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REMODELLING AFTER DISTAL FOREARM FRACTURES IN CHILDREN

III. *Correction of Residual Angulation in Fractures of the Radius*

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The outcome of residual angulation of the radius after 38 distal forearm fractures in children was investigated. The period of observation ranged from 4 months to 10 years and 8 months.

The correction of a residual angulation after a fracture was shown to be governed by three factors.

1. An increase in the time between healing of the fracture and completed growth at the epiphyseal plates resulted in a more complete correction.
2. A larger adaxial dislocation of the epiphyseal plate at the time of healing of the fracture, reflecting a larger primary fracture angulation and a greater distance from the fracture to the epiphyseal plate, resulted in a less complete correction.
3. A more complete correction or overcorrection of the distal epiphyseal plate increased the correction of the angulation of the fracture.

These findings strongly indicate that the process of correction of a residual angulation after a healed fracture can be explained in terms of the combined effects of the direction and amount of longitudinal growth at the epiphyseal plate. A trigonometrical equation based on this theory predicted the residual angulations of the fractures, at follow-up, with an error of less than 1 degree.

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

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The spontaneous correction of residual angulations after fractures of the long bones in children is a well-known phenomenon (Önne & Sandblom 1949, Attenborough 1953. Gandhi et al. 1962, Miyagi & Murayama 1964, Lanzi 1965, Bennek & Steinert 1966, Grewe & Niemann 1966, Nonnemann 1969, Spissak et al. 1969, Swaan & Oppers 1971, Hansen et al. 1976, Högström et al. 1976).

The major concepts of the process of spontaneous correction have been summarized by Blount (1955), Sharrard (1971) and Ryöppy (1972). Thus, it is generally accepted that a younger child has a greater capacity for correction. Also, a larger angulation at the time of healing of the fracture and a longer distance between the fracture and the epiphyseal plate are factors claimed to result in a less complete correction. Finally, the plane of movement in an adjacent hinge-joint is said to be of significance, viz. a residual angulation located in the same plane as the movement is claimed to have a greater capacity for correction than an angulation in a plane not used by the joint. However, a more detailed analysis of the contribution of each of these factors to the correction obtained has not yet been made. This is reflected in clinical practice where only crude predictions can be made of the amount of

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correction to be expected in a specific patient with a specific fracture.

It has recently been proved that the epiphyseal plates at both ends of a fractured long bone take an active part in the remodelling process. The epiphyseal plates change their direction of growth and normalize their inclinations in relation to the long axis of the bone (Friberg 1974, 1979a,b, Ryöppy & Karaharju 1974, Karaharju et al. 1976). This normalization of the steric orientation of the epiphyseal plates has been suggested to be of immediate importance for the correction of a residual angulation of a fracture. Normalization of the epiphyseal inclination combined with longitudinal growth will automatically reduce any abnormal angulation of the diaphyseal part of the bone (Friberg 1979a,b).

The recent finding that the epiphyseal plates play an active role in the remodelling process after fractures made it necessary to investigate the correction of angulations at the fracture site with regard to the combined effect of the change in orientation of the epiphyseal plates and longitudinal growth. In the present study the process of correction of residual angulation after distal forearm fractures was investigated.

MATERIAL AND METHODS

Thirty-seven children with residual angulation after a fracture in the distal fifth of the forearm were studied. The primary angulation of the distal radial fracture at the time of healing was compared with the angulation at the time of the follow-up examination. 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

Table 1. Distribution in the series of the variables used for the statistical analysis of the results. Total number of observations = 38. Means and standard deviations are given where not otherwise stated. Ranges in brackets.

Age at fracture, years: months	9:4 ± 3:2 (2:5–14:9)	Primary fracture angulation, degrees	11.84 ± 6.57 (1–30)
Sex, no. of boys/girls	19/19		
Side, no. of right/left	19/19	Distance of fracture from the distal epiphyseal plate, millimetres	16.2 ± 6.8 (6–35)
Observation time, years: months	4:6 ± 3:10 (0:4–11:0)		
Corrected observation time*, years: months	3:8 ± 3:3 (0:4–10:8)	Distance of fracture from the distal epiphyseal plate in per cent of the total diaphyseal length of the radius	10.1 ± 4.6 (2–19)
Type of fracture, No. of Torus	12	The adaxial displacement ** of the distal radial epiphyseal plate, millimetres	3.35 ± 2.57 (0.2–13.4)
Greenstick	14		
Complete	12		
		The final angulation of the distal epiphyseal plate of the radius, degrees	0.32 ± 3.07 (−4–12)

*Corrected observation time: In 10 cases with closed epiphyseal plates at follow-up, the time from healing of the fracture to the 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 observation time.

