GROWTH CHANGES IN FRACTURED LONG-BONES

A STUDY OF 126 CHILDREN

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In this study of fractures of the shaft of the tibia and femur in children, the growth rate of these long bones after injury was assessed by serial radiographical measurements of bone length, accurate to the nearest millimetre. Within three months of injury the rate of growth was at its maximum and was 38 per cent in excess of normal. The rate then decreased but remained significantly raised for two years and returned to normal in the tibia approximately 40 months after injury and in the femur between 50 and 60 months. The uninjured tibia in the same limb as a fractured femur also underwent an acceleration of growth, but to a lesser degree. An uninjured femur was not so affected by an injured tibia. The growth rate in these limbs was unaffected by the age or sex of the child, or the site or direction of the fracture. These findings may be of clinical use in the timing of corrective treatment where a leg length discrepancy exists as a result of injury to, or malunion of, a long bone in the lower limb of a child.

There have been previous observations of increased growth after injury to the shaft of a long bone in children (Ollier 1859; Speed 1923; David 1924; Cole 1925; Clark 1926; Cole 1926; Bisgard 1936; Blount, Schaefer and Fox 1944; McFarland 1958; Barfod and Christensen 1959; Henry 1963; Hedstrom 1969). This increase has been regarded as either a precise compensatory mechanism by which the discrepancy in length after injury becomes adjusted, or as an inevitable and unvarying physiological response to trauma with no such compensatory role.

Eighty-four fractures of the shaft of the tibia and 42 fractures of the shaft of the femur found in children less than 13 years of age were therefore studied in order to determine the effects of such injuries upon the subsequent growth of these bones.

METHODS

The injuries were treated by conservative methods and no attempt was made to achieve anatomical reductions. One injury was treated by internal fixation, and the results for this child have been considered separately.

The first of a series of accurate measurements of bone length was made, using a radiographical technique, between six and 12 weeks after the injury when all the fractures had united sufficiently to be left free of support. For each patient the following information was recorded: the age and sex; the site and type of the fracture; the initial severity of the fracture, measured in terms of comminution, displacement, and compounding; the presence of an associated fracture of the fibula with tibial fractures; reduction, measured in terms of shortening and angulation; the lengths of both major bones of both lower limbs; and the maturation of the bone, taken from radiographs of the wrist (Tupman 1962).

Further radiographic measurements were taken at intervals of six months for as long as possible. The information for any child observed over a period of at least nine months was useful. The observations of greatest value were those from the 55 children with tibial fractures and the 32 children with femoral fractures who were followed for between two and five years.

All measurements were obtained by scanography (Vaughan 1966). The child was placed on top of a cassette containing a single film and both limbs were exposed simultaneously, from hips to ankles, by means of a travelling source discharging through a slit diaphragm. This slit was placed directly beneath the focal spot and, since the beam was not divergent, there was no magnification. Accuracy to within one millimetre was possible using the mid-points of the joint spaces of the hip, knee and ankle as reference points.

The use of a slit diaphragm and a low-intensity travelling source permitted the use of a very small dose of radiation. Even after repeated exposures to this dose at intervals of six months, a patient received less cumulative radiation than that from one standard radiograph of a lower limb.

RESULTS

The distributions of the children according to their sex and age are shown in Figures 1 and 2.

Acceleration in growth after injury for the series of femoral and tibial fractures is shown in Figures 3 and 4 respectively. In these graphs the mean difference in length of the injured and uninjured bones was subtracted from each individual difference to reduce the variation between the patients. To obtain an approximate curve the average differences in length were calculated at the central time point for each cluster of results.

The length of the uninjured limb was used as the normal and the differences in length between injured and uninjured bones as the index of the change in the growth rate of injured bones. The slope of the curve
shown that the growth rate increased above normal and the flattening of this curve indicated that the growth rate of the injured bone eventually returned to normal. The acceleration in growth of the fractured bones reached a maximum between three and six months after injury. Thereafter the acceleration was progressively less marked and eventually the growth rate returned to normal between three and five years after injury.

In this curve it is valid to include results from patients able to attend only for a short follow-up period or spasmodically. It was not necessary to account for the differences in length which normally occur between similar bones, since it was the rate of the growth which was being measured and not absolute differences in length. Spontaneous variations in the general rate of growth do not affect the comparison as both the injured and uninjured bones are equally involved. The curves for each patient were similar in general shape.

