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Correlation of the Epiphyseal Closure and Ossification of the Ulnar Sesamoid Bone of the Metacarpophalangeal Joint of the Thumb

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CORRELATION OF THE EPIPHYSEAL CLOSURE AND OSSIFICATION OF THE ULNAR SESAMOID BONE OF THE METACARPOPHALANGEAL JOINT OF THE THUMB

by

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A Thesis in Partial Fulfillment
of the Requirements for the Degree
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Each person whose signature appears below certifies that he has read this thesis and that in his opinion it is adequate, in scope and quality, as a thesis for the degree of Master of Science in the field of Orthodontics.

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CHAPTER I

INTRODUCTION

The importance of predicting the adolescent growth spurt has been the goal of orthodontists for many years as an aid in treatment planning. Burstone (1963) said the advantages of treating at the time of the peak velocity during the adolescent growth spurt is twofold. (1) The process of growth is proceeding at its maximum rate. By differential control of growth vectors at different sites the amount of actual tooth movement is minimized. (2) The possibility remains that ease of tooth movement may be enhanced by increased endocrine activity associated with these growth changes.

At the turn of the century a method of rating the development of children was being sought. Chronological age no longer seemed to be satisfactory since many children functioned at a level higher or lower than expected from their chronological age.

Two growth parameters that have been used to compare an individual with his peers are weight and height. It is not as simple as that, according to Greulich and Pyle (1959). If a child's height and weight approximate the average of his contemporaries, it is generally assumed that development is proceeding satisfactorily. If the individuals in the United States were more homogeneous genetically, this assumption would be more valid. As a whole, however, the population is very heterogeneous in national and racial origin. Even among the

Caucasian population of the United States there are such diverse types as short-statured Mediterranean people; taller, heavier Scandinavians; and more moderately-sized people of Central European origin, to mention a few. In addition, and perhaps more important, there is almost every possible mixture that compose the United States. It is this genetic diversity plus significant nutritional differences that are largely responsible for the fact that in the United States, height-weight-age tables of children, while being representative of the original sample, are seldom wholly satisfactory when applied to the total population.

Another factor also makes it difficult to determine the developmental status of children from their height, weight and age alone. The presence of early-maturing as well as late-maturing strains in our population makes for a wide age range at the onset of puberty and consequently, in the age at which the maximum annual increment in height occurs. This is termed the adolescent growth spurt. Because of this variability, the chronological age of a child during the early part of the second decade of life is often but little more than a measure of the length of time that he or she has lived; it does not necessarily bear a close relationship to the amount of progress which a child has made toward attaining adulthood.

A method that has been developed to assess growth is the comparison of biologic age to chronologic age by the use of the hand radiograph which serves as an index of skeletal maturation.

Pryor (1907) has been a pioneer in investigation of the ossification centers of the hand and wrist as an index of growth and development. This led to further investigation by Todd (1927, 1937), Greulich and Pyle (1950, 1959), Acheson (1954), Noback (1954), Tanner and Whitehouse (1959), Noback and Moss (1960).

Garn, Rohmann, and Apfelbaum (1961) stated that ideally information should be available on the timing of epiphyseal union of the digital and metacarpal epiphyses with some indication of the degree of pattern regularity. Information concerning the suitability of the hand as an indicator of osseous completion, and of completion of statural growth would also be desirable. Under these circumstances, it would be possible to evaluate the utility of the hand as a measure of developmental progress during adolescence. Garn and Rohmann (1962) also observed the value of the ulnar sesamoid bone of the metacarpophalangeal joint of the thumb in adolescent treatment timing as an assessment of the developmental age.

Bjork and Helm (1967) stated that a close association existed between the age of maximum growth in body height and the age of ossification of the ulnar sesamoid of the metacarpophalangeal joint of the thumb.

Nivison (1969) initiated a growth study at Loma Linda University Similar to Bjork and Helm (1967).

The purpose of this project is to determine if there is a correlation of the epiphyseal closure of the hand and ossification of the ulnar sesamoid bone of the thumb. It would be of particular value to find a pattern of epiphyseal closure that would enable the clinician to determine the time of the first appearance of the ulnar sesamoid. This information can then be applied to determining the developmental age of the child and stage of progress in adolescent puberal growth.

CHAPTER II

REVIEW OF THE LITERATURE

Before the evolution of clinical radiology, studies of the ossification of skeletal cartilage were conducted solely on cadavers of children, sometimes by microscopy, but often only with the naked eye. Within ten years of Roentgen's discovery, however, widespread use was being made of the fact that calcium is radiopaque while cartilage is not, so that the earliest stages of the ossification process are clearly visible on a radiograph.

Pryor, a young anatomist at the State College of Kentucky, was the first investigator to seriously consider the biological implications of the changing shadows he could see in radiographs of children's hands. Pryor (1907) made three important statements which, although questioned and contradicted in the ensuing years, are generally accepted today. They are as follows:

1. "The bones of the female ossify in advance of those of the male." This is measured at first by days, then months, and then years.

2. "Regardless of variations (normal) the ossification is bilaterally symmetrical."

3. "Variation in the ossification of bones is a hereditable trait."

Pryor's work, although it certainly has direct clinical applications, was essentially biological in emphasis. However, it came to the attention of a contemporary pediatrician, Rotch (1909), who had already published his views of the potentialities of studying hand radiographs of normal children and who was to develop a concept of utmost importance. Rotch was concerned because he found a child's chronological age to be a poor indicator of general developmental status; moreover, he could derive little additional information of value from height, weight or the number of teeth. He therefore discussed with Pryor the procedure for obtaining wrist radiographs and carried out what was for the opening decade of the century an exhaustive study of ossification patterns in the extremities. Rotch, in his work of analysis of ossification patterns in the extremities, came to the conclusion that in the process of development from birth to adolescence the normal changes which take place in the wrist compare so closely to other joints that in the great majority of individuals, the wrist may be accepted as a fairly accurate index of general development.

Rotch (1909) put forward the idea that the number of centers in the carpus, together with the primary and secondary bony centers of the radius and ulna, made visible by roentgenography, may give a truly accurate indication of developmental status. Because it was based on physical observations and because it was to supersede, or at least to supplement, true age in the evaluation of the developing child, he termed this concept "anatomic age". He then evolved a system of assessment which consisted of a hand and wrist radiograph describing thirteen stages through which each child must pass in normal development. Stages were based on the first appearance of calcification in the carpals, radius and ulna. This method enjoyed a period of popularity which has long since been superseded by other methods.

Thus, by the outbreak of the First World War, foundations had been laid upon which much of the subsequent work in this field has been built. The fact that the bilateral symmetry of the ossification process had been recognized, taken together with Rotch's findings that the hand is a fair indicator of what is going on elsewhere in the body, meant that investigators could concentrate on a single hand film. The seeds of controversy were also sown; the extent to which the genetically determined patterns of ossification can be modified by the environment had not yet been ascertained nor had a satisfactory compromise been reached between efficient measurement of skeletal maturation and what Rotch called "anatomic age", later to be termed "bone" or "skeletal age".

