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REMODELLING AFTER DISTAL FOREARM FRACTURES IN CHILDREN

II. *The Final Orientation of the Distal and Proximal Epiphyseal Plates of the Radius*

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In 39 children the steric orientation of both the distal and the proximal epiphyseal plates of the radius was evaluated 4 months to 10 years after distal forearm fractures that had healed with residual angulation.

A residual fracture angulation was found to induce a change in orientation of both the distal and proximal epiphyseal plates. The final result of the reorientation was a normalization of the inclination of the plates in relation to the long axis of the bone. The proximal epiphyseal plate attained practically a normal orientation. The distal epiphyseal plate tended towards overcorrection.

In two of the four cases with a primary angulation exceeding 20 degrees considerable normalization occurred, but a "normal" state was not reached. This indicates an upper limit for angulations permitting normalization of the orientation of the distal epiphyseal plate of the radius.

Key words: children; epiphyses; forearm; fracture; growth; remodelling

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It has recently been demonstrated that the epiphyseal plates participate in the total remodelling procedure after diaphyseal fractures of the long bones. In experimental studies on the tibia of the rat and dog Ryöppy & Karaharju (1974) and Karaharju et al. (1976) found that both the distal and the proximal epiphyseal plates changed their directions of growth after mid-diaphyseal fractures that had healed with residual angulation. In children, Friberg (1974, 1979) demonstrated that after a distal forearm fracture the distal epiphyseal plate of the radius shows a tendency towards spontaneous restoration of its normal orientation.

Our present knowledge of the behaviour of the epiphyseal plates after fracture healing with residual angulation can be summarized as follows. Residual angulation will induce a redistribution of growth at the epiphyseal plate (Ryöppy & Karaharju 1974). The redistribution of growth will subsequently lead to the normalization of an abnormal inclination of the epiphyseal plate. The rate of the normalization is independent of the age of the child and of the distance between the fracture and the epiphyseal plate, whereas the degree and direction of the primary angulation influences the rate of the correction. The reduction in abnormal inclination follows an exponential course (Friberg 1979). However, the final orientation of the epiphyseal plate after completion of the process of normalization has not yet been established. Furthermore, the maximum primary angulation still resulting in the complete normalization of an abnormal epiphyseal inclination is unknown.

The capacity of the epiphyseal plates to bring about spontaneous normalization of an abnormal inclination is important as it leads to a normalization of the inclination of the

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adjacent joint surface. In addition, it is probably of direct interest with regard to the correction of a residual fracture angulation since a normalization of the inclination combined with longitudinal growth at the plate must automatically reduce any abnormal inclination of the diaphyseal part of a bone (Friberg 1979).

In the present study an investigation was made of the spatial orientation of the distal and proximal epiphyseal plates of the radius after distal forearm fractures that had healed with residual angulation. The aim was to investigate the final orientation of the epiphyseal plate after completion of the process of normalization.

MATERIAL AND METHODS

The inclination of the distal and proximal epiphyseal plates of the radius was studied in 39 children with residual angulation of the fracture at the time of healing. All fractures were located in the distal fifth of the forearm. The patients were selected from all cases of distal forearm fractures treated in the Department of Orthopaedic Surgery at Umeå during 1965–1973. The selection was made so as to obtain a representative series with regard to ages, observation times and degrees of angulation.

The radiographs taken at the time of healing of the fracture were used as a basis for the evaluation. At re-examination, radiographs with frontal and lateral views of both the fractured and normal contralateral wrists and forearms were obtained. In 12 cases both epiphyseal plates of the radius were closed at the follow-up examination.

Forty observations were made. In 34 observations the fractures had an inclination visible in the dorso-volar plane (lateral view). Twenty-five of these were dislocated in the dorsal direction and nine in the volar direction. In the radio-ulnar plane (frontal view) four had an abnormal inclination in the radial direction and two in the ulnar direction. A concomitant ulnar fracture occurred in nine of the cases. Further details of the characteristics of the material are given in Table 1.

Radiographic technique

The radiographic technique used in this investigation was identical with that previously described by Friberg (1979).

Measuring technique

The *primary angulation* of the distal epiphyseal plate at the time of healing of the fracture was defined as the angle between the epiphyseal plate and a plane oriented 90 degrees to the axis of the distal third of the radius.

