

EXPERIENCES WITH EPIPHYSEAL ARREST IN CORRECTING DISCREPANCIES IN LENGTH OF THE LOWER EXTREMITIES IN INFANTILE PARALYSIS

A METHOD OF PREDICTING THE EFFECT*†

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Discrepancy in length of the lower extremities, if it exists to any considerable degree, is disabling. In infantile paralysis, this disability is greatly exaggerated by the associated paralysis and related skeletal abnormalities; so that measures to equalize the length of the extremities take on added importance.

When growth is complete, the only procedures available are direct lengthening or shortening of one of the long bones. In the growing child, however, the possibility occurs of modifying growth. The ideal arrangement would be to stimulate the growth of the shorter limb. Since no feasible method of accomplishing this exists at present, measures designed to inhibit the growth of the longer limb must be chosen. Surgical epiphyseal arrest, or epiphyseodesis, was first described by Phemister in 1933. This has proved to be a practical method of inhibiting growth, although deformities occurring after the procedure in certain instances have been described by Straub, Thompson, and Wilson, and by Regan and Chatterton. Roentgen irradiation has been shown to inhibit the growth of the epiphyses^{2, 3, 4}. Although the use of such a means to affect growth in the child was proposed by Judy, it remains to be demonstrated that undesirable effects do not arise from the irradiation and that its action on growth can be well controlled.

The important problem in surgical arrest is to choose the site of the procedure at the particular age which will allow equalization in length. This necessitates an ability to predict, within a practical amount, the growth in the lower extremity which will occur from various ages until maturity, as well as to estimate the proportion of growth which will be inhibited by the arrest. Although the procedure itself inhibits the growth of the longer limb, the index of its effect on the relative lengths of the extremities is based upon the growth of the shorter extremity.

Various techniques of predicting growth have been proposed. Hatcher adapted the Baldwin tables to obtain a derived length of the extremity⁵, and used a percentage from each epiphysis, as described originally by Digby. Gill and Abbott described a more complex method, which was likewise based upon a derived length for the extremity. They emphasized the importance of using skeletal rather than chronological ages in prediction. White and his associates suggested a simplified method, in which they proposed that the obliteration of either the upper tibial or the lower femoral epiphysis resulted in a loss in growth of one-quarter inch to three-eighths of an inch per year, with the assumption that growth terminated at the age of sixteen in girls and at seventeen in boys.

No method, however, has been based upon actual measured lengths of the femur and of the tibia; in fact, the authors are unable to locate published curves of growth of the femur and tibia, through the period of maturation, other than those which they presented recently¹ (Table I).

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TABLE I
AVERAGE LENGTHS OF THE BONES OF THE LOWER EXTREMITY
AS MEASURED FROM ORTHOROENTGENOGRAMS

Skeletal Age (Years)	Femur			Tibia		
	10th	Percentile* 50th	90th	10th	Percentile* 50th	90th
Girls						
5	24.7	26.1	27.6	19.2	20.4	21.8
6	26.7	28.2	30.2	21.0	22.4	23.8
7	28.6	30.2	32.6	22.6	24.3	25.7
8	30.6	31.9	34.6	24.0	25.2	27.3
9	32.4	34.0	36.1	25.1	26.9	28.9
10	33.4	35.6	37.7	26.0	28.2	30.5
11	35.0	37.4	40.1	27.5	29.4	32.2
12	36.3	39.2	41.9	28.8	31.0	33.7
13	38.0	41.2	43.9	30.3	32.8	35.6
14	39.5	41.8	44.4	31.0	33.0	36.2
15	40.3	42.3	44.8	31.4	33.0	36.6
16	40.1	42.3	45.4	31.2	33.6	36.9
Boys						
5	24.2	25.6	26.8	18.8	20.3	21.5
6	26.0	28.0	29.2	20.3	21.9	23.7
7	27.8	29.8	31.6	21.8	23.5	25.4
8	29.6	32.1	33.6	23.4	25.1	27.0
9	31.8	34.1	36.1	24.8	26.5	28.6
10	33.7	35.7	38.2	26.0	28.0	30.1
11	35.1	37.4	40.0	26.9	29.2	31.2
12	36.6	39.3	42.2	28.3	30.6	33.2
13	38.5	41.2	43.9	29.8	32.8	35.0
14	40.2	43.5	46.8	30.9	34.6	36.5
15	42.6	45.4	47.7	33.2	36.0	38.1
16	42.8	46.6	49.4	33.4	37.0	39.2
17	42.6	45.8	49.6	32.6	37.0	39.1
18	42.9	45.8	49.4	32.5	37.0	39.0

*If, in a group of cases, a particular measurement is distributed on the basis of size, the dimension of the individual which is larger than 90 per cent. and smaller than 10 per cent. of the cases may be said to define the ninetieth percentile for the distribution. Similarly, the "fiftieth percentile" describes the size of the middle individual (the median),—the case above and below which lie one-half the cases in the entire series. The "tenth percentile" indicates the level below which lie 10 per cent. of the measurements for the group, and above which lie 90 per cent.

It is the purpose of this communication to report a method of prediction, for use in epiphyseal arrests, which is based upon cumulative roentgenographic measurements of the femur and of the tibia in growing children. It is proposed, also, to outline the experiences with epiphyseal arrests at The Children's Hospital, Boston, regarding both the accuracy of the predicted effect and the incidence of deformities. In all references in this paper to arrest of the proximal tibial epiphysis, it is to be inferred that it is accompanied by arrest of the upper fibular epiphysis.

The chart which is presented for use in prediction must be considered a tentative one, and it will be revised as more data are accumulated. It represents a part of the