Bardeen (1921) further developed the Rotch method; however, he unwisely concentrated wholly on the carpus which consists of round bones and cannot be taken as representative of other parts of the skeleton which grow and mature differently.

In an effort to overcome the problem of variation in the order of bone appearance, and to take into account osteogenesis, as it proceeded between the initial stages of calcification and the achievement of bone maturity, many authors during the 1920's and early 1930's made direct measurements of the amount of relevant bony tissue on the radiograph (Lowell and Woodrow, 1922; Carter, 1926; Flory, 1936). Attention was usually concentrated on the wrist, and simple planimetry was carried out. Later, however, elaborate ratios were devised in an attempt to correct for size variations in children of equal maturity. The attempts were unsuccessful. Another shortcoming of the planimetric approach was that again attention was concentrated on the carpus; probably for a variety of reasons, the chief of which was that the majority of the workers in this era were educators seeking a more efficient method than chronological age for placing children in a class. The carpus does show maximal changes in the age group in which they were interested. Also, in the child entering primary school, the carpal bones tend to be larger and more clearly defined than the digital epiphyses and are therefore easier to measure.

A third time-honored method, which is still used by some physicians, has been to take radiographs of several joints and to judge "bone age" from the epiphysis in which ossification has most recently begun. This method was elevated to a high degree of sophistication by Sontag and Lipford (1943), but even with their refinements it has two inherent drawbacks. First, this method concerns itself only with the initial deposit of calcium in the bones which is probably the most variable aspect of the entire maturation of a center. Second, it involves extensive radioexposure of the child which is both expensive and unhealthful.

For the modern critic, it is easy to see that what all these early methods lacked was a sequential study, in any single bone, of the characteristics of increasing maturity between the beginning of ossification and the onset of epiphyseal fusion. Nor was this surprising, because none of the workers in the field had yet clarified the concept of skeletal maturation. This process must be clearly differentiated from growth, which is the formation of new tissue and which in many limb bones occurs in the epiphyseal growth cartilage plates. In the skeleton of the healthy child the two processes; growth, or the creation of new cells and tissues, and maturation, or the subsequent consolidation of the tissues into permanent form, proceed concurrently.

Hellman (1928) published a detailed description of the serial changes in radiographic appearance by a growth cartilage plate during the process of fusion of the epiphysis with the diaphysis. Todd (1937) saw a potential of fundamental importance in these and called them "determinators of maturity". Todd set about defining and describing equivalent changes; first, in the short and long bones prior to the time of ossification of the growth cartilage plate and later, in the round bones throughout their period of development. He looked upon "maturity determinators" as "successive changes in outline . . . and in contour."

By developing the concept of "maturity determinators" or "indicators", Todd and his co-workers had taken a great step in making the assessment of skeletal maturation possible for pediatricians, educators and other disciplines interested in the physical development of children. Yet "determinators" by themselves were insufficient. Obviously, it was necessary to relate them to what could be expected in the normal child. To do this Todd attempted to produce an integrated picture of the maturation process in each anatomical area he was studying. Before integrating he explained the maturation of each developing center separately.

Todd made hand radiographs of the same group of children from Cleveland, Ohio, that Hellman utilized in his 1928 study. These were taken at periodic intervals over a number of years. He then picked out the radiograph that most children of a certain age matched and assigned their chronological age as the "skeletal age" of the radiograph. This resultant research is presented in the Todd Atlas of Skeletal Maturation (1937).

Greulich and Pyle (1950) renamed Todd's determinators of maturity to "maturity indicators" and clarified this important concept in the following terms: "Maturity indicators are those features of individual bones that can be seen in the roentgenogram . . . and which, because they tend to occur regularly and in a definitive and irreversible order, mark their progress toward maturity." The importance of this step of identifying and describing the determinators or indicators of maturity was immense. No longer did the assessor have to search the joints to find a newly ossified center in order to assess the maturity of the developing skeleton. Neither was he tempted to record the size of an ossific shadow. He could, by simple inspection, judge the development of each center by studying the shadows cast by the newly forming bony tissue as it replaced the radiotranslucent cartilage.

The original hand atlas has been revised by Greulich and Pyle in 1959, and atlases of the foot and knee based on the same population of children have been published. Because of the care and thought that have gone into their compilation and the expertise of their authors, they hold a place among standards of reference on child development that is unlikely to be challenged. Dr. Pyle was a pupil of Todd's and made the preparation and publication of these atlases her life's work.

There can be no question that for the pediatrician, the orthopedic surgeon, the orthodontist and the educator that these atlases will serve to appraise the developing child. Twenty-five years after the publication of Todd's first edition it still offers the simplest and most reliable means of differentiating the fast and slow developer. Now one needs only to match a hand radiograph to an atlas radiograph to determine the child's skeletal age. According to Acheson, Vincinus, and Fowler (1963), this is accurate only within an eight to twelve month range because genetic factors determine the sequence of epiphyseal-diaphyseal fusion among the bones. Dr. Pyle has attempted to correct for this by assigning a skeletal age to each center on the radiograph and then to average all the centers for a determination of the true skeletal age.

Acheson (1954, 1957a) used Todd's films and assigned a number score ranging from 1-8 points to each of Todd's "maturity indicators". The score was based on the amount of calcification occurring in each area. He then totaled the scores and employed this total to determine the skeletal age. This is known as the "Oxford method".

Dreizen (1957) studied 227 males and 223 females from one month to sixteen years and eleven months of age to compare skeletal ages derived from radiographs of the right and left hands. He found that only five of 450 children showed a dissimilarity of more than six months between the skeletal age derived from the two hands. In thirteen percent of the cases the right hand was slightly more advanced.

Tanner, Whitehouse (1959, 1962) used a sample of British children. They assigned a percentage score to each of the maturity indicators which correlated the ossification period of one indicator as a proportion of total ossification of all indicators. The scores were then weighted so one-half of the total of an adult score was derived from the round bones of the carpus and one-half of the total adult score from the long and short bones of the hand. Recently, questions have been raised regarding the validity of the round bones in this respect because they mature earlier and do not have epiphyses.

Skeletal age, as judged by this method, is about one year older than when determined by the Greulich and Pyle atlas (1959). That is because Greulich and Pyle's study was done on more rapidly maturing children here in the United States. This is known as the "Tanner-Whitehouse method". This method has been standardized for British children and, in due course, standards will be available for children of six other countries.