The measurements pertaining to the follow-up examination were performed on superimposed

Table 1. Distribution in the series of the variables used for the statistical analysis of the results. Means and standard deviations are indicated where not otherwise stated. Total number of observations = 40

Age at fracture, years: months (range)	9:8 ± 3:5 (2:5 – 16:4)	Primary angulation of the epiphyseal plate, degrees	12.4 ± 6.8
Sex, no. of boys/girls	19/21	Type of fracture	
Side, no. of right/left	19/21	No. of Torus	12
Observation time, years: months (range)	4:5 ± 3:9 (0:4 – 11:0)	Greenstick	14
		Complete	14
Corrected observation time*, years: months (range)	3:6 ± 3:2 (0:4 – 10:8)		
		Distance of fracture from the distal epiphyseal plate, millimetres (range)	16.2 + 6.7 (6 – 29)

* Corrected observation time: in the 12 cases with closed epiphyseal plates at follow-up, the time from healing of the fracture to expected completion of longitudinal growth at the distal epiphyseal plate of the radius [boys 16 and girls 15 years of age (cf. Maresh 1955, Kothari 1974)]. In the remaining cases with radiographically normal epiphyseal plates, the actual period of observation.

drawings of the radiographs as illustrated in Figure 1 and were all expressed as a difference between the normal and fractured side. The proximal half of the diaphysis up to the proximal metaphyseal area of the radius was used as a reference for the superimposition of the radiographs. The *final angulation* of the distal and proximal epiphyseal plates at the follow-up examination was defined as the difference in inclination between the epiphyseal plates on the normal and on the fractured side. The *orientation of the long axis* of the fractured radius was defined as the angle between the two lines connecting the midpoints of the proximal and the distal epiphyseal plates on the normal and on the fractured side. The final angulation of the proximal epiphyseal plate and the orientation of the long axis were only measured in fractures showing angulation in the dorso-volar plane. Two of these observations had to be excluded due to technically inadequate X-ray films.

The total error of the measuring procedures was evaluated by repeated measurements by the author and was found to be 0.8 degrees + s.d. = 0.3 for the final angulation of the distal epiphyseal plate. For the final angulation of the proximal epiphyseal plate the mean error was 0.5 degrees ± s.d. = 0.4, and for the orientation of the long axis of the bone the figure was 0.2 degrees ± s.d. = 0.5.

Statistics

The means and standard deviations are given. Standard computer programs were used for the