**Adaxial displacement = sine of primary angulation of the fracture × distance of fracture from the epiphyseal plate (cf. Figure 5).

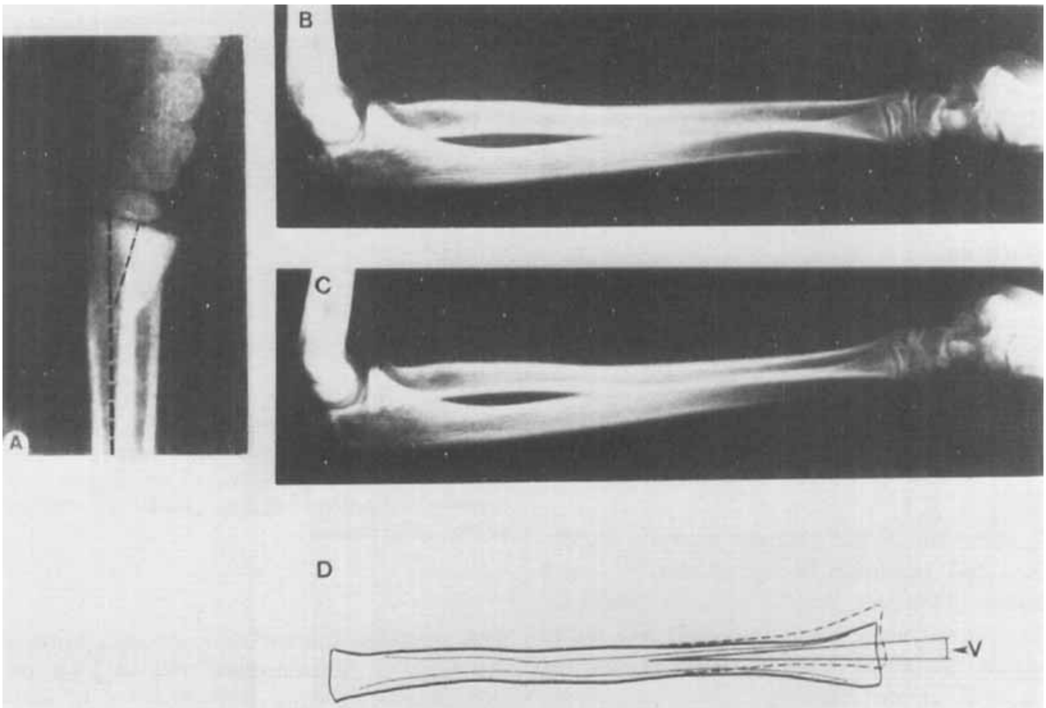

Figure 1. A boy aged 3 years at the time of a fracture in the distal part of the radius. The follow-up examination was performed 9 years later.
A. *The fracture at the time of removal of the cast. An angulation of the epiphyseal plate of 16 degrees in the dorsal direction is present.*
B. *The fractured forearm at follow-up.*
C. *The normal forearm at follow-up.*
D. *Superimposed drawings of B and C. The residual fracture angulation is 3 degrees.*

different ages, observation times and degrees of residual angulation. Radiographs taken when the fractures were considered to be healed were used as a basis for the evaluation. At re-examination radiographs in the frontal and lateral view of both the fractured and normal contralateral wrists and forearms were obtained.

Thirty-eight observations were made. In 32 the fractures had a visible inclination in the dorsovolar plane (lateral view). Twenty-three 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 was present in nine of the cases. Further details of the characteristics of the series are given in Table 1.

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

Measuring technique

The *primary angulation* of the fracture at the time of healing was defined as the angulation of the epiphyseal plate in relation to a plane oriented 90 degrees to the axis of the distal third of the proximal fragment. All measurements pertaining to the follow-up examinations were performed on superimposed drawings of the radiographs and were expressed as the 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 *remaining angulation of the fracture* at follow-up was defined as the angle between the axes of the distal part of the radius on the fractured and on the normal side (Figure 1). The method used for determining the *final angulation of the distal epiphyseal* plate was identical with that previously described by Friberg (1979b).