The staff of the Fels Research Institute at Yellow Springs, Ohio, has always maintained an individual approach to the assessment of skeletal maturity. They have at their disposal longitudinal data compiled from a series of local families. In many of these families the second generation is now being studied. The interest of Sontag (Sontag and Lipford, 1943) and more recently of Garn and his co-workers (Garn and Rohmann, 1960a and b; Garn, Rohmann, and Davis, 1963a) has been confined to the onset of ossification and, in secondary centers, to epiphyseal fusion in the hand and foot.

Recently these investigators have undertaken analyses leading to the construction of a series of correlation matrices that interrelate the age at the onset of ossification for each of fifty-two bony centers in the hand and foot (Garn, Silverman and Rohmann, 1964). Those bones for which the correlation coefficients are high provide a good predictive value for the age of onset of the others; those for which the correlation is low have no such value. It was found that the correlations are higher for girls than for boys; also that they are higher for the short bones of the fingers and toes than for the round bones of the wrist and ankle. On this basis, it was contended that, since round bones are poor predictors of the age of onset in other bones, they should be excluded from any skeletal maturation assessment method. On the same basis some of the short bones, together with the radius, ulna, tibia and fibula, should also be excluded. The correlation coefficients among the nineteen bones with the highest original correlation coefficients are then recalculated, a procedure that raises the coefficients from the order of 0.5 to at least 0.6. Garn and his group suggest that these centers alone should be used in skeletal maturation assessments and they are now proceeding to investigate ossification patterns in the knee, elbow, hip and shoulder in the same way, taking epiphyseal fusion into consideration as well as the onset of ossification. Their most recent work indicates that the highest correlations for age of ossification onset are hand-foot, knee-elbow and shoulder-hip. This suggests that the operation of the genes controlling the early stages of the second phase of skeletal maturation is related to how proximal or distal is the relevant center.

Obviously, it will be some time before this research leads to a practical method of assessing skeletal maturation throughout the developmental period. In the interim, a significant contribution to our knowledge of physical development is being made.

The most recently investigated, and from all appearances the most accurate maturity indicator is the time of appearance of the ulnar sesamoid bone of the metacarpophalangeal joint of the thumb. The sesamoid bones of the hand are very small round bones, somewhat flat and spongy appearing. They adhere at the joints in the tendons of the muscles that move the fingers.

In the adult hand there are usually five sesamoids (Hubay, 1949). The two sesamoids (radial and ulnar) of the metacarpophalangeal joint of the thumb are constant. The remaining sesamoids are not constant and only appear in certain subjects. The ulnar sesamoid bone appears 100 percent of the time according to Fawcett (1896); Flory (1936); Hubay (1949). A percentage of 98.2 was given by Bizarro in 1920.

Data on the ossification timing of the ulnar sesamoid bone of the thumb are surprisingly meager. Baldwin (1928) was the first investigator to give the range in ages of both girls and boys for its ossification. The range was 10-14 years for girls and 12-16 years for boys. Other authors have given a range in ages for its ossification: Francis (1940) 8-13 years for girls and 9-15 years for boys; Buehl and Pyle (1942) 10.5-14 years for girls and 12-16 years for boys; Fleckner (1942) 9.5-13.5 years for girls and 13-16 years for boys; Joseph (1951) 10-12 years for girls and 12-15 years for boys; Hansman and Maresh (1961) 9.0-14.0 years for girls and 11.0-16.0 years for boys; Garn and Rohmann (1962) 8-13 years for girls and 10-16 years for boys; Bjork and Helm (1967) 10-13 years for girls and 11-15.5 years for boys; Nivison (1969) 10.4-13.8 years for girls and 11.2-15.8 years for boys.

Investigative studies by Garn (1962) revealed that the ulnar sesamoid has more in common with epiphyseal union and sexual maturation than with age of appearance of specific ossification centers.

Bjork and Helm (1967) have done research in this field in Denmark. They stated three years ago that the sesamoid ossified on the average of 12 $\pm$ 2.1 months before maximum adolescent growth for girls and 9 $\pm$ 1.4 months before the maximum adolescent growth for boys.

A longitudinal growth study was begun at Loma Linda University Department of Orthodontics in 1967 and reported by Nivison in 1969.

Growth records have been taken at regular three month intervals on orthodontic patients. It is from these records that a correlation study of the ossification of the ulnar sesamoid bone of the metacarpo-phalangeal joint of the thumb with the epiphyseal closure was begun for this study.

CHAPTER III

MATERIAL AND METHODS

Sample

Two hundred eighty-four orthodontic patients were screened in this study. Two hundred twenty-four patients were from the orthodontic clinic of the Loma Linda University School of Dentistry. Sixty-four were from the private practice of Roland D. Walters, Loma Linda and Riverside, California. Both sexes in good clinical health, with subjects ranging in age from 10 to 15 years with various ethnic and socio-economic backgrounds, were represented in the group. Twenty-three boys and fourteen girls were finally selected for use in this study.

Hand-Wrist Radiographic Procedure

Radiographs of the right hand and wrist were taken to determine those patients that had a sesamoid bone which was just beginning to ossify. These selected patients were then rescheduled for hand-wrist radiographs on a regular three month basis.

A standard cephalostat with a target to film distance of sixty inches was employed to take the antero-posterior hand-wrist radiographs.

Cephalometric size (8" x 10") Du Pont Cronex High Speed MI film with high speed screen without a grid was used on average and large size hands. Panorex size (5" x 12") Du Pont Pan-O-Screen MI film with Par Speed screen without a grid was used on small size hands.

The radiographic machine employed was a Universal Cephalometrix

#3298-1A, Moss Corporation, Chicago, with a rotating anode. A focal spot of 0.8 mm and an exposure of 65 KvP, 50 Ma, 1/12 sec. was utilized.

Data Collection

The hand radiographs were taken by a technician in the oral diagnosis department of Loma Linda University School of Dentistry. They were read by the author. The first appearance of the radiopaque shadow opposite the metacarpophalangeal joint of the thumb was the standard used to identify ossification of the ulnar sesamoid bone. The disappearance of the radiolucent line between the epiphysis and metaphysis of the phalanges and metacarpal of the hand was the standard used to identify epiphyseal closure.

Figures 1 and 2 show the method of identifying and recording the data collected. Figure 1 identifies the nineteen epiphyseal centers of the hand and also the ulnar sesamoid bone. Figure 2 was used to record the epiphyses that were closed at the appearance of the sesamoid bone and at three month intervals thereafter on each patient. The males were in one group (twenty-three in number) and the females in another group (fourteen in number).

