REMODELLING OF ANGULAR DEFORMITY AFTER FEMORAL SHAFT FRACTURES IN CHILDREN

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We reviewed 28 children with unilateral middle-third fractures of the femoral shaft who had an angular deformity after union of 10° to 26°. At an average follow-up of 45 months (20 to 66), we measured remodelling of the proximal physis, the distal physis and the femoral shaft.

The average correction was 85% of the initial deformity. We found that 74% of correction occurred at the physes and only 26% at the fracture site. Neither the direction nor the magnitude of the angulation much influenced the degree of remodelling. Younger children remodelled only a little better than older children.

We conclude that in children under 13 years of age, malunion of as much as 25° in any plane will remodel enough to give normal alignment of the joint surfaces.

Overgrowth after the conservative management of fractures of the femoral shaft in children has been clearly defined (Viljanto, Kiviluoto and Paananen 1975; Reynolds 1981; Clement and Colton 1986; Malkawi, Shan-nak and Hadidi 1986), and it has also been reported that rotational deformities can remodel (Brouwer, Molenaar and van Linge 1981; Hägglund, Hansson and Norman 1983). The importance of angular deformity after fracture is less clear although it has been reported in as many as 40% of cases (Malkawi et al 1986). Opinions vary on the potential for remodelling in regard to both the degree and the plane of the angulation.

Neer and Cadman (1957) and Griffin, Anderson and Green (1972) suggested that a 20° angulation would remodel in any plane, while Barford and Christensen (1958) considered that 25° was acceptable. Other authors thought that varus and valgus deformities corrected poorly (Blount 1954; Dameron and Thompson 1959; Viljanto et al 1975), and that, in accordance with Wolff's law, remodelling was maximal in the plane of joint motion. Irani, Nicholson and Chung (1976) considered that 30° of anterior and 15° of medial angulation were acceptable, and Malkawi et al (1986) suggested that

initial angular deformities of up to 20° in the coronal plane and 30° in the sagittal plane would remodel into satisfactory alignment.

In all these reports only the changes at the fracture site were assessed; growth changes occurring at the physes during remodelling were not taken into consideration. In 1975, Pauwels postulated that the physis responds to malalignment by differential growth which tends to realign the shaft perpendicular to the major joint reaction forces (Ogden 1991). This physal contribution to remodelling has been confirmed experimentally by Ryöppy and Karaharju (1974), Karaharju, Ryöppy and Mäkinen (1976) and Abraham (1989).

We have studied this physal response to angular deformity in a series of clinical cases.

PATIENTS AND METHODS

We retrospectively reviewed 341 cases of unilateral fracture of the femoral shaft in children treated at the Red Cross Children's Hospital from June 1984 to November 1988. Of these, 70 had angulation of 10° or more at the fracture site after union and we were able to make detailed studies of 28 of them at an average period of 45 months after fracture (20 to 66). There were 11 female and 17 male patients with an average age of 6.3 years (3 to 12). All the fractures involved the middle third of the shaft, and the major direction of tilt of the distal fragment was varus in 13, valgus in two, anterior in five, and posterior in eight.

Clinical disability and abnormality of alignment were assessed and full-length anteroposterior and lateral radiographs were taken of both femurs in each patient. We did not measure rotational deformity at initial union,

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but assessed this clinically, not radiographically, at follow-up. The patient was examined prone with the hip extended; no patient had a difference in range of rotation of more than 15° between the two sides.

On the radiographs we measured the residual angle at the fracture site, and also the interphyseal angle in the coronal and sagittal planes. The latter was recorded as the angle between a line through the proximal physis and one through the distal physis (Fig. 1), measured for both femurs in each case. At the time of union the difference in physeal tilt between the fractured and normal femurs was equivalent to the angulation at the fracture site, but during growth, the physeal lines of the fractured femur tended to regain their former orientation. Where the

interphyseal angle had become the same in both femurs at follow-up it was considered that complete remodelling and joint realignment had taken place, so that the joint surfaces were again directed normally. Any residual difference in the interphyseal angle represented residual angular deformity. The contribution of the proximal and distal physes was determined by extending the lines drawn through the residual angle at the old fracture site to the physes and using trigonometric formulae.

The interphyseal angle (χ) is measured at the intersection of the lines extended from proximal and distal physes.

Fig. 1

Fig. 2

The fracture-site angle on follow-up radiographs is measured between lines drawn on the unaffected shaft about 3 cm on either side of the fracture itself. Local remodelling can give a false impression of the correction of angulation.

Fig. 3a

Fig. 3b

Figure 3a – An anteroposterior radiograph of the femur of a seven-year-old child showing a 12° varus tilt at union. Figure 3b – Remodelling at 4.5 years after fracture shows a residual fracture-site angle of 8° . The difference in interphyseal angles has improved from 12° to 1° , however, implying an 11° correction by differential physeal growth.