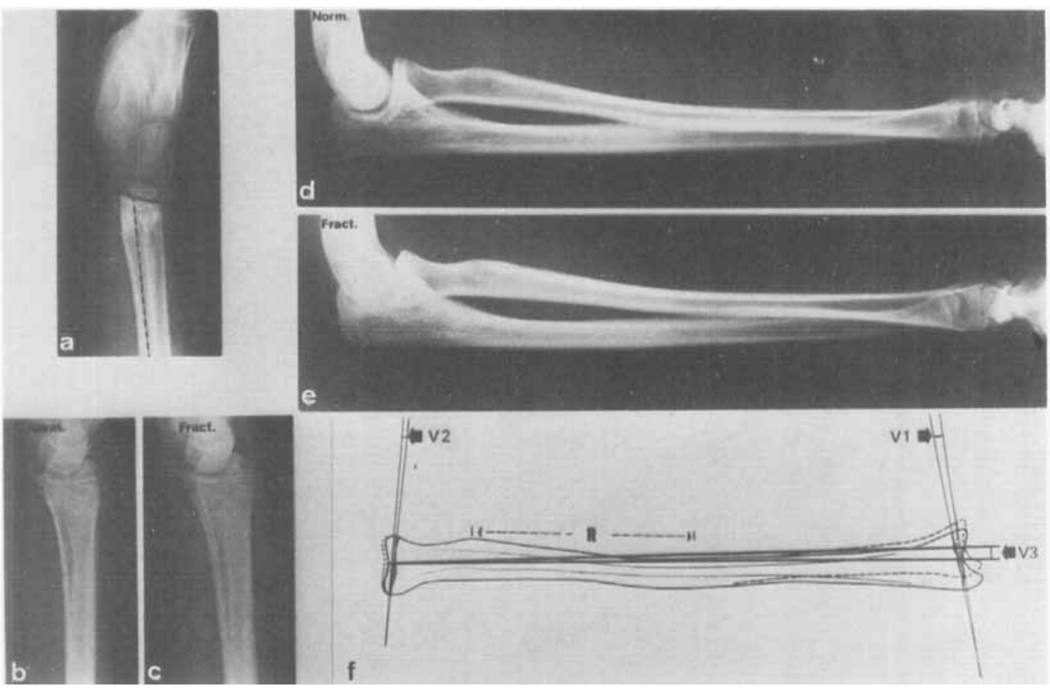

Figure 1. The primary angulation of the distal epiphyseal plate of the radius in a boy aged 5 years 5 months at the time of the fracture and the final angulation of the distal and proximal epiphyseal plates and the orientation of the long axis of the bone when the boy was 14 years and 9 months old.

(a) = At the time of healing of the fracture, 21 degrees dorsal inclination of the epiphyseal plate. (b, c, d, e) = Normal and fractured wrist and normal and fractured forearm at the follow-up examination. (f) = Superimposed drawings of b–e, the distal epiphyseal plate shows an overcorrection of 2 degrees and the proximal epiphyseal plate and the total long axis of the fractured bone have changed their orientation by 1 degree.

V_1 = Final angulation of the distal epiphyseal plate. V_2 = Final angulation of the proximal epiphyseal plate. V_3 = Orientation of the long axis of the fractured bone. R = Part of the radius used for reference when superimposing the forearm films.

statistical procedures (SPSS vers. 6) (Nie et al. 1975). The influence was not considered to be significant at levels of $P > 0.05$.

RESULTS

The distal epiphyseal plate of the radius

In the majority of the observations ($n = 33$) the final angulation of the distal epiphyseal plate was 2 degrees or less. In two observations an overcorrection exceeding 2 degrees was found on the fractured side. The results of the measurements for the complete series are illustrated in Figure 2.

In five observations the final angulation exceeded 2 degrees. In two of these the corrected observation time should have been sufficient to achieve a normalization within 2 degrees (cf. Friberg 1979). The remaining three cases showed the common feature that closure of the epiphyseal plate had obviously interrupted the process of normalization. In two cases, girls aged sixteen at the time of the fracture, no change at all in inclination was observed despite observation periods of 28 and 31 months, respectively. Both showed clear evidence of completed growth in the form of diminished width of the epiphyseal plates at the time of the fracture. In the third case, a boy aged 14 years and 9 months at the time of the fracture, 12 degrees of normalization had occurred. The estimated time for the normalization achieved was calculated to be 9 months (cf. Friberg 1979). These three cases, all with a primary inclination in