Method Used to Process Data-Descriptive Statistics

The data recorded as shown in Figure 2 was used in formulating a series of graphs and tables. Figures 3 and 4 are frequency histograms for the time of appearance of the sesamoid bone in male and female subjects studied. The graphs in Figures 5 through 8 plotted curves based on accumulative frequency of the number of epiphyses closed for individual patients. The X axis on all four graphs

1 - Epiphysis of distal phalanx of the first digit.
2 - Epiphysis of proximal phalanx of the first digit.
3 - Epiphysis of the first metacarpal.
4 - Epiphysis of distal phalanx of the second digit.
5 - Epiphysis of middle phalanx of the second digit.
6 - Epiphysis of proximal phalanx of the second digit.
7 - Epiphysis of the second metacarpal.
8 - Epiphysis of distal phalanx of the third digit.
9 - Epiphysis of middle phalanx of the third digit.
10 - Epiphysis of proximal phalanx of the third digit.
11 - Epiphysis of the third metacarpal.
12 - Epiphysis of distal phalanx of the fourth digit.
13 - Epiphysis of middle phalanx of the fourth digit.
14 - Epiphysis of proximal phalanx of the fourth digit.
15 - Epiphysis of the fourth metacarpal.
16 - Epiphysis of distal phalanx of the fifth digit.
17 - Epiphysis of middle phalanx of the fifth digit.
18 - Epiphysis of proximal phalanx of the fifth digit.
19 - Epiphysis of the fifth metacarpal.
20 - Ulnar sesamoid.

REFERENCE NUMBERS FOR THE EPIPHYSES OF

THE HAND AS USED IN THIS STUDY

LEGEND FOR FIGURE 1

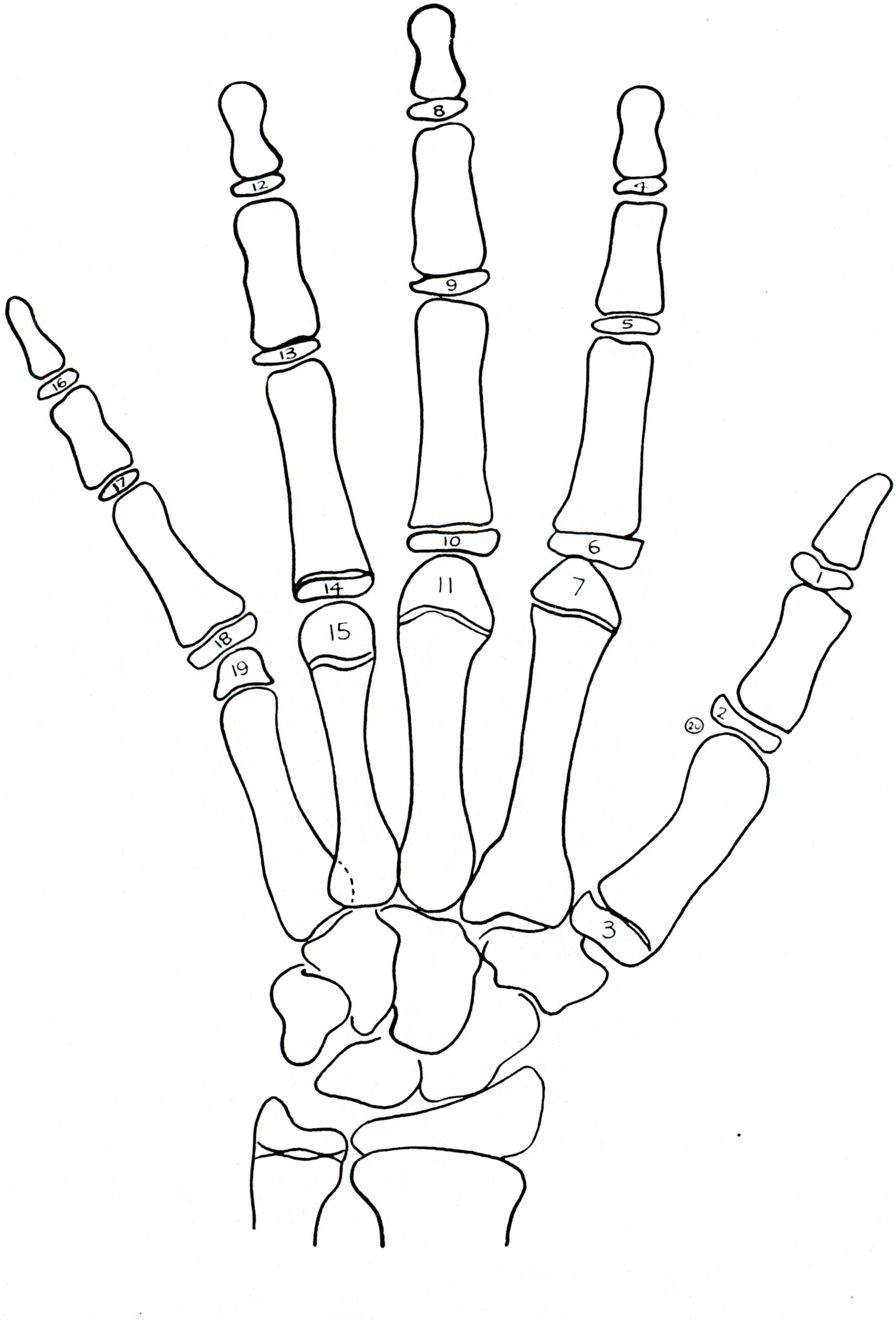


FIGURE 1

PATIENT STUDY NUMBER _____

AGE AT APPEARANCE OF ULNAR SESAMOID _____

	EPIPHYSIS CLOSED																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
At sesamoid																			
3 months after																			
6 months after																			
9 months after																			
12 months after																			
15 months after																			
18 months after																			
21 months after																			
24 months after																			

KEY:

1 - Epiphysis of distal phalanx of the first digit.
2 - Epiphysis of proximal phalanx of the first digit.
3 - Epiphysis of the first metacarpal.
4 - Epiphysis of distal phalanx of the second digit.
5 - Epiphysis of middle phalanx of the second digit.
6 - Epiphysis of proximal phalanx of the second digit.
7 - Epiphysis of the second metacarpal.
8 - Epiphysis of distal phalanx of the third digit.
9 - Epiphysis of middle phalanx of the third digit.
10 - Epiphysis of proximal phalanx of the third digit.
11 - Epiphysis of the third metacarpal.
12 - Epiphysis of distal phalanx of the fourth digit.
13 - Epiphysis of middle phalanx of the fourth digit.
14 - Epiphysis of proximal phalanx of the fourth digit.
15 - Epiphysis of the fourth metacarpal.
16 - Epiphysis of distal phalanx of the fifth digit.
17 - Epiphysis of middle phalanx of the fifth digit.
18 - Epiphysis of proximal phalanx of the fifth digit.
19 - Epiphysis of the fifth metacarpal.
20 - Ulnar sesamoid.

FIGURE 2. DATA RECORDING CHART

represents the number of epiphyses closed. The Y axis on the graphs in Figures 5 and 6 gives the age in years of the patients in three month intervals. The Y axis of graphs in Figures 7 and 8 indicates the time interval since ulnar sesamoid first appeared, recorded at three month intervals.