The total error of the measuring procedure was evaluated by repeated measurements and was found to be 0.6 degrees ± s.d. = 0.4 for the residual angulation of the fracture. The errors of the other measurements have been given in previous studies (Friberg 1979a,b).

Statistics

The means and standard deviations are given. Standard computer programs were used for the stastistical procedures (SPSS vers. 6) (Nie et al. 1975). The influence was not considered to be significant at levels of $P > 0.05$.

RESULTS

A reduction of the primary fracture angulation had occurred in all of the 38 cases studied. However, despite prolonged observation times complete normalization was found in only four cases. A slight overcorrection had occurred in one fracture.

A concomitant distal ulnar fracture ($n = 9$) did not influence (Student's t-test) the rate of correction. No differences (X^2analysis) in the rate of correction were found when the different directions of primary angulation were compared. The reduction in fracture angulation is illustrated in relation to the corrected observation time (cf. Table 1) in Figure 2.

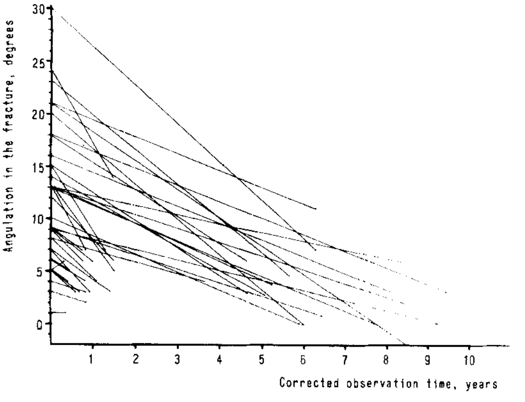

Figure 2. The angulation of the fracture in relation to the corrected observation time. It should be noted that the lines do not illustrate the course of the process but only connect observations in the same patient.

Influence of different variables on the residual fracture angulation

The residual angulation in all planes was tested to determine the effect of the different variables used for classification of the material (Table 1). The total number of observations was 38. The methods used were bivariate correlation analyses, stepwise regression analysis and direct discriminant analysis. Only significant relations between the dependent and independent variables are indicated.

The correlation analyses demonstrated that a longer corrected observation time (P = 0.0086, corr. coeff. = −0.38) resulted in a more complete correction of the angulation of the fracture. Furthermore, the younger the child was at the time of the fracture the more complete was the correction (P = 0.0023, corr. coeff. = −0.45). It should be noted that the correlation between age and the corrected observation time was very high (P = 0.001, corr. coeff. = −0.73).

A larger primary angulation in the fracture (P = 0.023, corr. coeff. = 0.33) and an increase in the distance from the fracture to the distal epiphyseal plate of the radius (P = 0.0086, corr. coeff. = 0.42) resulted in a less complete correction. The combined effects of these two parameters were also reflected in the finding that an increased adaxial displacement of the distal epiphyseal plate resulted in a greater residual angulation (P = 0.0003, corr. coeff. = 0.60).

Finally, a more complete correction or overcorrection of the distal epiphyseal plate (P = 0.00001, corr. coeff. = 0.75) was correlated with a smaller residual angulation of the fracture. The stepwise regression analysis showed that the final position of the distal epiphyseal plate ($P < 0.001$), the corrected observation time (P = 0.007) and the adaxial displacement of the plate ($P < 0.001$) were the only three variables which significantly