The normal growth rates for both tibiae and femora were found by Tupman (1962) and Anderson, Messner

Figure 1 — The ages of children with fracture of the femur. The ratio of girls to boys is 1:2. The black area represents 32 cases followed for more than two years after injury. Figure 2 — The ages of children with fracture of the tibia. The ratio of girls to boys is 3:5. The black area represents 55 cases followed for more than two years after injury.

Figure 3 — Changes in the growth of the femur after injury. Figure 4 — Changes in the growth of the tibia after injury (see text).
and Green (1964) to be of the order of 0.13 centimetre per month. Figures 5 and 6 show that for both these bones after injury the growth rate can exceed this normal rate by as much as 0.05 centimetre per month during the period of maximal acceleration. This is almost 38 per cent above the normal rate. The tibial growth rate increased in the first three months after injury, subsequently slowed down by half after 12 months and returned to normal by about 40 months. In contrast the femoral growth rate increased over a longer period, the rate was not halved until 18 months after injury, and a normal growth rate was reached between 50 and 60 months after injury. Significant measurable overgrowth therefore ceased within 1.5 years after fracture of the tibia and within two years after fracture of the femur. Therefore, in general, the femur eventually achieves a considerably greater absolute increase in length than the tibia.

It was found that the increased growth rate of a fractured femur was accompanied by an increase in that of the ipsilateral tibia, although to a much lesser extent than in the femur. The maximal growth rate, which was about 0.1 millimetre per month above normal for the uninjured tibia, was reached at approximately the same time as that of the injured bone and returned to normal between 12 and 15 months after injury. By this time the tibia was rarely more than one or two millimetres longer than the tibia in the other leg which was of no clinical significance. In contrast, no such increase occurred in the ipsilateral femur of a leg with an injured tibia.

It would be useful to know if the increase in the growth rate varies according to the different type of injury. Therefore results from children with similar fractures were compared with the results for the whole series. The fractures were categorised according to the location of the fracture within the bone; the direction of the fracture line; the severity of the fracture; the horizontal displacement and the shortening of the ends of the bone (Table I).

The results revealed no relationship between the increase in the rate of growth after injury and the patient’s age or sex, the direction of the fracture line, the fracture site, or its severity. The numbers of comminuted and compound injuries were insufficient for statistical analysis, but the individual results showed no more than average acceleration.

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**Table 1. Features of the tibial and femoral fractures**

<table>
<thead>
<tr>
<th>Location of fracture</th>
<th>Tibia</th>
<th>Femur</th>
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<tbody>
<tr>
<td>Proximal juxta-epiphysial</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Proximal third of shaft</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Middle third of shaft</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Distal third of shaft</td>
<td>39</td>
<td>4</td>
</tr>
<tr>
<td>Distal juxta-epiphysial</td>
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<td>1</td>
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<table>
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<th>Line of fracture</th>
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<th>Femur</th>
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<tbody>
<tr>
<td>Transverse</td>
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<td>22</td>
</tr>
<tr>
<td>Oblique</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Spiral</td>
<td>31</td>
<td>12</td>
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<table>
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<tr>
<th>Severity of fracture</th>
<th>Tibia</th>
<th>Femur</th>
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<tbody>
<tr>
<td>Incomplete</td>
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<td>2</td>
</tr>
<tr>
<td>Complete</td>
<td>52</td>
<td>40</td>
</tr>
<tr>
<td>No displacement</td>
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<td>5</td>
</tr>
<tr>
<td>Moderate displacement *</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>Marked displacement †</td>
<td>7</td>
<td>12</td>
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<tr>
<td>Comminuted</td>
<td>4</td>
<td>1</td>
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<tr>
<td>Compound</td>
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<table>
<thead>
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<th>Shortening (centimetres)</th>
<th>Tibia</th>
<th>Femur</th>
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</thead>
<tbody>
<tr>
<td>None</td>
<td>54</td>
<td>9</td>
</tr>
<tr>
<td>&lt;0.5</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>0.6–0.9</td>
<td>9</td>
<td>14</td>
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<td>1.0–1.4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>&gt;1.5</td>
<td>5</td>
<td></td>
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</tbody>
</table>

*<one diameter, †>one diameter

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Figure 7—The relationship between initial and final length difference for fractured femora. The initial difference in length is measured between six and 12 weeks after injury and the final difference after the increase in growth has finished. Figure 8—The relationship between initial and final length difference for fractured tibiae. Figure 9—The relationship between initial length difference and the increased growth achieved in fractured tibiae. Figure 10—The relationship between the initial difference in length and the increased growth achieved in fractured femora.
Only two features were shown to have any relationship to a change in the rate of growth after injury: the amount of shortening sustained as a result of the injury and the degree of residual angulation.