The graphs in Figures 9 and 10 are composites of Figures 7 and 8 showing the average number of epiphyses closed for groups of subjects followed for 6, 12, 18, and 24 months respectively. The X axis on both graphs records the average number of epiphyses closed. The Y axis of both graphs in Figures 9 and 10 record at three month intervals the time elapsed since the ulnar sesamoid first appeared.

The last series of four graphs are on normal probability paper. Two of the graphs (Figures 11 and 12) record at three month intervals the proportions of epiphyses closed of individual patients over a 24-month period. Two graphs (Figures 13 and 14) record the average proportion of epiphyses closed of the patients over a 24-month period also recorded at three month intervals. The X axis records the proportions of epiphyses closed and the Y axis records the time post sesamoid appearance in months.

Table I presents female patients showing the percentage having the accumulative number of closures.

Table II presents male patients showing the percentage having the accumulative number of closures.

Table III presents female patients showing the percentage of specific epiphysis closed.

Table IV presents male patients showing the percentage of specific epiphysis closed.

Table V presents the pattern of epiphyseal closure in females.

Table VI presents the pattern of epiphyseal closure in males.

CHAPTER IV

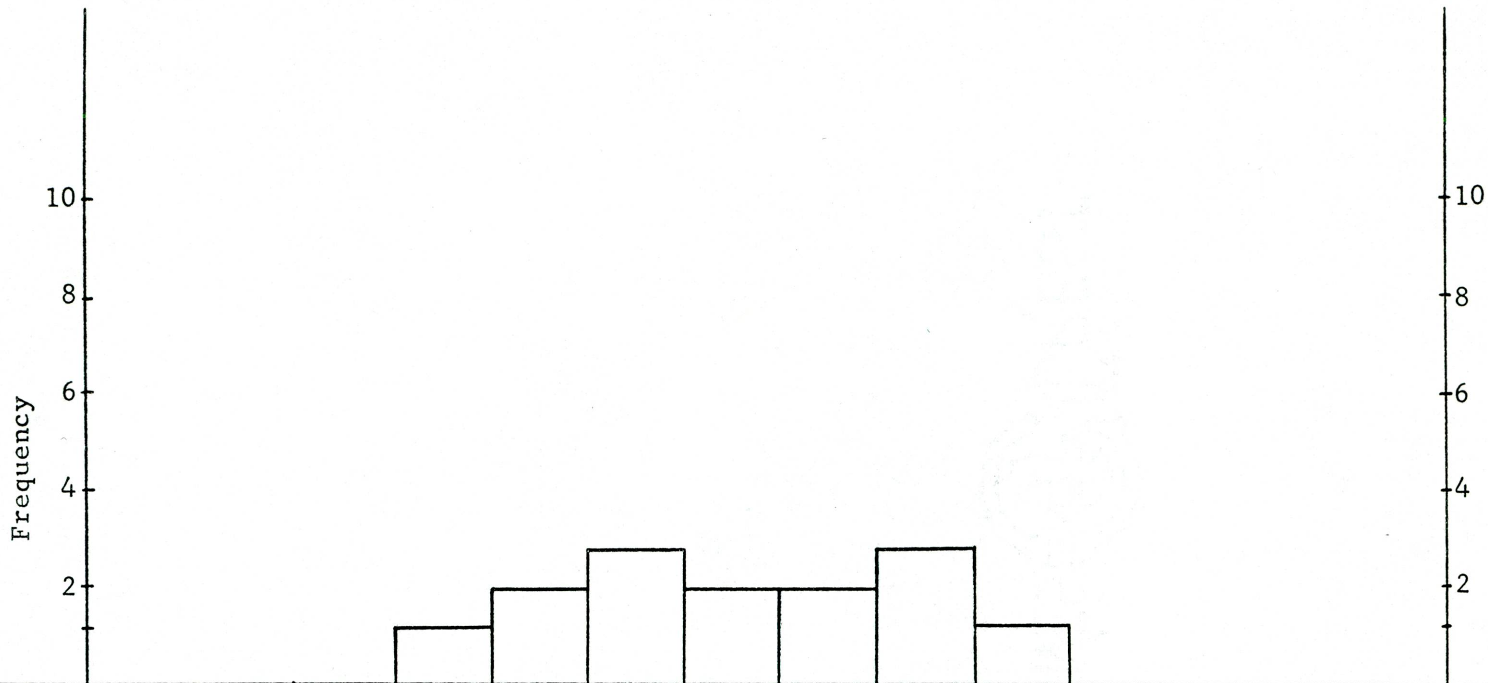
DISCUSSION AND RESULTS

Data was not available for the same time period for many subjects in this study. This is not because subjects were dropped from the study but because the sesamoid bone appeared at a variable age and time in each subject studied. Though followed for some time less than 24 months in this present study, these subjects will continue to be followed until all epiphyses in the hand are closed.

Of the twenty-three males studied over varying periods of from 9 to 24 months, five did not have closures. All the female patients showed closures in the 3 to 24 months they were followed.

Figures 3 and 4 present histograms for the time of appearance of the sesamoid bone in the male and female subjects. The results are not remarkable. A more definite central peaking would be expected with a larger population. The range in age of sesamoid appearance was 10 years 7 months to 13 years 11 months for females and 10 years 10 months to 14 years 6 months for males. The average age of sesamoid appearance for females was 12 years 2 months. The average age of sesamoid appearance for males was 13 years 3 months. This compared favorably with the study of Nivison (1969).