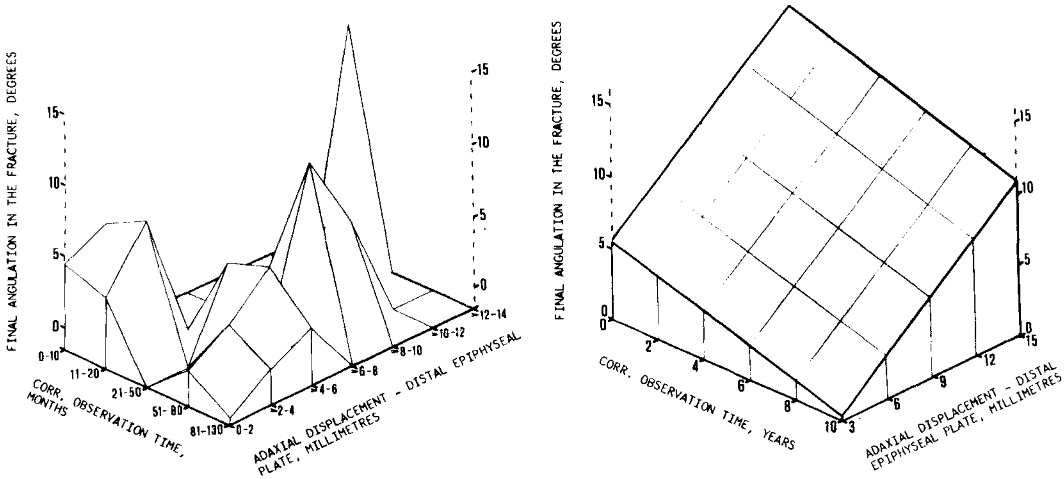

Figure 3. Three-dimensional plots of the relations between the residual fracture angulation, the corrected observation time and the adaxial displacement. In Figure 3A the height of each pyramid illustrates the mean value or value for the residual angulation found in the cases or case constituting the pyramid. The values of the parameters defining the cases in each pyramid are given in the figure. Figure 3B illustrates the regression plane of the three parameters.

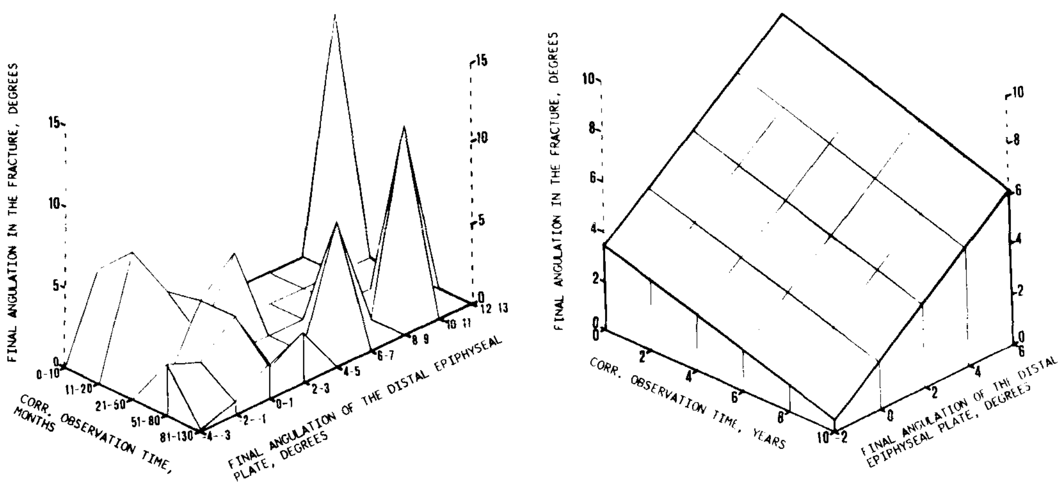

Figure 4. Three-dimensional plots showing the relationship between the residual fracture angulation, the corrected observation time and the final angulation of the distal epiphyseal plate. In Figure 4A the height of each pyramid illustrates the mean value or value for the residual angulation found in the cases or case constituting the pyramid. The values of the parameters defining the cases in each pyramid are given in the figure. Figure 4B illustrates the regression plane of the three parameters.

explained (79 per cent) the variance found in the results.

For the discriminant analysis the series was divided into two groups. The first group consisted of 18 cases with a residual fracture angulation of 3 degrees or less; the second group of 20 cases had a residual angulation of 4 degrees or more. The analysis showed that 90 per cent of the cases were correctly classified when all variables were used for the prediction ($P < 0.001$). A second discriminant analysis including only the corrected observation time and the adaxial displacement of the epiphyseal plate as independent variables

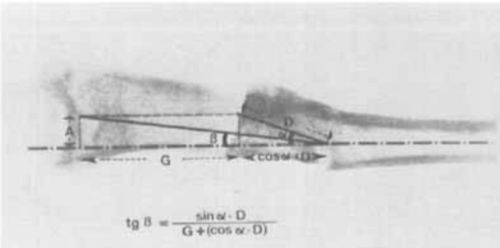

Figure 5. The formula used for calculation of the theoretical residual fracture angulation.
G = The longitudinal growth produced by the epiphyseal plate.
D = Distance from the fracture to the epiphyseal plate.
A = Sin α × D = Adaxial displacement of the epiphyseal plate.
α = Angulation of the fracture at the time of healing.
β = Residual angulation of the fracture.