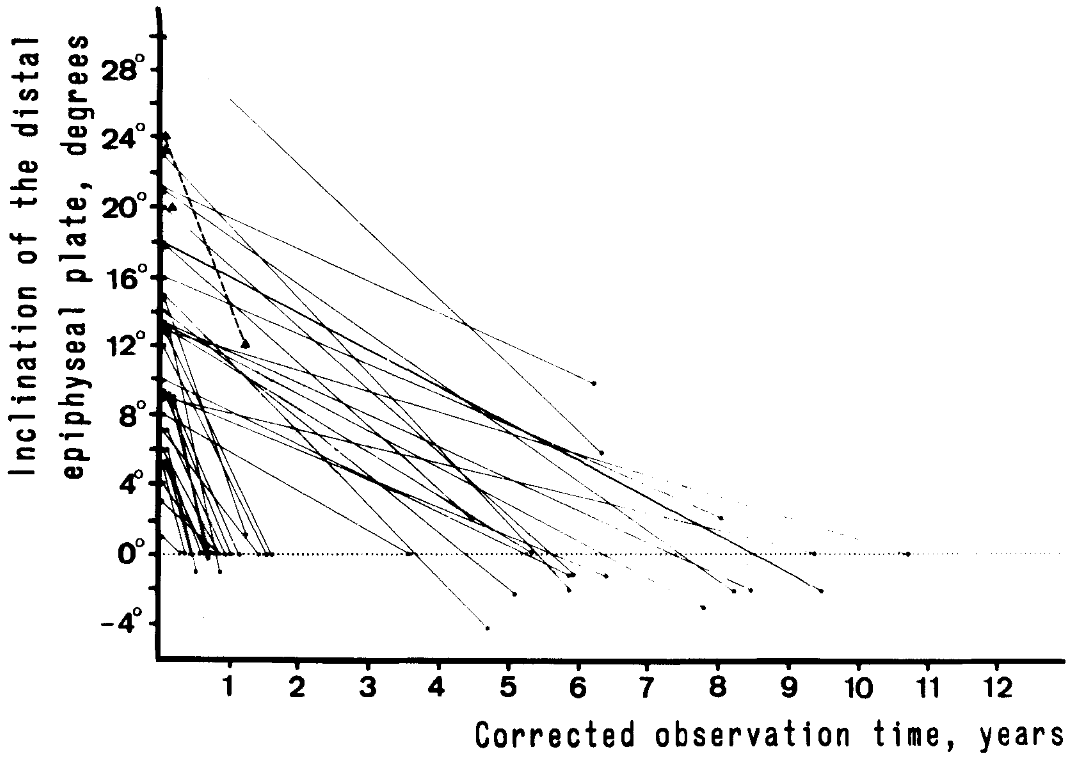

Figure 2. The primary and the final angulation of the distal epiphyseal plate at follow-up in relation to the corrected observation time. It should be noted that the lines do not illustrate the course of the process, but are only intended to connect observations in the same patient. ▲ = The cases in which epiphyseal closure interfered with the process of normalization.

the dorsal direction, are not included in the following analysis of the results noted at the distal epiphyseal plate.

The final angulation. At follow-up the cases ($n = 22$) with a primary angulation in the dorsal direction had a final angulation of the epiphyseal plate of 0.5 degrees ± 2.8. The final angulation in the cases with a primary angulation in the volar direction showed a slight overcorrection of the epiphyseal plate amounting to −1.2 degrees ± 1.4 ($n = 9$). The mean inclination for primary angulations in the radial direction was 0 degrees ± 0 ($n = 4$) and for angulations in the ulnar direction 0 degrees ± ($n = 2$). No influence (χ^2 analysis) of the different directions of the primary angulation on the final angulation of the plate was found. For this analysis the cases with a primary angulation in the radial and ulnar direction were combined into one group. It was also shown that a concomitant distal ulnar fracture ($n = 9$) had no influence (Student's t-test) on the final angulation of the plate.

Influence of different variables on the final angulation. The final angulation of the epiphyseal plate ($n = 37$) was tested to determine the effect of the different variables used for classification of the material (Table 1). The methods used were bivariate correlation analyses and stepwise regression analysis. Only significant relations between the dependent and independent variables are given.

The correlation analyses showed that a larger primary angulation of the plate ($P = 0.032$, corr. coeff. = 0.31) resulted in a larger final angulation. However, when the two cases with a final angulation of 7 and 10 degrees, respectively, were excluded the same analysis showed the reverse relationship in the 35 remaining cases. A larger primary angulation ($P = 0.034$, corr. coeff. = −0.31) then resulted in a more pronounced overcorrection. In this part of the material it was further found that an increase in corrected observation time resulted ($P = 0.020$, corr. coeff. = −0.35) in a more pronounced overcorrection of the epiphyseal plate. The orientation of the epiphyseal plate in the 19 cases with a corrected observation time under 2 years was an overcorrection of −0.05 degrees ± 0.40. In the 16 cases with longer observation times this overcorrection had increased to 1.00 degree ± 1.63.

According to the stepwise regression analysis none of the variables had any influence on the final angulation of the distal radial epiphyseal plate.

In conclusion, the statistical analysis showed that large primary angulations resulted in less complete normalization of the epiphyseal plate. When the two cases with large primary angulations and a lack of normalization were excluded, increased observation times and larger primary angulations resulted in a more pronounced overcorrection of the plate.

The final angulation in relation to the orientation of the long axis of the bone. The cases with a primary angulation in the dorsovolar plane ($n = 29$) were analysed in relation to the orientation of the long axis of the radius by the statistical methods described above. The general finding was that the epiphyseal plate on the fractured side was overcorrected 1.3 degrees ± 2.0 in relation to the long axis of the bone. The correlation analyses showed that the orientation of the long axis of the fractured radius was highly significantly ($P = 0.00001$, corr. coeff. = 0.79) correlated with the final angulation of the epiphyseal plate. When the two cases with inadequate normalization were excluded, the relationship between the two variables was weaker ($P = 0.046$, corr. coeff. = 0.33) (Figure 3). Stepwise regression analysis confirmed the intercorrelation between the two variables.