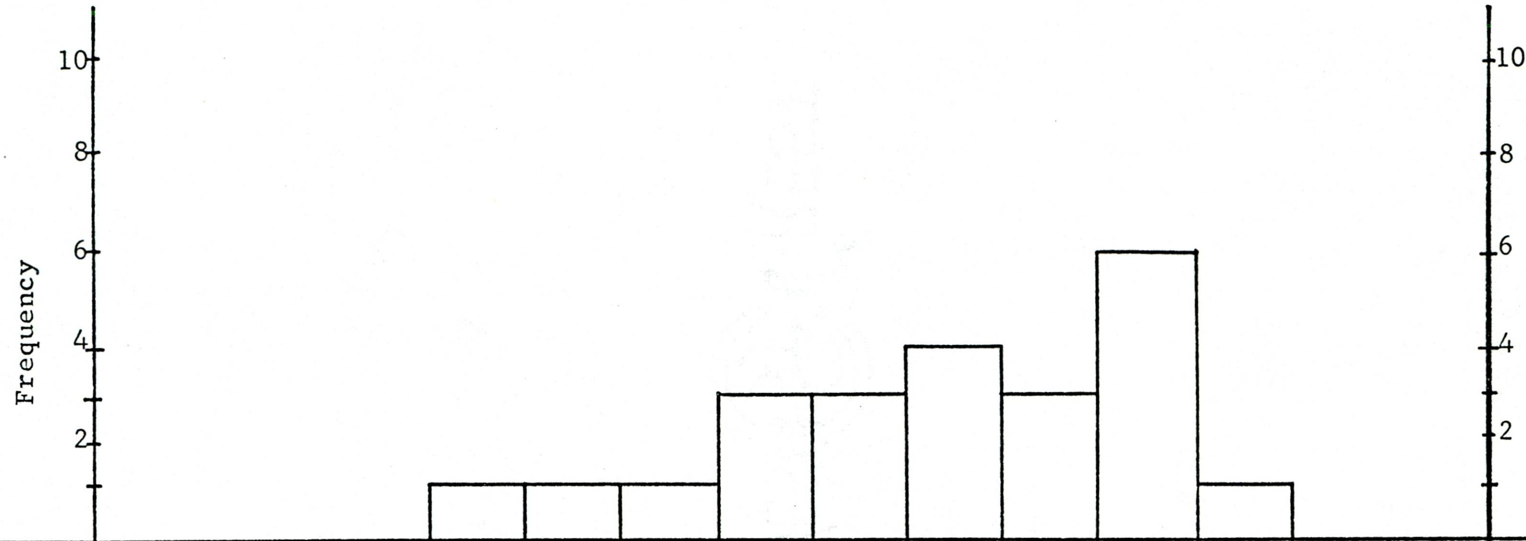
The graphs in Figures 5 and 6 plotted curves on each individual female and male patient used in this study with respect to age of the patient at sesamoid bone appearance and three month intervals thereafter. It also included the accumulative frequency of the number of



Age Range (yrs)	9.0- 9.4	9.5- 9.9	10.0- 10.4	10.5- 10.9	11.0- 11.4	11.5- 11.9	12.0- 12.4	12.5- 12.9	13.0- 13.4	13.5- 13.9	14.0- 14.4	14.5- 14.9	15.0- 15.4	15.5 15.9	Total
Number	0	0	0	1	2	3	2	2	3	1	0	0	0	0	14
Percent				7.1	14.3	21.4	14.3	14.3	21.4	7.2					100

FIGURE 3. FREQUENCY DISTRIBUTION FOR AGE AT SESAMOID APPEARANCE IN FEMALES

MEAN 12.2 YEARS



Age Range (yrs)	9.0-9.4	9.5-9.9	10.0-10.4	10.5-10.9	11.0-11.4	11.5-11.9	12.0-12.4	12.5-12.9	13.0-13.4	13.5-13.9	14.0-14.4	14.5-14.9	15.0-15.4	15.5-15.9	Total
Number	0	0	0	1	1	1	3	3	4	3	6	1	0	0	23
Percent				4.4	4.4	4.4	13	13	17.4	13	26	4.4			100

FIGURE 4. FREQUENCY DISTRIBUTION FOR AGE AT SESAMOID APPEARANCE IN MALES

MEAN 13.3 YEARS

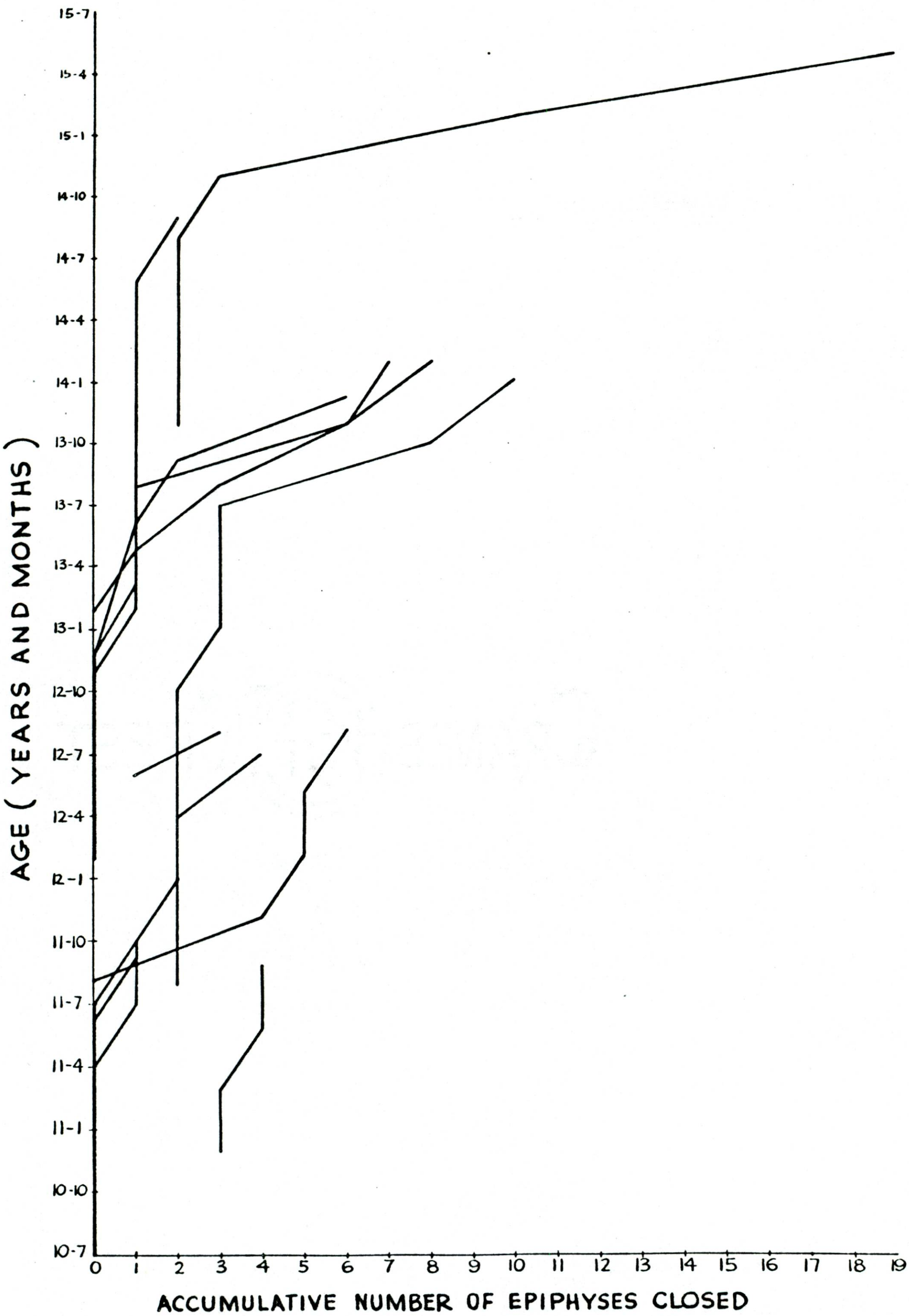


FIGURE 5. EPIPHYSEAL CLOSURES IN 14 INDIVIDUAL FEMALE PATIENTS WITH INITIAL OBSERVATION AT THE TIME OF SESAMOID APPEARANCE