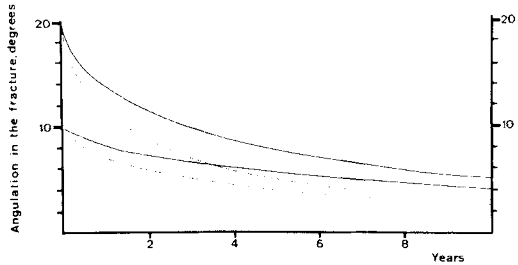

Figure 6. The correction of angulation of distal forearm fractures in four hypothetical cases according to the formula used in the study.
———— = 10 mm of adaxial displacement of the distal epiphyseal plate.
– – – – – = 5 mm of adaxial displacement of the distal epiphyseal plate.

resulted in a correct classification in 82 per cent of the cases ($P < 0.001$).

In conclusion, the statistical analysis showed that the residual angulation of the fracture at the follow-up examination was explained by three different circumstances. An increase in observation time up to the time of completed growth at the epiphyseal plates resulted in a more complete correction. A larger adaxial displacement of the distal epiphyseal plate, reflecting a greater primary angulation and a longer distance from the fracture to the epiphyseal plate, increased the residual angulation. A more complete correction or overcorrection of the distal epiphyseal plate resulted in a more complete correction of the angulation of the fracture. The relations between these three circumstances are illustrated in Figures 3 and 4.

Theoretical correction versus actual correction of the fracture angulation

For the calculation of the theoretical correction of the fracture angulation a formula was devised on the assumption that no "correction of angulation" would occur at the site of the fracture. The basis for this calculation was, then, that the direction and amount of longitudinal growth at the distal epiphyseal plate were the only factors influencing the reduction in angulation at the fracture site. The formula is illustrated in Figure 5 and the correction in hypothetical cases according to the formula in Figure 6.

In the calculations the slight increase in adaxial displacement that might theoretically occur before the orientation of the epiphyseal plate normalized was ignored. Also, the overcorrection of the distal epiphyseal plate that occurs with a longer period of observation was not taken into account. Thus, the final orientation of the plate was assumed to be equal to that on the normal side. For calculations of the longitudinal growth a figure of 0.94 mm/month was used for the first 12 months. This was the figure for the mean longitudinal growth actually produced by the distal epiphyseal plate of the radius during the first year after a distal forearm fracture (Friberg 1977). After the first year a growth rate of 0.64 mm/month was used. This figure was based on a total increase in the diaphyseal length of the radius of 0.80 mm/month (cf. Maresh 1955, Diethelm 1968 and Valk 1971) and the finding that after a distal forearm fracture 80 per cent of the total increase in diaphyseal length is produced at the distal epiphyseal plate (Friberg 1977).

When the correction actually achieved and the calculated theoretical correction were compared it was found that the formula resulted in a slight but nonsignificant (Students *t*-test) underestimation of the correction (0.34 degrees $\pm$ 172). The theoretical correction was also compared with the actual correction of the fracture angulation by a bivariate correlation analysis. The correlation found between the theoretical and the actual correction of fracture angulation was 0.83 ($P = 0.00001$). Thus the residual angulation of the fracture was almost completely explained by the effect of longitudinal growth provided that normalization of the orientation of the plate had occurred.

DISCUSSION

The correction of residual fracture angulation of the radius after healed distal forearm fractures in children was studied. The general result was that a correction of the primary angulation had occurred in all cases, but despite extensive periods of observation only isolated cases had reached full correction. However, the residual angulation of the fracture, at the follow-up examination, was relatively small in the cases with longer observation times. Thus, the present results are generally in agreement with the view that, provided adequate time has elapsed, a more or less complete normalization of a residual fracture angulation can be expected after a distal forearm fracture (Önne & Sandblom 1949, Gandhi et al. 1962, Miyagi & Murayama 1964, Lanzi 1965, Buck et al. 1966, Blount 1967, Nonnemann 1969).

In order to investigate in detail the process of correction of residual fracture angulation, several variables were analysed for their specific influence on the residual angulation. Primarily, the factors already claimed to influence correction were investigated, i.e. age, the degree of primary angulation of the fracture, the distance from the fracture to the adjacent joint (Blount 1955, Sharrard 1971, Ryöppy 1972). In addition, the influence of the orientation of the distal epiphyseal plate was taken into account as it has been proved that the epiphyseal plates normalize their inclinations in relation to the long axis of the bone (Friberg 1974, 1979a, b, Ryöppy & Karaharju 1974, Karaharju et al. 1976). On theoretical grounds, normalization of the orientation in combination with longitudinal growth at the plate has been suggested to reduce automatically the measured angulation of the fracture (Friberg 1979a,b).