Prediction of the time needed for full correction. In a previous study the following exponential formula was suggested for estimating the time needed for adequate correction of the epiphyseal plate:

$$t = \frac{\ln (V_0/2)}{\beta} \cdot$$

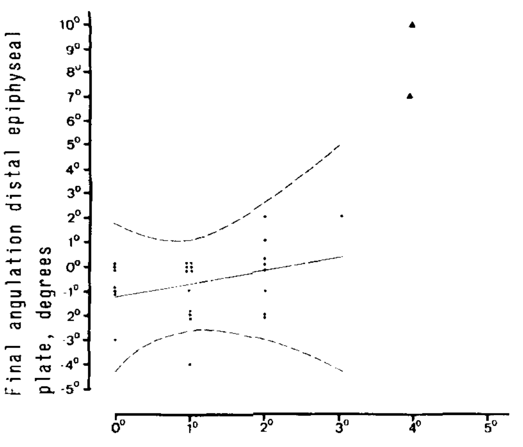

Figure 3. The final angulation of the distal epiphyseal plate in relation to the orientation of the long axis of the bone. The linear regression line and 95 per cent confidence intervals are given. A minus sign signifies overcorrection. The two cases with inadequate correction are indicated in the figure (▲), but are not included in the statistics.

This formula was applied to the 19 cases with an observation time of less than 2 years using the mean values of β for each direction of angulation (Friberg 1979). When the time calculated from the formula was compared with the corrected observation time, it was found that the "normal" position was reached 2.4 months $\pm$ 5.5 before the mean time predicted by the formula.

The proximal radial epiphyseal plate

The two patients aged 16 years with closed epiphyseal plates at the time of the fracture are not included in the analyses of the results obtained at the proximal epiphyseal plate. In 16 of the 30 remaining observations a change in inclination was observed. The change in inclination of the proximal epiphyseal plate was without exception in the same direction as that of the distal epiphyseal plate, e.g. a fracture with a primary angulation in the dorsal direction resulted in a reorientation of both the distal and proximal epiphyseal plates in a volar direction.

The final angulation. For a primary angulation at the fracture site in the dorsal direction ($n = 23$) a volar inclination of the plate amounting to 1.2 degrees $\pm$ 1.5 was found. A volar angulation at the fracture site ($n = 7$) resulted in an inclination in the dorsal direction of 2.3 degrees $\pm$ 0.8. No differences (χ^2 analysis) existed between the results for the two directions of primary angulation.

Influence of the different variables on the final angulation. The influence of the variables used for classification of the material ($n = 30$) on the final angulation of the proximal epiphyseal plate was analysed by bivariate correlation, and stepwise regression analysis. Only significant relations between the dependent and independent variables are indicated.

The correlation analyses showed that an increase in the primary angulation ($P = 0.003$, corr. coeff. = 0.48) and an increase in the distance between the fracture and the distal epiphyseal plate ($P = 0.008$, corr. coeff. = 0.44) increased the amount of correction found at the proximal epiphyseal plate. In addition, a more complete fracture resulted in an increased correction ($P = 0.0002$, corr. coeff. = 0.60). In this context it must be noted that a more complete fracture was also significantly correlated with an increased primary angulation ($P = 0.01$) and with an increase in the distance between the fracture and the distal epiphyseal plate ($P = 0.003$).

The stepwise regression analysis on the other hand showed that the type of fracture was the only variable that significantly ($P < 0.001$) influenced the results.

To sum up, the statistical analysis showed that the type of fracture exerted the main influence on the final angulation. However, the type of fracture was also closely related to the primary angulation and the distance between the fracture and the distal epiphyseal plate, variables which in turn had a strong influence on the results.