ANNUAL INCREMENTS IN LENGTH OF FEMUR AND TIBIA: MEANS AND EXTREMES OBSERVED AT CONSECUTIVE AGE INTERVALS

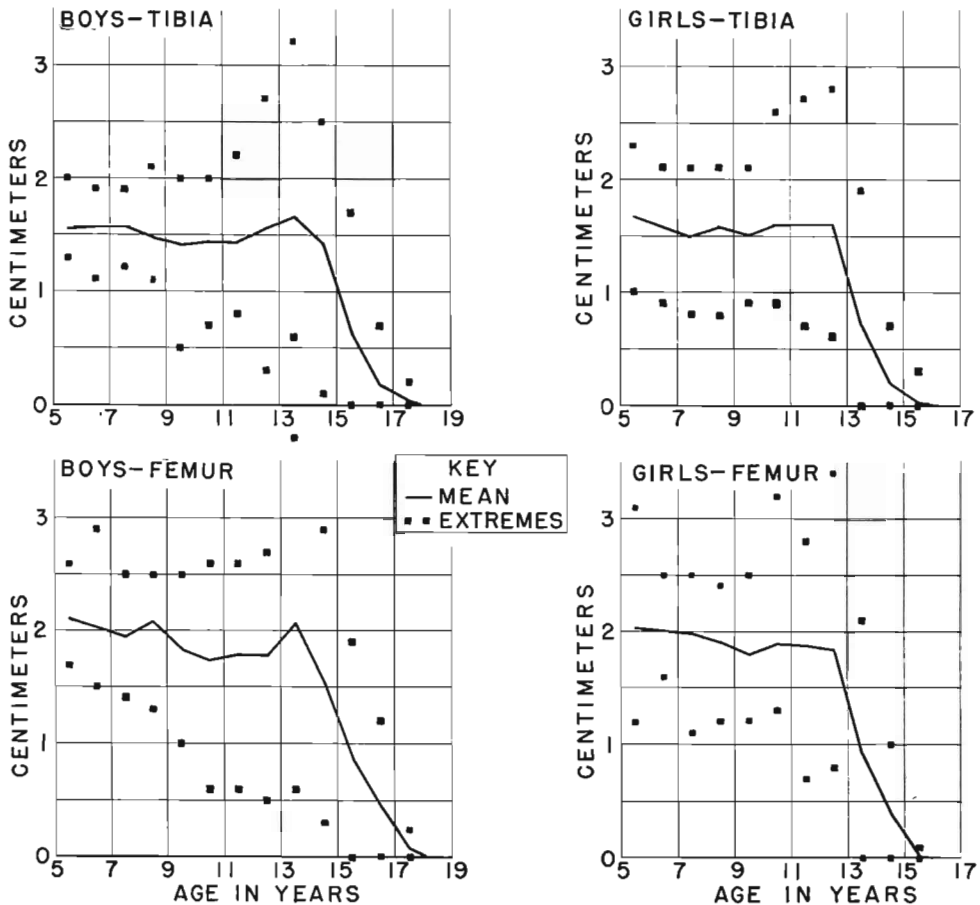


FIG. 1

These values for the annual increments of the bones of the lower extremity constitute the basic data from which the prediction curves were derived. All measurements were made from orthoroentgenograms, which give the true lengths of the bones.

material from a study of growth which has been in progress since 1940. This study involves approximately 700 children, 87 per cent. of whom have residual paralysis in one lower extremity with a normal extremity on the other side; and it also includes observations on 158 normal children, who are the subject of study in the Department of Maternal and Child Health, Harvard School of Public Health.

Studies of growth should be longitudinal,—that is, they should follow the same individual throughout the period of growth, until maturity. The present study follows this principle. However, a sufficient time has not elapsed for the tables to be constructed from completely longitudinal data; and the report represents a combination of limited longitudinal observations of the various children.

The study includes various measurements of the children, performed at regular intervals. Orthoroentgenograms of the femur and of the tibia of each child are taken at yearly intervals; in certain cases they are taken as often as once every three months. This technique of roentgenographic measurement has been described by Green, Wyatt, and Anderson, and is accurate enough to allow the recording of such quarterly increments of growth. For the purposes of this report, the lengths of the bones, as measured roentgenographically,

TABLE II
CENTIMETERS OF CORRECTION TO BE DERIVED FROM ARREST OF THE DISTAL
FEMORAL OR THE PROXIMAL TIBIAL EPIPHYSIS
(Tentative Table, January 1947)

Skeletal Age (Years)	Distal Femoral Epiphysis			Proximal Tibial Epiphysis		
	Low	Average	High	Low	Average	High
Girls						
8	6.7	7.4	8.1	4.4	4.9	5.4
9	5.4	6.1	6.8	3.4	4.0	4.5
10	4.1	4.8	5.5	2.6	3.2	3.7
11	2.8	3.5	4.2	1.7	2.3	2.8
12	1.5	2.2	2.9	0.8	1.4	1.9
13	0.2	0.9	1.6	0	0.6	1.1
14	0	0.3	0.7	0	0.1	0.3
15	0	0	0	0	0	0.1
Boys						
10	6.1	7.1	8.1	4.0	4.7	5.4
11	4.9	5.9	6.9	3.2	3.9	4.6
12	3.7	4.7	5.7	2.4	3.1	3.8
13	2.4	3.4	4.4	1.5	2.2	2.9
14	0.8	1.8	2.8	0.6	1.3	2.0
15	0	0.7	1.7	0	0.4	1.1
16	0	0.3	0.8	0	0.1	0.4
17	0	0	0.2	0	0	0.1

form the essential data. Observations of the patients who have had epiphyseal arrests include lateral roentgenograms of the knees, taken either semiannually or annually until the time of epiphyseal closure.

DERIVATION OF THE METHOD

The method of predicting the effect of epiphyseal arrests which the authors are proposing is based upon a cumulative series of the annual increments in the growth of the long bones of the lower extremity between consecutive ages (Fig. 1). These increments have been computed separately for the femur and for the tibia, and are subdivided as to sex. Measurements were derived from three to six annual orthoroentgenograms of the normal lower extremity of each of seventy-one boys and fifty-one girls with anterior poliomyelitis, and from eight to ten consecutive yearly roentgenographic measurements of twenty boys and eighteen girls who are normal individuals. The average number of increments for each age level was thirty. The extremes are recorded in graphic form, as are the averages. In the derivation of these original average increments, to avoid criticism, only those individuals were used whose chronological ages corresponded to the skeletal ages, as evaluated by the method of Todd*.

For practical usage, curves were constructed to show how much correction might be

*Children with markedly retarded or advanced maturation were placed in a separate series, and the ages of all the individuals in this group were adjusted to conform to their skeletal ages. Yearly increments of bone lengths, derived for this series by the use of skeletal age, corresponded so closely to those for the group which was used that the two could have been combined, if skeletal age had been used for the entire distribution. This, with other evidences which will be discussed later, emphasizes the importance of the assessment of relative skeletal maturity in considerations of growth.