The results showed that the observation time up to the time of completed growth at the distal epiphyseal plate was one of the major factors explaining the residual angulation of the fracture. This is also reflected in the finding that the younger the patient was at the time of the fracture the more complete was the correction. This finding is compatible with the general opinion with regard to the correction of fracture angulation (Blount 1955, Önne & Sandblom 1949, Miyagi & Murayama 1964, Högström et al. 1976). However, it is important to note that further analysis of the results indicated that it is not the age of the child *per se* that is of importance, but the remaining period of time up to epiphyseal closure. Gandhi et al. (1962) and Hansen et al. (1976) also found in their studies on the correction of residual fracture angulation that the age of the child at the time of fracture did not influence the rate of correction.

The primary angulation of the fracture and the distance from the fracture to the epiphyseal plate have also been known to influence the capacity for correction of residual fracture angulation (Blount 1955, 1967). These two variables were shown also in the present investigation to have a decisive influence on the results. However, the analysis strongly suggests that it is the combined effect of the two variables which is more important, i.e. the adaxial displacement of the epiphyseal plate.

Studies regarding the correction of angulations of the tibia have shown that the capacity for correction is not equal in all planes (Bennek & Steinert 1966, Spissak et al. 1969). According to Blount (1955) the plane of motion of an adjacent hinge-joint influences the capacity for correction. In the present study the direction of the angulation of the fracture was of no importance for the results. However, the wrist joint has a range of movement that incorporates all the directions the fracture was measured in. Thus the relevance of this factor could not be studied in the present investigation.

It has been suggested by Ryöppy & Karaharju (1974), Karaharju et al. (1976) and Friberg (1979a,b) that the orientation of and growth at the epiphyseal plates should be of importance for the correction of residual angulation after a fracture. The present results show that the orientation of the distal epiphyseal plate of the radius is of primary importance for the correction of a fracture angulation in the distal part of the radius.

The actual mechanism of the correction of a residual angulation of a diaphyseal fracture has not been fully investigated. However, it is generally implied that the correction occurs at the fracture site (Blount 1955, Sharrard 1971). Certainly, resorption of bone on the convex side and apposition of new bone on the concave side occur at the fracture site (Frost 1964). However, this process will not alter the actual inclination between the fracture fragments but will make angulation less prominent to the eye when radiographs are compared. Furthermore, an error may be introduced if the midpoint of the fracture is used as one of the measuring points when the correction of a fracture angulation is assessed.

The findings of the present study strongly support the suggestion (Friberg 1979a,b) that the correction is an effect of the orientation of the epiphyseal plate in combination with longitudinal growth. The results clearly showed that the orientation of the distal epiphyseal plate was of primary importance for the results. Furthermore, it was shown that an increase in the period of observation up to the time of completed growth increased the degree of correction. This can be translated to mean that an increased potential for longitudinal growth increases the amount of correction to be expected. Finally, the finding that the primary angulation and the distance of the fracture to the epiphyseal plate and especially the combined effect of these two parameters, i.e. the adaxial displacement of the epiphyseal plate, played a decisive role in the correction further supported the hypothesis that the correction is due to the orientation of and growth at the plate (cf. Figure 5).

With a view to predicting the expected correction of a residual fracture angulation, a trigonometrical formula (Figure 5) was devised. This formula was deduced from the hypothesis mentioned above, and, accordingly, it was assumed that no real correction occurs in the diaphyseal part of the bone. It was demonstrated that the formula produced an accurate prediction of the residual angulation actually observed in the series. The findings imply that no major change in the adaxial displacement of the epiphyseal plate occurred during the period of observation. Consequently, the results indicate that no real correction of clinical importance occurred at the fracture site and that, for example, "cortical drift" (Enlow 1962, Garn et al. 1969, Stanek 1969) played no role as a remodelling factor in the remaining part of the diaphysis of the bone. Thus, the results strongly support the opinion that the process of correction of a residual angulation of a fracture is a fictive correction and that, in reality, it is brought about by the combined effects of the direction and amount of growth at the epiphyseal plate.

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