡                 | 1       | 1       | 1       | 1      |

* in segments with a less-remoulded site
† in segments without a less-remoulded site
However, our data led us to hypothesise that in order to reduce the risk of fracture, rods need to be exchanged when the rod-tip area coincides with a less-remodelled fracture or osteotomy site. When the sleeve tip is at such a site, exchange of the sleeve alone could eliminate the risk of fracture. Conversely, when the obturator tip is at a less-remodelled site, it is the obturator that should be exchanged (Fig. 6). However, the exchange of an obturator with a T-piece may damage the articular cartilage of the distal femur, and we suggest that in this situation an interlocking telescopic rod may have merit.  

We have shown that the long bones of patients with OI have a substantial risk of fracture even after intramedullary rodding, and analysed the risk factors for fracture in TIMR bone segments. The study has limitations because it was retrospective and may be affected by confounding factors, which make it unlikely to be free from bias. The severity of the disease varied considerably in the patient cohort. The analysis was based on the assumption that the deforming force is distributed evenly over the whole long-bone segment, and that the fracture occurs at the weakest point. Furthermore, femora and tibiae in the same patients were considered as separate cases instead of including only one bone segment from each. As the remodelling status or TIMR region relationships in the bone segments of the same patients usually differ from segment to segment, we felt that this approach was justified. The risk of fracture should also be related to the thickness of the rod. However, the complex relationship between the thickness of the rod and the diameter of the medullary canal could not be analysed in this study. Therefore, we can only claim that our analysis represents a rough estimation of the risk of fracture without including all relevant factors. Nevertheless, this is the first attempt to analyse relationships between TIMR regions and the risk of fracture.

In conclusion, we have shown that long bones containing a TIMR in patients with OI are still at significant risk of fracture, and that less-remodelled fracture or osteotomy sites and the TIMR rod-tip region are weak points. Furthermore, the coincidence of these two risk factors seems to increase the fracture risk maximally. Although no method is currently available to accelerate the remodelling of fracture or osteotomy sites and the presence of the rod-tip region is unavoidable in TIMR-implanted long bones, timely exchange of rods could prevent the coincidence of these factors and thereby possibly reduce the risk of fracture. However, the effectiveness of this strategy remains to be proven.

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**References**