The final angulation in relation to the orientation of the long axis of the bone. The final angulation of the proximal epiphyseal plate of the radius was very closely correlated ($P = 0.00001$, corr. coeff. = 0.80) with the orientation of the long axis of the bone ($n = 30$). In fact, the proximal epiphyseal plate almost completely normalized its orientation in relation to the long axis of the bone (Figure 4). The results of a stepwise

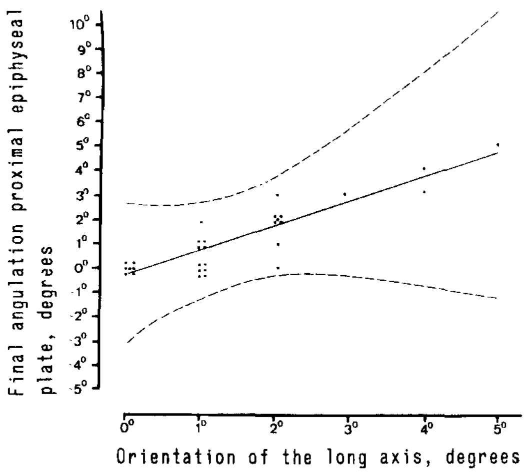

Figure 4. The final angulation of the proximal epiphyseal plate in relation to the orientation of the long axis of the bone. The linear regression line and 95 per cent confidence intervals are given. A minus sign signifies overcorrection.

regression analysis, also including the variables used for classification of the material, confirmed that the change in orientation of the long axis of the bone was the variable which had the greatest influence on the final angulation of the plate.

A separate regression analysis was performed to study the relations between the orientation of the long axis and the variables used for classification of the material. This showed that the distance between the fracture and the epiphyseal plate ($P < 0.001$) and the primary angulation ($P = 0.015$) were the only two variables which influenced the orientation of the long axis of the radius.

DISCUSSION

The final spatial orientation of the distal and proximal epiphyseal plates of the radius was investigated in children after distal forearm fractures that had healed with residual angulation.

The result was that in the majority of the cases the epiphyseal plates of the radius had normalized their inclinations in relation to the long axis of the fractured bone. This confirms that the epiphyseal plates react with a redistribution of growth after fracture healing with residual angulation (Friberg 1974, 1979, Ryöppy & Karaharju 1974, Karaharju et al. 1976). Furthermore, it shows that this process in the forearm is capable of restoring an almost normal orientation of the epiphyseal plates.

An exception to this general finding was noted in two of the four cases with a primary inclination of more than 20 degrees. In these two cases the normalization of the orientation of the epiphyseal plate was incomplete. This suggests that an upper limit exists for the normalization process. The number of observations is of course too small to permit any definite conclusions, but until proven otherwise, one cannot assume that complete normalization will take place after a distal forearm fracture healing with a primary angulation of more than 20 degrees. This view is also supported by the results obtained from studies of the correction of residual fracture angulations. Nonnemann (1969) ascertained as a general rule an upper limit of 30 degrees for adequate correction. Buch et al. (1966) concluded that angulations of more than 20 degrees should not be tolerated in a distal radial fracture, as the correction in these cases was incomplete.

When the two cases with incomplete normalization were excluded, the analyses of the orientation of the distal epiphyseal plate of the radius showed that in the patients with an observation period of less than 2 years an almost complete normalization of the inclination of the plate had occurred. However, the orientation found during the two first years was, in reality, not the "final position" as a longer period of observation showed a slight but significant overcorrection of the plate. The orientation of the plate was further influenced by the primary angulation in the sense that a larger primary angulation increased the amount of overcorrection achieved. This tendency towards an overcorrection is of importance because as growth proceeds in the epiphyseal plate, it results in an automatic reduction of the remaining adaxial displacement of the distal epiphyseal plate and thus must enhance the automatic reduction of angulations at the fracture site produced by longitudinal growth.

The finding that a substantial increase in the observation time resulted in an overcorrection supported the view that the course of the process of normalization of an abnormal epiphyseal inclination can be described by an exponential equation (Friberg 1979). It also indicates that the equation should not be formulated with a completely normal position as the final position of the epiphyseal plate. Instead, it suggested that an overcorrection of 1 to 2 degrees should be used.

The exponential formula was further tested for accuracy by applying it in those cases where the normal position of the epiphyseal plate could be assumed to have been attained recently (obs. time < 2 years). It was found that the formula resulted in a slight overestimation in relation to the actual observation time. This safety margin is desirable, however. Thus, the present results confirm that the formula is valid for clinical use.