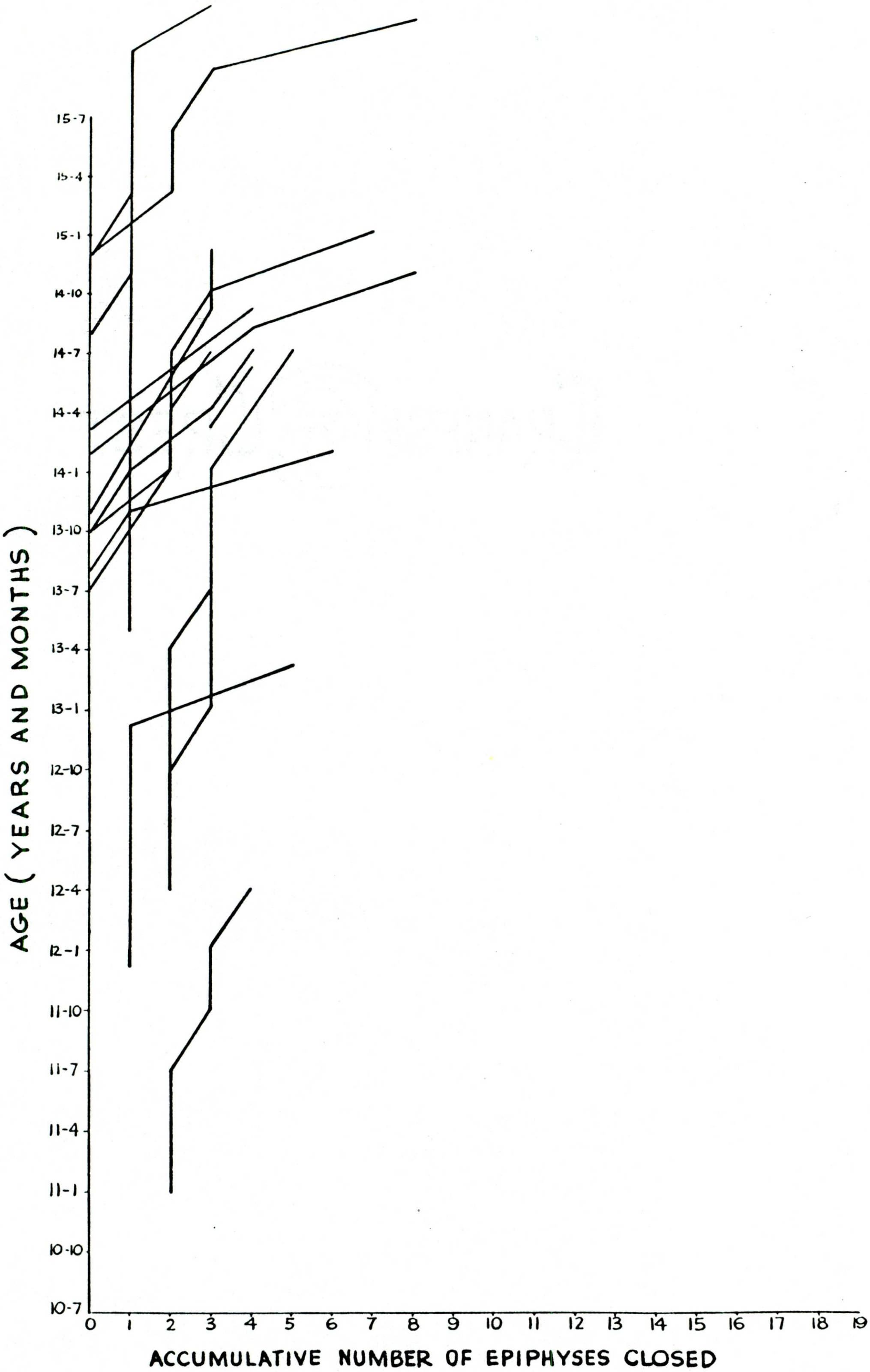


FIGURE 6. EPIPHYSEAL CLOSURES IN 23 INDIVIDUAL MALE PATIENTS WITH INITIAL OBSERVATION AT THE TIME OF SESAMOID APPEARANCE

epiphyses closed. The first point on each patient's curve represents the time at which the sesamoid bone appeared and the number of closures at that time.

These graphs show a wide variation both on time of initial sesamoid appearance and rate of epiphyseal closure after sesamoid appearance. It is readily seen that there is no close central grouping. There is some indication that rate of closure of epiphyses after sesamoid appearance is higher in older patients but a larger sample would be needed to verify this hypothesis.

The graphs in Figures 7 and 8 show the total number of epiphyses closed in individual female and male patients as a function of the time post sesamoid ossification. Zero time is at the first radiograph showing sesamoid appearance.

Each of these graphs shows considerable individual variation, but there is much more uniformity than in Figures 5 and 6. This may be taken to indicate a possible correlation between sesamoid appearance and epiphyseal closure. The data for the females in Figure 7 is noticeably more scattered than that for the males in Figure 8.

The graphs in Figures 9 and 10 show the average number of epiphyses closed for the total patient group as a function of time post sesamoid appearance. Separate lines for groups of patients followed separate time periods.

Each graph (Figures 9 and 10) shows a rapid increase in epiphyseal closure beyond 15 months. This rapid increase is suggestive of a time relation between sesamoid ossification and epiphyseal closure, but a larger sample would be needed to show the dependability of such a possible relation. For the last six months only three subjects were