CENTIMETERS OF CORRECTION TO BE DERIVED
FROM ARREST OF DISTAL FEMUR OR PROXIMAL TIBIA
PRELIMINARY CHART, 1947

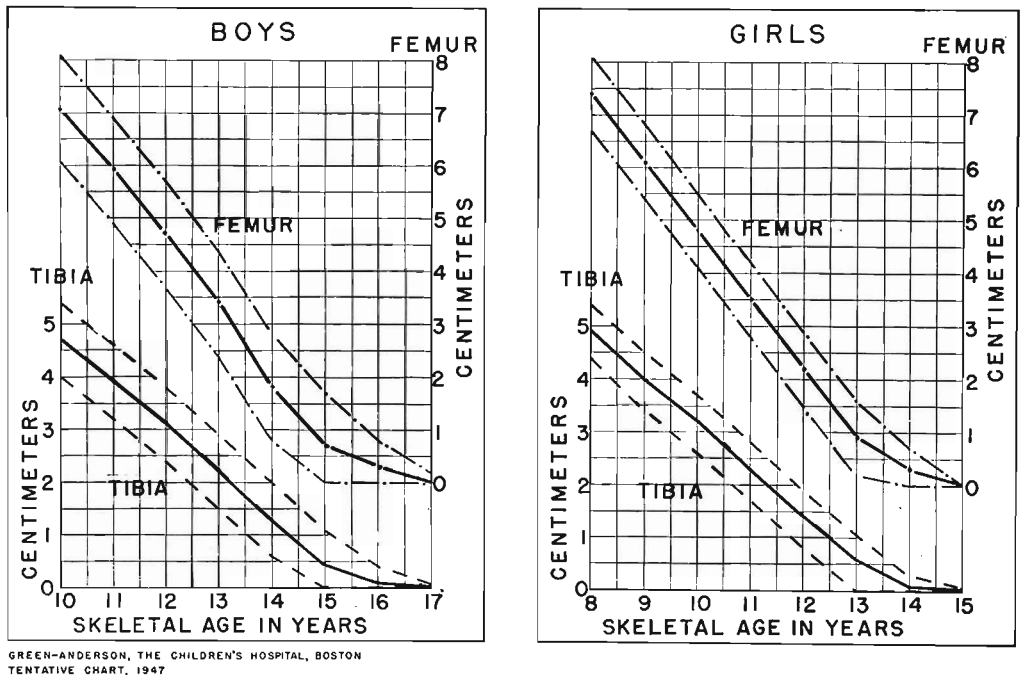


Fig. 2

The amount of growth to be eliminated after epiphyseal arrest can be estimated from this chart. The central line represents the average correction; the secondary lines, the useful range. The extremes are not indicated.

expected at each age from an arrest of either the lower femoral or the upper tibial epiphysis (Fig. 2 and Table II). The proportion of growth of the femur assigned to the lower femoral epiphysis was 70 per cent.; the upper tibial epiphysis was assigned 56 per cent. of tibial growth. These were the averages obtained from a small number of cases which had measurable transverse lines of temporary growth disturbance evident at the ends of the bones. These percentages correspond closely to the original figures of Digby, and to the amounts proposed by others. The prediction chart (Fig. 2) represents a product of the cumulative average annual increments of growth derived from a particular bone and the percentage which the specific epiphysis contributes to growth. The dense central line represents the average correction to be expected from an epiphyseal arrest at the corresponding skeletal age on the chart; a derived range is also indicated for each age level*.

In the use of the chart, various factors can modify the position between the ranges, which will be chosen as the amount predicted for a particular individual. A tall person with long legs, for example, should approach the upper limit of the predicted amount; a short individual, the lower range. Likewise, an individual with a high percentage of inhibited growth in the affected lower extremity would be expected to receive less correction than one whose coefficient of inhibited growth is less; and, therefore, the predicted amount will be adjusted toward the lower figure for the age. When a patient has not had accurate measurements long enough for the percentage of retarded growth to be determined, it may be approximated by relating the existing shortening to the estimated growth since

*Because no case in this series has yet been observed over the entire age range covered by the chart, it is impossible at this time to present actual values for the extremes. An artificial range of predictions is, therefore, included, which has been derived from the standard deviations computed at each annual interval.

the onset of the disease. (In the patients of this series with 75 per cent. or less of musculature remaining, the average retardation of the affected extremity was 10 per cent. in the femur and 12 per cent. in the tibia.) Theoretically, mathematical formulae should be applied to correct these variants, but more data are necessary before such precise adjustments can be made. Shifting the position on the chart within the range indicated for the individual's age, according to the factors mentioned, has worked in practice. As an aid in estimating the relative bone lengths in a given child, a table is included here of the average lengths of the femur and the tibia, derived from orthoroentgenographic measurements (Table I).

The curves of prediction of the effect of epiphyseal arrest presented here do not go below the ages of eight years for girls or ten years for boys. This is an adequate age range for the correction of discrepancies in length, due to infantile paralysis. In the series under study, there have been no discrepancies greater than thirteen centimeters. Arrest at the minimum ages would effect as much correction as this; and it is doubtful whether it would be desirable to deprive an individual of more than five inches in total height in order to equalize the length of his extremities.

The chart (Fig. 2) is based upon the annual increments of growth of a normal lower extremity, rather than upon the average correction observed after epiphyseal arrest, for two reasons. In the first place, a larger group of measurements could thus be used, which gave more reliable averages and ranges in predicted values; in addition, if the corrections obtained from epiphyseal arrests were used, the figures would contain certain uncontrollable variables, which would depend upon the relative effectiveness of the epiphyseal arrest itself.

The average correction after epiphyseal arrest in this series of patients was 65 per cent. in the distal portion of the femur, and 46 per cent. in the proximal portion of the tibia. If these percentages, which are computed on the basis of the growth of the paralyzed limb, were corrected on the basis of the average coefficient of inhibition which has been observed in the paralyzed extremities, the values would be 69 per cent. of normal femoral growth and 52 per cent. of normal tibial growth. These figures are remarkably similar to the average values used in the chart of prediction—70 per cent. and 56 per cent., respectively—particularly when one considers that the figures obtained from epiphyseal arrests represent averages and, therefore, must include some cases in which an effective fusion has been slow in developing.

RELATIVE SKELETAL MATURITY AND AGE AT TIME OF EPIPHYSEAL CLOSURE

Early in this study of growth, the authors discovered that it was essential to make some sort of assessment of the relative maturity of each individual. The method proposed by Todd has been found to be the most valuable guide which exists at this time, although it has certain limitations. The importance of using skeletal age, rather than chronological age, in prediction may be illustrated by comparing the effect of femoral arrest in two girls of the same chronological age. In Case A, with a chronological age of eleven and a skeletal age of eleven, a correction of 3.0 centimeters was obtained. In Case B, with a chronological age of eleven years and four months but with a skeletal age of thirteen years and six months, only 0.9 centimeter of equalization was accomplished.

It was the authors' rule to use the skeletal age in predictions, first, if the skeletal age deviated nine months or more from the chronological age or, second, if it varied consistently in serial examinations by as much as six months.

The importance of assessment of the degree of skeletal maturity is further emphasized by considering the age at which the epiphyses of the lower extremities fuse. As judged by serial roentgenograms, this fusion occurred at an average skeletal age of fifteen years and three months in girls and of seventeen years and three months in boys. In all instances, the fusion was observed within one year of these skeletal ages, whereas the chronological

age at which epiphyseal fusion occurred varied tremendously, covering a range of four or five years. Very little growth occurred during the year preceding the closure of the epiphyses, so that the skeletal ages of fourteen years and three months in girls and sixteen years and three months in boys can, for practical purposes, be used as the ages at which growth of the lower extremities terminates.

ACCURACY OF PREDICTION

Although the effect of epiphyseal arrest in correcting discrepancy can be determined once growth is complete, not all cases in this category can be used in testing the accuracy of methods of prediction.

Seventy-seven cases of epiphyseal arrest in this group have been followed through the period of completion of growth in the lower extremities; however, for the purpose of evaluating predictions, it was necessary to omit cases in which accurate serial roentgenographic measurements were not available, those in which the skeletal age was not recorded at the time of the procedure, and individuals in whom other operations complicated the measurements. Likewise, patients were omitted in whom the paralytic involvement was bilateral; those in whom the epiphyseal arrest was definitely slow in producing its effect, as determined by postoperative roentgenograms; and those in whom a postoperative deformity occurred.