The orientation of the distal epiphyseal plate was also found to be closely related to the orientation of the long axis of the fractured bone. This indicates that the orientation of the long axis of the bone is of importance for the final orientation of the distal epiphyseal plate and thus indirectly supports the suggestion that a biomechanical factor governs the process of normalization (Ryöppy & Karaharju 1974, Pauwels 1975). Earlier experimental work (Appleton 1934, Haas 1945, Strobino et al. 1952, Arkin & Katz 1956, Hinrichsen & Storey 1968) has shown that alterations in the direction or amplitude of the normal forces acting on an epiphyseal plate are capable of influencing growth in the plate. The general results of these experiments show that an increase in pressure results in a reduced growth potential. However, the duration and amplitude of the pressures applied in these experiments must be considered to be beyond the limits normally encountered in the skeletal system. Pauwels (1975) advocated the opposite view and suggested that after fractures with residual angulation the part of the epiphyseal plate subjected to increased physiological pressure would react with increased growth. This theory seems more plausible to the present writer mainly because it is compatible with the results found by Ryöppy & Karaharju (1974) and Karaharju et al. (1976).

In their experimental studies of the effect of mid-diaphyseal fractures Ryöppy & Karaharju (1974) and Karaharju et al. (1976) showed that both epiphyseal plates of the tibia reacted with a change in their directions of growth. However, no studies have been made of the reaction of an epiphyseal plate to a fracture near the other end of the bone. In the present study the residual angulation after a fracture in the distal fifth of the forearm was found to influence the distribution of growth within the proximal epiphyseal plate of the radius. The redistribution of growth in this plate resulted in a change in orientation of the proximal epiphyseal plate in the same direction as that found at the distal plate. Similar to the findings at the distal epiphyseal plate the new orientation of the long axis of the bone was found to influence the final orientation of the proximal plate.

In conclusion, the present study showed that both the distal and proximal epiphyseal plates will normalize their orientations after a distal radial fracture that has healed with residual angulation. The orientation finally attained by the epiphyseal plates is closely related to the orientation of the long axis of the fractured bone.

REFERENCES

Appleton, A. B. (1934) Postural deformities and bone growth. *Lancet* **i,** 451–454.

Arkin, M. A. & de Katz, J. F. (1956) The effect of pressure on epiphyseal growth. *J. Bone Jt Surg.* **38**-A, 1056–1076.

Buch, P., Folschveiller, J. & Jenny, G. (1966) Über die Behandlung von 376 Vorderarmschaftbrüchen bei Kinder. *Hefte Unfallheilkl* **89,** 51–54.

Friberg, S. (1974) Spontan korrektion av felställning efter läkning av distala underarmsfrakturer hos barn. Läkarsällslapets riksstämma sammanfattningar, 353, Stockholm.

Friberg, S. (1979) Remodelling after distal forearm fractures in children. I. The effect of residual angulation on the spatial orientation of the epiphyseal plates. *Acta orthop. scand.* **50,** 537–546.

Haas, S. L. (1945) Retardation of bone growth by a wire loop. *J. Bone Jt Surg.* **27,** 25–36.

Hinrichsen, G. J. & Storey, E. (1968) The effect of force on bone and bones. *Angle Orthodont.* **38,** 155–165.

Karaharju, E. O., Ryöppy, S. A. & Mäkinen, R. J. (1976) Remodelling by asymmetrical epiphyseal growth. *J. Bone Jt Surg.* **58**-B, 122–126.

Kothari, D. R. (1974) Age of epiphyseal union at elbow and wrist joints in Marwar region of Rajasthan. *J. Indian med. Ass.* **63,** 252–256.

Maresh, M. M. (1955) Linear growth of long bones of extremities from infancy through adolescence. *Amer. J. Dis. Child.* **89,** 725–742.

Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K. & Bent, O. N. (1975) *Statistical package for the social sciences.* 2nd ed. McGraw-Hill Co, New York.

Nonnemann, H. C. (1969) Grenzen der spontankorrektur Fehlgeheilter Frakturen bei Jugendlichen. *Langenbecks Arch. klin. Chir.* **324,** 78–86.

Pauwels, F. (1975) Eine klinische Beobachtung als Beispiel und Beweis für funktionelle Anpassung des Knochens durch Längenwachstum. *Z. Orthop.* **113,** 1–5.

Ryöppy, S. & Karaharju, E. O. (1974) Alteration of epiphyseal growth by an experimentally produced angular deformity. *Acta orthop. scand.* **45,** 490–498.

Strobino, L. J., French, G. O. & Colonna, P. C. (1952) The effect of increasing tension on the growth of epiphyseal bone. *Surg. Gynec. Obstet.* **95,** 694–700.

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