**Shortening.** (In a few children, where the increase in the growth rate was very marked and sufficiently rapid to overtake any shortening, or where asymmetry between the limbs had existed, the initial measurement of difference in length may be a positive value actually showing an increase in length rather than a shortening).

There was a strong statistical relationship between the initial shortening measured at the time of clinical union and the maximal increase in the growth rate of the injured bone. This association was analysed using the information from the 54 tibial fractures and 32 femoral fractures followed for periods of two years or longer.

Figures 7 and 8 show that for both the tibia and femur the greater the overlap of fragments at the time of union the greater the final amount of shortening. However, this relationship is not direct since an increase in the growth rate always occurs, and must therefore influence the result. This influence is shown in Figures 9 and 10 where the change in length is used to indicate the increase in the growth rate.

Figure 9 shows that even with perfect reduction and no initial shortening some increase in the rate of growth occurs in fractures of the tibias. The injured bone therefore becomes longer than its normal counterpart in the other leg. An increase in the rate of growth cannot be considered simply as a compensatory mechanism to restore the lost length since no length has been lost in these children.

However, it is evident from the slope of the curve in Figure 9 that there is some compensatory element. The coefficient for the correlation between the increase in growth and the initial difference in the length of the injured bones is 0.473 (P<0.005) for the tibia and 0.432 (P<0.02) for the femur. This significant relationship indicates that the greater the initial shortening the greater the increase in the growth rate.

The fractured femur increased in length on average by 0.70 to 0.80 centimetre. The least increase was 0.10 centimetre and the greatest 1.70 centimetres. Every femur exhibited some increase in the growth rate. The average increase in the tibia was 0.30 to 0.40 centimetre, the maximum was 1.10 centimetres and in three children there was no increase.

**Angulation.** Five of the tibial fractures united in 15 degrees or more of either varus or valgus angulation. All these fractures were in the distal half of the bone and in all the degree of angulation was gradually reduced in the course of remodelling. During this time the average increase achieved was 0.70 to 0.80 centimetre which was twice the average for the tibia group as a whole. In contrast, five femoral fractures which united in a similar angulation achieved less correction of the angulation. The residual angulation persisted almost unchanged and the increase in the growth rate of these five femora was no different from the average.

The one child who was operated upon has not been included in the general series. The injury was a subtrochanteric fracture of the femur which had been grossly displaced initially. Open reduction was performed, and the femur held with a nail-plate which was later removed. After each procedure an increase in the growth rate, much in excess of any similar injury treated conservatively, was recorded. Four years after injury the fractured femur was 4.20 centimetres longer than the femur on the normal side.

**DISCUSSION**

In this study, it has been demonstrated that after fracture of the shafts of the tibia or femur in a child, an increase in the rate of growth of the injured bone occurs. Although the increase after injury varied considerably between children, in general the greatest rate of growth occurred after injuries which resulted in overlap of the fragments. Where there was little or no overlap the increase of the growth rate was minimal. No matter how severe or how minimal the injury, at the end of growth any discrepancy in the length between the injured and ipsilateral bones is unlikely to exceed half a centimetre. This explains why conservative methods of treatment of such fractures in children produce adequate results. Provided at least a moderate degree of reduction is achieved, natural processes will add the finishing touches. There is therefore no need to strive for perfect reductions in children. Particularly with the more severely displaced injuries, a perfect reduction might in theory actually bring about a greater inequality due to excessive lengthening than would occur with conservative treatment (Bisgard and Martenson 1937; Blomqvist and Rudström 1943; Blount 1954).

It is possible that over a longer period even differences of half a centimetre may eventually be completely corrected. However, in these children who were followed for up to five years after injury there was no indication that this was occurring. This corresponds with the observations of others (Truesdell 1921; Levander 1929; Neer and Cadman 1957; Staheli 1967).

For their advice on the interpretation of the data, I am indebted to the Statistical Research Unit of the Medical Research Council.

**REFERENCES**