Satisfying the demands were forty-one arrests, performed on twenty-nine patients. The other arrests were used in evaluating the result of the procedure, but not in evaluating the method of prediction. The general pattern of the action of the arrest in each of these forty-one operations was nearly always parallel to the predicted curve (Figs. 3-A and 3-B). Of the 190 points representing levels of prediction at the various ages, only 4 per cent. were outside the indicated range, and in those the deviations were of minor degree.

The accuracy of this method of prediction was compared with that of four other methods of estimating the effect of epiphyseal arrest:

1. The Baldwin-Hatcher table, assuming that the distal portion of the femur contributes 40 per cent. and the proximal portion of the tibia 27 per cent. of the growth in the lower extremity.

2. The Gill-Abbott method.

3. White's method, assuming that the distal portion of the femur contributes three-eighths of an inch per year and the proximal portion of the tibia contributes one-quarter inch per year until the age of sixteen years in girls and of seventeen years in boys.

4. A method utilizing a fixed yearly increment of growth and skeletal age.

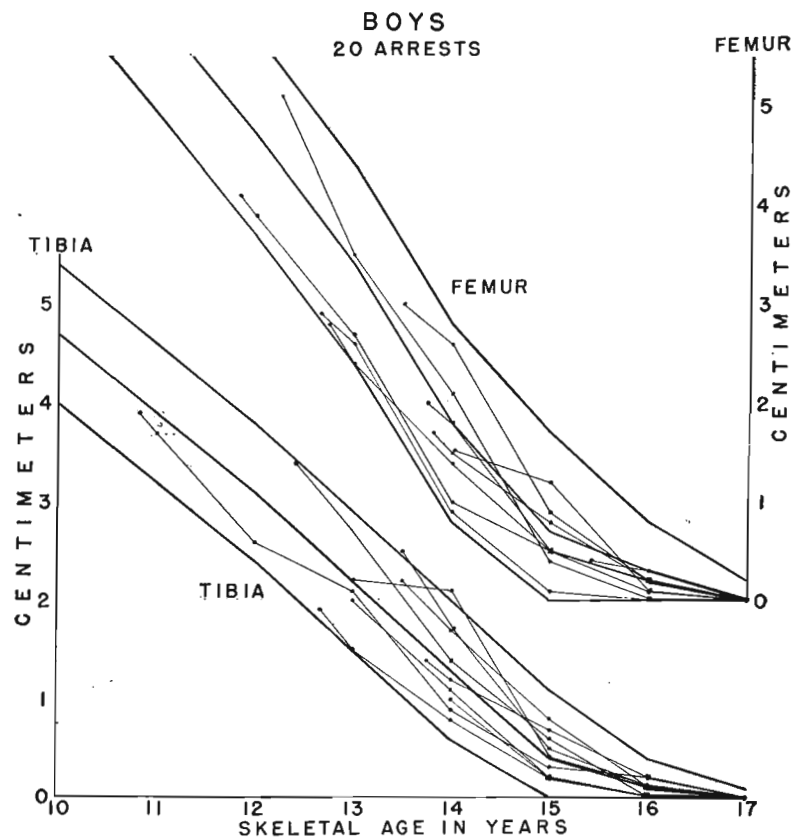
The fourth method might be considered a modification of the method of White, and will be described in detail. In all instances, except the original method of White, skeletal ages rather than chronological ages were used (Fig. 4).

The Baldwin-Hatcher table gave a high figure for the predicted result in the boys in this series, but the girls in the group obtained corrections quite similar to those predicted. When this method was employed, in conjunction with a correction for skeletal age, predictions were more accurate than one would anticipate, when it is considered that the table is derived from anthropometric measurements. Baldwin's measurements, which were used by Hatcher, indicate that extremities grow more rapidly in boys than in girls; the authors' data, on the other hand, indicate that boys grow at essentially the same rate, but continue to grow two years longer than girls.

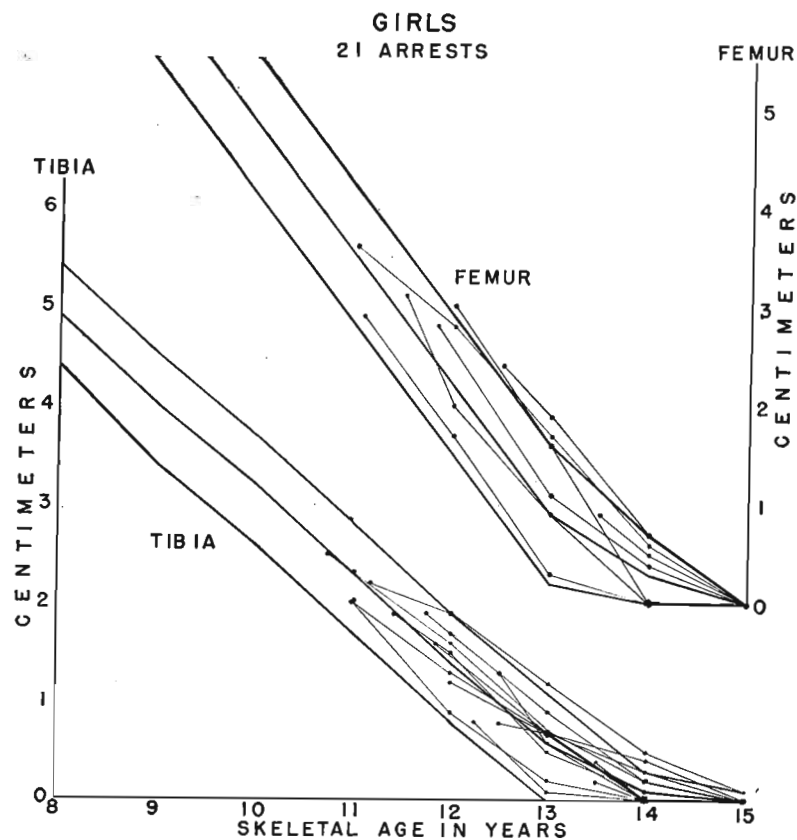
The Gill-Abbott method, although more complicated, has the virtue of being the only one in which the height of the individual is taken into consideration. Their predictions coincided very well with the results obtained in the authors' cases, with the exception of boys' femora, in which the amount predicted exceeded greatly that which was obtained in this series.

White's method has the great advantage that predictions are made without a chart;

INDIVIDUAL CORRECTION CURVES AFTER ARREST COMPARED WITH THE PREDICTED EFFECT



INDIVIDUAL CORRECTION CURVES AFTER ARREST COMPARED WITH THE PREDICTED EFFECT



The amounts of correction observed at consecutive skeletal-age levels, after forty-one epiphyseal arrests, follow the pattern indicated by the prediction curves.