Figure 4a – A lateral radiograph of a five-year-old child with a 20° posterior tilt at union. Figure 4b – After four years there is no change in the fracture-site angle, but the difference in interphyseal angles has improved from 20° to 1°.

Fig. 5

The relative contributions of the physes and the shaft to correction of angulation.

Fig. 6

The percentage correction of angulation related to time.

The measurement of the angle at a fracture site is shown in Figure 2. Local remodelling results in new bone deposition on the concave side and resorption on the convex side. This rounding-off at the fracture site could be misinterpreted as remodelling of the angular deformity. To avoid this error we drew the axis of the relatively unaffected shaft 2 to 3 cm on either side of the fracture and recorded the angle of intersection of these lines, as shown in Figures 3 and 4.

RESULTS

The average value of the main angulation in either plane at the time of union was 13.3° (10 to 26). At follow-up an average of 85% of the interphyseal angulation had been corrected. We studied various features of this remodelling process.

Site. Of the correction of angulation, 74% had occurred at the physes and only 26% at the fracture site. Of the physeal remodelling, 53% was at the proximal and 47% at the distal physis (Fig. 5).

In seven femurs there had been no discernible change in angulation at the fracture site but almost full realignment of the physes. This finding may account for reports of complete lack of remodelling from studies in which only fracture-site angulation was measured at follow-up.

Direction. We found that varus tilt of the distal fragment had corrected by 77%, valgus tilt by 88%, anterior tilt by 79% and posterior tilt by 90%. These differences were discounted because of the small numbers and varying duration of follow-up in some groups.

Rate and duration. The amount of remodelling was related to the time from fracture, but with a fairly wide scatter of results (Fig. 6). On average 75% of the deformity had remodelled by three years. At five years, remodelling was virtually complete although in three patients there was only 70% correction. In three patients there was overcorrection by 5%.

Age. We found only marginally better remodelling in younger children; the rate of remodelling was much the same.

Degree of angulation. The size of the initial angulation appeared to have some influence on remodelling: greater degrees of malunion tended to correct more fully. The rate of remodelling was the same, however, regardless of the original angle.

DISCUSSION

The basic mechanism which corrects angular deformities in growing long bones is not well understood. Remodelling at the fracture site accords with Wolff's law: new bone is laid down on the compression or concave side of the long bone, and the traditional understanding of this has been that it is maximal in the plane of joint movement and when the fracture is close to the end of the bone. The differential growth response of a physis under unequal loading has been described as the Hueter-Volkmann law (Ogden 1991).

Experimental studies showed that 50% of the remodelling of angulated fractures in dog tibiae occurred by differential physal growth (Karaharju et al 1976). Abraham (1989) demonstrated in baboon forearms and tibiae that 33% to 47% of growth correction took place at the physes and 25% to 45% at the fracture site. Our method of calculating the interphysal angle is similar to that for the growth-plate angle described by Abraham, but we differ in our measurement of the fracture-site angle (see Fig. 2). In a clinical setting, we found that 75% of the remodelling of femoral shaft fractures occurred at the physes.

We also observed that remodelling took place equally well in both the sagittal and the coronal planes. In the 13 patients with varus tilt, the largest group, 77% of the initial deformity was corrected. This is in contrast with varus and valgus deformities at the elbow which notoriously do not remodel. Part of the explanation may be the greater contribution made to growth by the lower femoral physis compared with that of the distal humeral physis.

It has been reported that remodelling may continue for more than five years after a fracture (Viljanto et al 1975; Malkawi et al 1986). Our Figure 6 shows that

nearly 100% of the remodelling took place in the first six years. This difference may be because these authors measured only the fracture angle and not the interphysal angle, and therefore underestimated the changes.

In our series, the younger children remodelled at the same rate but marginally better (90%) than older children (80%). This is at variance with the findings of Viljanto et al (1975) and Malkawi et al (1986). The largest angulation that we studied was 26°, and there may be a limit beyond which full correction is impossible. Remodelling of an angle of 35° was reported by Karaharju et al (1976).

We did not study rotational remodelling, and it can be argued that unmeasured rotation may have influenced our interpretation of changes in angular deformities. We do not believe, however, that rotation played a significant role. We did not measure rotation at fracture union, but found that the radiological angular deformity at fracture union was always maximal in one plane: either varus, valgus, anterior or posterior tilt. Hägglund et al (1983) showed that at initial union after treatment by skin traction, rotational deformity never exceeded 20°. Our patients were all treated either by skin traction in a Thomas splint or immediate spica application and in a separate study of 50 patients treated by an immediate spica we confirmed that no patient at union had a difference in rotation of over 20°. Our clinical finding at follow-up of a difference of rotation between the two sides of less than 15° is within the normal physiological range (Brouwer et al 1981).

Each year, we treat approximately 200 children under 12 years of age with fractured femoral shafts, using early spica application for about 100 between the ages of two and ten years. Of these 15% unite with angulation of 10° or more, and our study has reassured us that up to 25° of angulation in children of 12 years or younger will remodel satisfactorily.

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