COMPARISON OF METHODS OF PREDICTION AGAINST 41 FINAL RESULTS

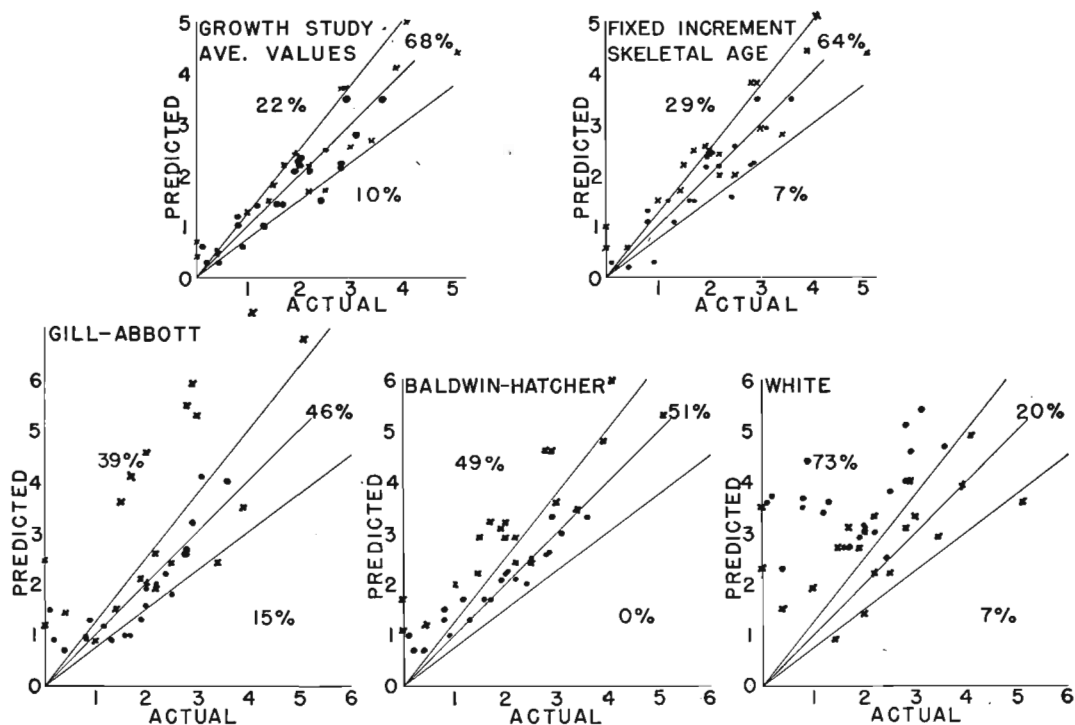


FIG. 4

Each of these charts has been constructed with a diagonal line, indicating perfect agreement between actual and predicted results; and with two other lines, spaced so as to include all cases within a 25 per cent. error of prediction. Arrests on boys are indicated by a cross; on girls, by a solid circle.

The forty-one final results in the test series corresponded more closely to the values from the authors' prediction chart (growth study, average values) than to those of the other methods.

but, on the basis of the cases tested, it was less accurate than the other methods. However, the amounts of yearly growth which White described as occurring at the epiphyses did not show great variations from those observed in the authors' cases. The inaccuracy arises largely from the fact that relative skeletal maturity is not considered, and that the ages which White used as indicating the cessation of growth could not be corroborated.

If various modifications are made in the method described by White, a technique is evolved which, as applied to the authors' cases, was quite accurate. This may be called the "fixed increment-skeletal age" method. The value used in prediction represents fundamentally a product of a fixed increment of growth, assigned to the particular epiphysis under consideration, and the number of years of growth remaining.

All computations are made with a correction for skeletal age, the ages of fourteen years and three months for girls and sixteen years and three months for boys being used as the times when growth in the extremities terminates. The yearly increments used are the average amounts which were observed in normal lower extremities of boys and girls in this series during the years of active growth. These are 1.3 centimeters for the distal femoral epiphysis and 0.9 centimeter for the proximal tibial epiphysis, except during the last year of growth, when the amount is approximately half these figures. To allow for this reduced growth in the terminal period, the figures are adjusted, for purposes of computation, as though the full increment were followed for a period of one-half year less than the actual period of growth. The effect of an arrest at a given age may then be approximated

by subtracting the age of the individual under consideration from thirteen and three-quarters years for girls and from fifteen and three-quarters years for boys, in order to obtain the number of years of growth on the basis of the full yearly increment. The figure so obtained is multiplied by the average increment of growth for the particular bone. In a boy ten and three-quarters years of age, for example, the formula for the effect of a femoral arrest would be as follows: $1.3 \times (15\frac{3}{4} - 10\frac{3}{4}) = 6.5$ centimeters.

To determine the indicated age for an arrest in a particular individual, one takes the amount of shortening in centimeters, divides this figure by the yearly increment of the femur (1.3), the tibia (0.9), or the combination of the two (2.2), as indicated, to ascertain the number of years required for the equalization. This figure is then subtracted from the age of thirteen and three-quarters years in girls or fifteen and three-quarters years in boys, to determine the age at which the arrest is indicated. The method has various defects, chief of which is that not enough data have been collected to indicate the range of individual variation in increments. It was, however, the second most accurate method when applied to the cases in this series, and does allow a prediction when no chart is available.

TABLE III
FINAL RESULTS COMPARED WITH THE PREDICTED EFFECT

	No. of Arrests	Per Cent.
Result within one-half inch of predicted amount	54	88.5
Result one-half inch or more above average prediction	1	1.7
Result one-half inch or more below average prediction	6	9.8
Delayed operative effect	4	
Other (one case)	2	
Total arrests with adequate measurements	61	100.0

The chart (Fig. 2) provided the most accurate prediction for the forty-one cases of arrest in this series which were available for the test (Fig. 4). It may be well to comment again that these cases were not included in the construction of the original table. In none of the uncomplicated cases in the test series did the outcome vary as much as 1.2 centimeters (one-half inch) from the average value predicted; in a larger group, to be discussed later, however, there were six individuals in whom a greater deviation occurred.

This chart has the advantage of providing a single graph which may be used directly, without mathematical computation. Moreover, it provides a range within which an individual may be placed, after consideration has been given to the various factors which might modify the expected amount of correction.

RESULTS OF EPIPHYSEAL ARRESTS

The clinical results of epiphyseal arrest in cases of infantile paralysis were evaluated in all patients in whom growth was complete and in whom observations existed before and after operation. Falling into this category were seventy-seven arrests, representing fifty cases; forty-one of the seventy-seven were in the test group discussed previously. The operations did not follow a constant technique, and the procedures were carried out by many different surgeons. Thirteen of the operations were done at other hospitals. All of the patients were available for evaluation of deformities and complications; in sixteen arrests, however, the measurements were inadequate to compare the amount of correction obtained with the result which had been predicted. These were mainly the cases in which teleoroentgenograms had been used for the early measurements.

INDIVIDUAL CORRECTION CURVES AFTER ARREST COMPARED WITH THE PREDICTED EFFECT

CASES NOT QUALIFYING FOR THE TEST GROUP

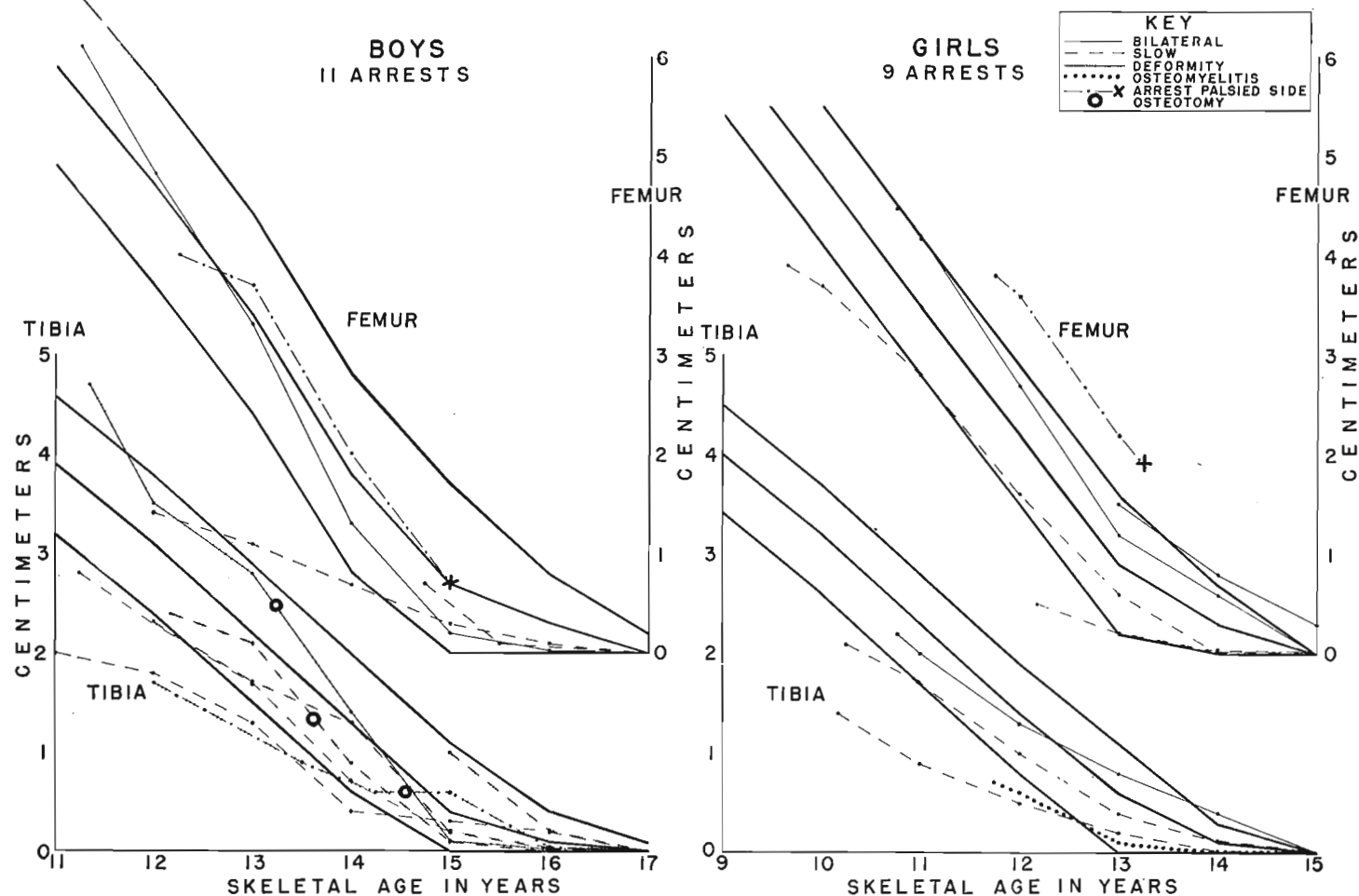


FIG. 5

The results of these twenty arrests could be measured adequately, but could not be used to test the methods of prediction because, for the various reasons indicated, they comprised an abnormal series.

CORRECTION OBTAINED

Not all cases adhered as closely to the prediction graph as did those used in the evaluation of the method. Of the sixty-one arrests which could be evaluated, the result was below the range predicted in ten; and in five the result obtained was above the range of prediction (Fig. 5). However, the discrepancy was small in most of these. In only seven arrests, represented by six cases, was the deviation as much as 1.2 centimeters from the average prediction; in six of these, the correction was less than that predicted; in one, the correction was 1.3 centimeters greater than the average prediction (Table III). The six arrests in which the result was less than that predicted showed a mean discrepancy from the average prediction curve of 1.8 centimeters, although one arrest which was technically ineffective deviated by 3.3 centimeters.

Deviations from the estimated amount seemed to be due primarily to two causes,—either an arrest which was not immediately effective on a technical basis, or an individual with marked irregularity of maturation, as judged by skeletal age. Secondary considerations were a patient with either very short extremities and a small increment of growth, or very long extremities and a very large increment of growth; and an arrest in a patient who showed marked inhibition of growth in a paralyzed extremity.

In four of the six arrests in which the correction was significantly less than had been predicted, the procedure was not effective for quite a long time after the operation. Examination of serial roentgenograms showed that these epiphyses remained open for a longer interval than normal. The slowness of the effect could be traced more or less directly to the operative technique, including instances in which bone grafts were inserted without drilling or curettage of the epiphyseal line.

For example, one boy had a tibial arrest performed at a skeletal age of eleven years, in order to equalize a two-inch discrepancy. The average predicted effect was 3.9 centimeters, with a possible range on the chart of from 3.2 to 4.6 centimeters. However, the epiphyseal line remained open for an abnormally long time, and did not become fused until two years after the operation. The growth of the arrested tibia was inhibited only



FIG. 6-A

FIG. 6-B

FIG. 6-C

Fig. 6-A: W. B. had a tibial arrest at a skeletal age of twelve years and three months; genu valgum



FIG. 6-D



FIG. 6-E



FIG. 6-F

developed, requiring osteotomy. Roentgenogram, taken one month after arrest, shows the tibial epiphyseal line to be open only on the medial side.

Fig. 6-B: Roentgenogram, taken twelve months after the arrest, shows marked genu valgum.

Fig. 6-C: Shows correction after osteotomy.

Fig. 6-D: Preoperative photograph shows the two-inch shortening.

Fig. 6-E: The degree of knock-knee prior to osteotomy is shown.

Fig. 6-F: Photograph after osteotomy shows the good contour of the extremity. The final correction in discrepancy amounted to 3.4 centimeters.

26 per cent. during this period, instead of an average of 46 per cent.; and a femoral arrest was necessary. The total correction from the tibial arrest was only 1.9 centimeters; but the extremities were of equal length at maturity, because the femoral arrest was normally effective.

Two other arrests which were slow occurred in one patient, a girl, and were very unusual. The tibial arrest was performed at the age of ten years, and the femoral arrest at twelve years of age. The skeletal age was normal at these times. Both epiphyses closed promptly. The coefficient of inhibited growth in the paralyzed extremity prior to operation was only 14 per cent., which is close to the average figure for this series of cases; yet the result obtained in this patient showed the greatest deviation from the predicted result. She was a very short girl at all ages; her height was just above the tenth percentile*; and the tibia on the paralyzed side grew only 4.4 centimeters after the tibial arrest rather than the average increment of 6.7 centimeters. The effect was further reduced by the fact that the percentage of growth inhibited by the procedure was less than it should have been. A full explanation of the slowness was not apparent. In part, it occurred because of her short stature and lack of growth and because of an increase in the velocity of maturation after the arrest, but some other factor contributed to the unusual result. It seems likely that, for some unknown reason, there was an increase in the coefficient of inhibited

* See footnote to Table I.

TABLE IV
COMPLICATIONS FOLLOWING EPIPHYSEAL ARRESTS

	No. of Arrests	Per Cent.
Total arrests (50 cases with growth complete)	77	100.0
Tibia	43	
Femur	34	
Deformities (all in tibia)	5	6.5
Valgus	4	
Varus with genu recurvatum	1	
Osteomyelitis	1	1.3
Peroneal palsy (temporary)	1	1.3
Overcorrection of discrepancy	3	3.9

growth on the paralyzed side after operation. The interpretation was complicated by the fact that the patient had had a lumbar sympathectomy on the side of the short limb.

A patient who obtained more than the average predicted correction illustrates certain difficulties. Arrests of the upper tibial and fibular epiphyses were performed on a girl at the age of eleven years and three months, and a femoral arrest was carried out at the age of twelve years. Her skeletal age at these times was normal. The average predicted result for the two procedures was 4.3 centimeters, and the maximum was 5.6 centimeters. There was no reason to anticipate a deviation from the average prediction, since the patient was a child of average height and with only moderate involvement of the weak limb. After the arrests, however, she exhibited slowing of maturation, as judged by roentgenograms of her wrist; so that she grew for a longer period than was anticipated, and her shortening threatened to become overcorrected. A femoral arrest was performed on the paralyzed extremity at the age of thirteen, to make sure that the overcorrection would not be excessive. Examination, after growth was complete, showed that the bones of the extremity with the residual paralysis were 1.2 centimeters longer than those on the other side; but her limb lengths to the sole were equal, and her balance was symmetrical.

In two other cases the discrepancies were overcorrected, and in one a femoral arrest was performed on the opposite side to prevent further increase in length; however, the correction obtained in both instances was close to that predicted by the chart, and the error arose from choosing too early an age for operation (Table IV).

DEFORMITIES

Deformities following epiphyseal arrest have been reported by others. Straub, Thompson, and Wilson reported that, in 10 per cent. of their cases, deformities developed which were severe enough to require corrective operations. Regan and Chatterton described significant deformities in 11 per cent. of their patients.

In this series, five instances of deformities were observed in seventy-seven operations, and all followed tibiofibular arrests (Table IV). A valgus deformity was present in four; the other showed varus with associated genu recurvatum. Three of these patients have had osteotomies to correct the abnormality; following these, the final result was evaluated as good. In one, an osteotomy has been recommended; and in the other, the deformity is so slight that it does not warrant correction (Table V).

One of these patients (W.B.) showed almost immediate postoperative evidence of a developing deformity, because the operation for technical reasons failed to stop growth on the medial side (Figs. 6-A to 6-F, inclusive). A rearrest should have been performed before the deformity had progressed to the stage at which an osteotomy was needed. However, this boy exhibited increasing deformity for eighteen months, at which time a

TABLE V
SECONDARY OPERATIONS AFTER SEVENTY-SEVEN ARRESTS

	No.	Per Cent.
For deformities:		
Osteotomy.....	4	5.2
Done.....	3	
Advised.....	1	
Secondary arrest.....	1	1.3
For overcorrection:		
Femoral arrest in paralyzed lower extremity.....	2	2.6

wedge osteotomy was performed to correct the genu valgum. Following this, no further increase in the deformity occurred, and the final result was a limb of good contour with very little discrepancy in length.

In an analysis of the causes of deformity and the delay in effect of the arrest, the postoperative roentgenograms usually are a clue to the difficulty. Persistent asymmetry in the width of the epiphyseal line or failure of the line to become narrow and finally obliterated within a year are the important findings. If increments of growth are measured accurately and the correction does not follow the predicted pattern, one may suspect that the procedure has not been adequate. It is our custom, at this time, to insert a very small square of tantalum on the diaphyseal side of the plate, both medially and laterally. These squares, when visualized in serial roentgenograms, permit an accurate evaluation of the effectiveness and symmetry of the arrest. Roentgenograms of the area should be taken every three months until the epiphysis at the site of arrest has been completely obliterated. Careful clinical examinations should be performed at regular intervals, during the same period, to record any tendency toward deformity.

The technique of the operation seems to be the largest factor in determining the effectiveness of the procedure and the incidence of deformities. Certain of the surgeons carrying out the procedure in this series have had no cases in which deformities developed, and all of their arrests have been effective immediately.

TECHNIQUE OF OPERATION

The operative technique will be discussed only in so far as it affects the results of the procedure. The technique which is recommended includes a wide, thick graft on each side—ordinarily from seven-eighths of an inch to one inch (from 2 to 2.5 centimeters) in width—which should go well beyond the epiphyseal plate into the epiphysis, yet have a much longer portion on the diaphyseal side. It should extend at least one inch into the diaphysis so that, when the graft is reversed, the cartilage in the transplanted bone is well removed from its original position. In depth at the epiphyseal plate, the graft should be at least three-quarters of an inch (2 centimeters). The exposure of the epiphysis can often be facilitated by adding a transverse cut to the longitudinal incision in the periosteum. The operative sites should be located equidistant from the anterior and posterior surfaces of the bone; this will place the grafts in exact mid-lateral and mid-medial positions. The epiphyseal plate is drilled carefully throughout its extent with a hand drill, entry being made through the site from which the graft has been removed. The first drill point used is one-eighth of an inch in diameter, so that the cartilage may be followed accurately, by palpation with the drill point, as the drilling is performed. After this, drill points three-sixteenths of an inch and one-quarter inch in diameter are used, so that the epiphyseal plate will be thoroughly obliterated. Slivers of cancellous bone, pried from the bed of the graft in its extent in the

diaphysis, are then inserted into the obliterated plate so as to fill it in as completely as possible. Particular care is observed, when drilling the femoral epiphysis in the direction of the patellar groove and when drilling both bones directly posteriorly, not to go beyond the confines of the bone; the drilling of the posterior portion, however, should be thorough. The graft is rotated 180 degrees and reinserted so that cortical bone impinges upon cortical bone, with the graft fitting snugly and smoothly. This fit is facilitated by the use of matched osteotomes in pairs, when the graft is removed. The periosteum is reconstructed.

If this technique is followed carefully, postoperative deformity should be minimum, and arrest should be effective from the start.

COMMENT

It is well to recall that absolute equalization of length is not the goal in all cases. A patient who must wear a long brace with a locked knee joint, for example, is usually better with one or two centimeters of shortening on the side of the brace. Each problem should be considered individually.

For those who do not need a long brace, it is desirable for the extremities to approach equality of length. Procedures to correct discrepancy are particularly indicated when marked shortening exists in patients who do not require a brace.

To determine the degree of correction which is needed, the amount of lift required to restore balance in the standing position is the important consideration, and should be evaluated. Roentgenographic measurement of the bones and clinical measurements from the anterior superior spine of the ilium to the medial malleolus and to the sole should be recorded. The decision as to the amount of arrest needed arises from a combination of these evaluations. If a triple arthrodesis is planned for a later date, it is well to add one centimeter to the amount which is considered necessary, since this operative procedure reduces the height of the foot.

In planning the correction of a discrepancy of considerable degree, it is well not to wait until the age at which arrests of both the femoral and tibial epiphyses are indicated, but to perform one operation at a younger age and the other at the age when it is needed to complete the equalization. In this way less error will occur if, for some reason, such as a change in the pattern of maturation, the original prediction should not be accurate. Marked shortening of the leg (tibia) in girls is not desirable cosmetically.

In following the condition of patients who have asymmetrical involvement of the lower extremities, caused by infantile paralysis, not only the discrepancy, but the actual lengths of the extremities should be recorded at regular intervals. Highly desirable, but not essential, are accurate roentgenographic measurements at yearly intervals. Such information permits a calculation of the percentage of inhibited growth, as well as a record of the shortening and the length of the extremities. At intervals of a year or six months, roentgenograms of the wrist for evaluation of skeletal maturity are desirable. The evaluation of skeletal age by a single determination is very much less reliable than by serial examinations.

Finally, it must be stated again that the chart which has been presented is a tentative guide for the estimation of the effect of epiphyseal arrest, and not an absolute index. The irregularity of patterns of growth must be appreciated and considered as a limiting factor in any method.

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DISCUSSION

DR. FREDERIC C. BOST, SAN FRANCISCO, CALIFORNIA: Since the origination of epiphyseal arrest by Dr. Phemister, other methods of equalizing leg lengths have rarely been necessary. The use of epiphyseal arrest requires exact information regarding the growth of bone. Quite accurate information concerning the growth of bone was adduced by Hatcher, by Gill and Abbott, and by J. Warren White. All of them used information obtained from records made by other observers who were concerned with the general growth of the child, and information obtained by anthropological studies. It is interesting that these methods of estimation should prove so nearly correct, as Dr. Green has pointed out in his present paper.

Dr. Green is the first to give us very accurate information concerning the growth of bone. These data he has obtained by serial roentgenograms made at half-year or yearly intervals. From the information which he obtained, he has presented a simple chart which shows the average growth to be expected at any given age. This chart is sufficiently accurate to be of practical use in treating patients who have inequality in lengths of the lower extremities.

Dr. Green's statistics are based upon measurements obtained from a large number of children, but much more information must be adduced before the measurements may be considered infallible. While exact equality of lengths is not essential for a good clinical result, nonetheless we should all collect further information concerning bone growth in order that greater accuracy may be possible. Dr. Green's measurements were made from orthoroentgenograms, a measurement which he described in an earlier paper. Scanography, described by Millwee and also by Gill, would seem to be an even more accurate method for measuring actual bone length.

DR. J. WARREN WHITE, GREENVILLE, SOUTH CAROLINA: I want to express my appreciation for these papers, which are a real help to those of us who are intensely interested in this subject. I would like to ask Dr. Green, who persuaded me eight months ago to take cognizance of bone age, about the determination of this important figure. In every roentgenogram we have taken, we have had trouble making this determination. I hope that something will be published soon which will be more accurate than the Todd method. We recently have been in communication with Dr. Bayley of the University of California, and she has sent information which has been of considerable value. I wonder if Dr. Green can give us some information by which we can more accurately interpret the bone age.

DR. W. T. GREEN, BOSTON, MASSACHUSETTS (closing): As regards Dr. Bost's comment concerning the accuracy of the roentgenographic method, I should like to say that the method is accurate, as the determination depends upon focusing the tube consecutively over each joint, and hence upon the interception of the ends of each bone by parallel rays. This avoids magnification. The point of focus is recorded on the film by a marker in every instance, thus allowing us to check the technical accuracy of each film.

We shall always have some difficulty in predicting the effect of an arrest until we understand better the patterns of skeletal maturation, and are able to judge skeletal maturity more accurately. In 88 per cent.

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in cases with marked soft-tissue loss anteriorly, which made closure of the anterior wound impossible. Drainage of infections of the anterior quadrants of the thigh, especially of the medial quadrant, was unsatisfactory when this incision was used; and other means were required. After operation, the muscles were found to fall back together, as did the skin, so that small non-disabling scars were obtained even when the incisions were not sutured. Muscle scars or adhesions which limited the motion of the knee were not encountered, although the cases could not be followed sufficiently long to be certain of this. Sensory changes were minimum, as the incision lies between the skin areas supplied by the lateral femoral cutaneous nerve and the posterior femoral cutaneous nerve.

SUMMARY

The posterolateral approach to the femur gives easy anatomical access to the entire shaft of the bone with negligible blood loss, minimum muscle damage, and only slight, if any, circulatory or sensory impairment. It facilitates reduction, alignment, and fixation of the fracture, and allows for dependent drainage. The scar resulting from the incision is neither disabling nor disfiguring.

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DISCUSSION

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of the whole group, however, the effect from epiphyseal arrest, performed by many different surgeons in the hospital, was within one-half inch of the prediction. Most of the variations from the predicted effect were traced to the technique of the operation.

The details of the operative technique are most important, and the reason that many are critical of the procedure is that the operation is not performed satisfactorily. A poor arrest may not obtain the predicted effect because it does not slow down growth immediately; an arrest which is done poorly on one side will produce deformity. I think that epiphyseal arrest is a good procedure, and that it is the best way to equalize the length of the extremities of the growing child in most instances.

As regards Dr. White's question, I think we should appreciate that accuracy in prediction of skeletal maturity is essential, and that we still have difficulty with it. Particularly do we have trouble with those unusual children who show variations in their patterns of maturation. For example, a child may seem by roentgenographic evaluation to be retarded in skeletal maturation at a particular period, but subsequently he shows very rapid maturation, which changes the relative position of the skeletal to the chronological age. This child, therefore, grows for a shorter period than was anticipated, and thus the effect of an arrest will be less than that predicted. Problems likewise arise with those who seem to mark time in their skeletal maturation, with the result that they grow for a longer period than was anticipated. We hope to know more about this irregularity in the velocity of maturation as time goes on.