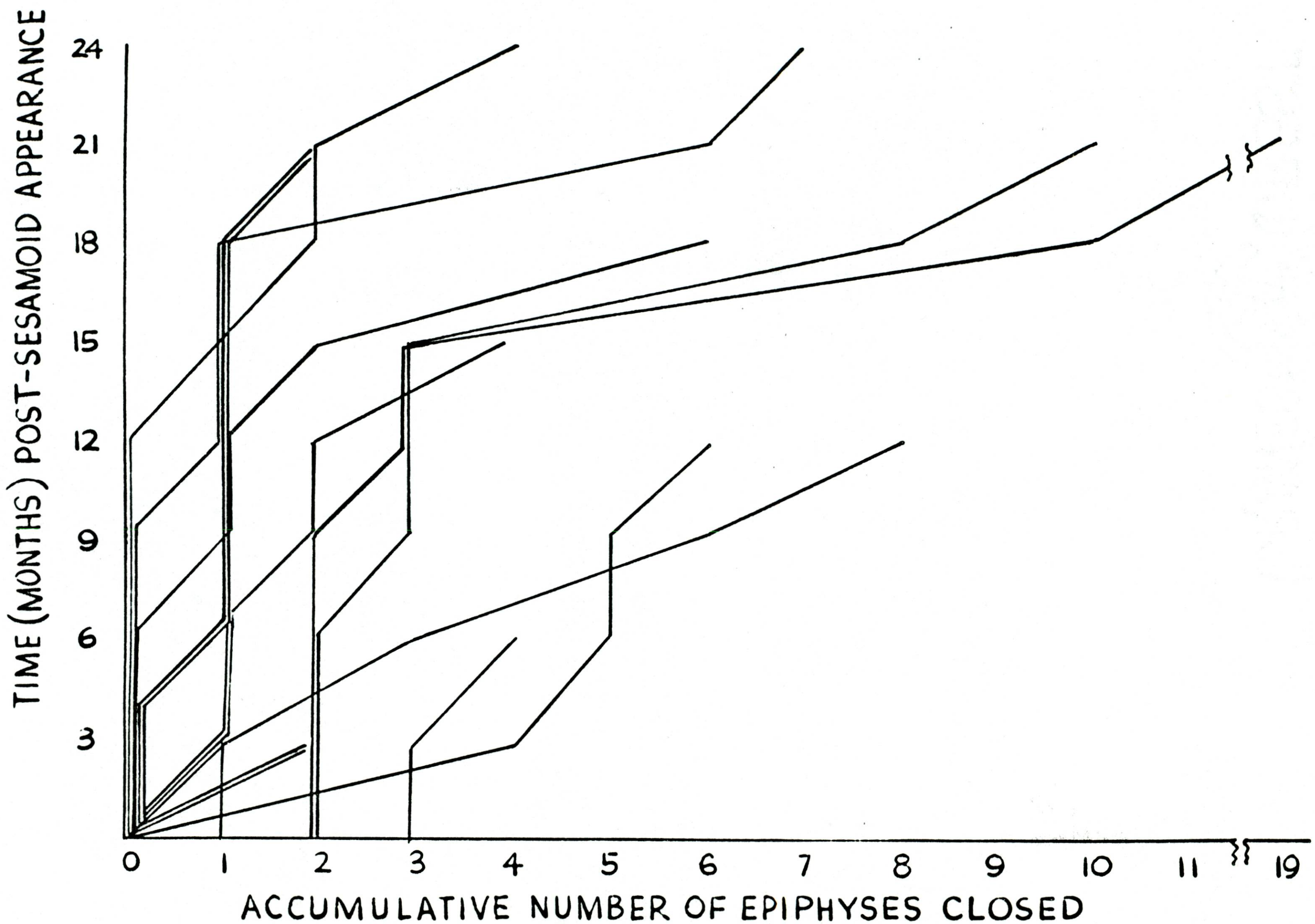


FIGURE 7. TOTAL NUMBER OF EPIPHYSES CLOSED IN 14 INDIVIDUAL FEMALE PATIENTS AS A FUNCTION OF TIME POST SESAMOID OSSIFICATION

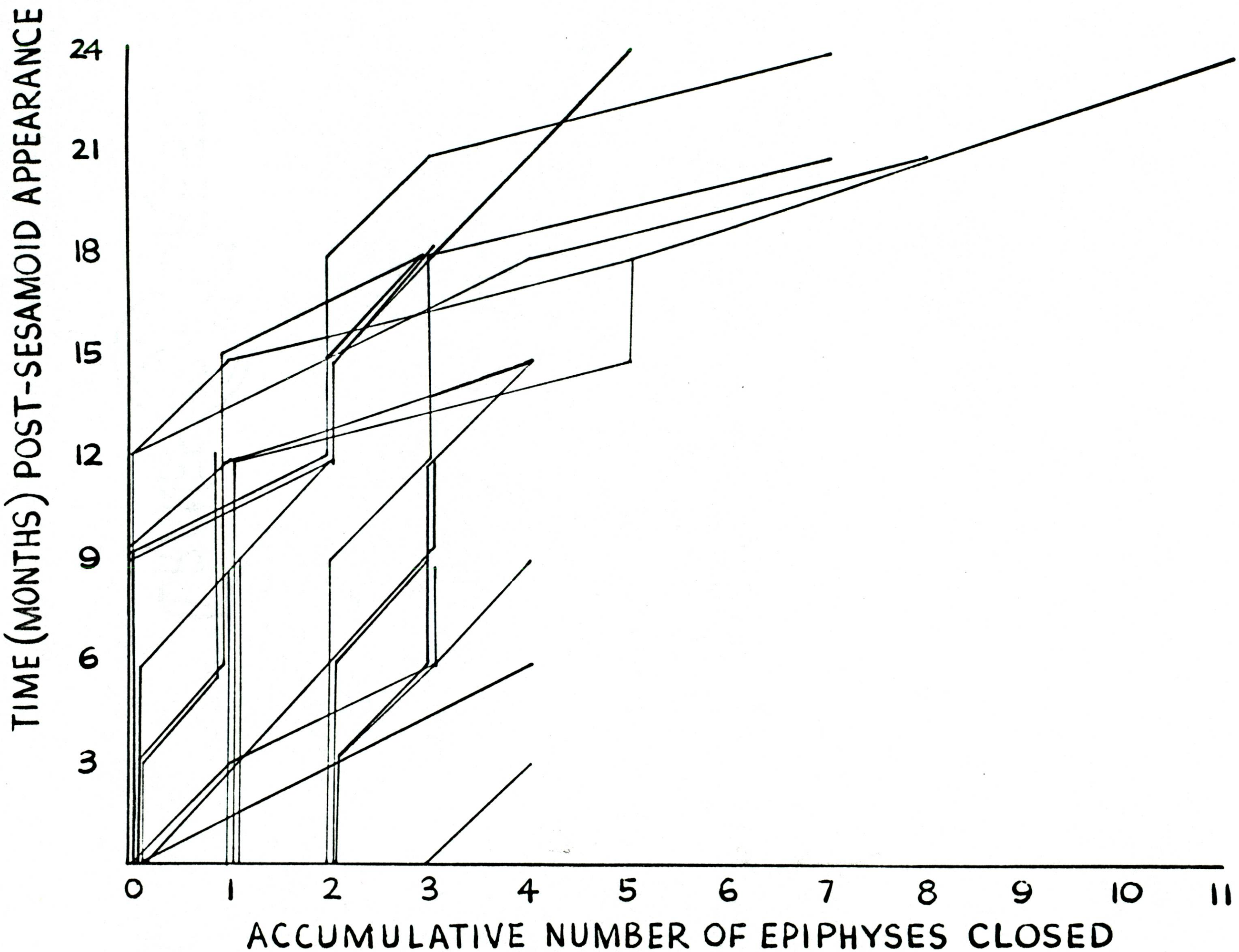


FIGURE 8. TOTAL NUMBER OF EPIPHYSES CLOSED IN 23 INDIVIDUAL MALE PATIENTS AS A FUNCTION OF TIME POST SESAMOID OSSIFICATION

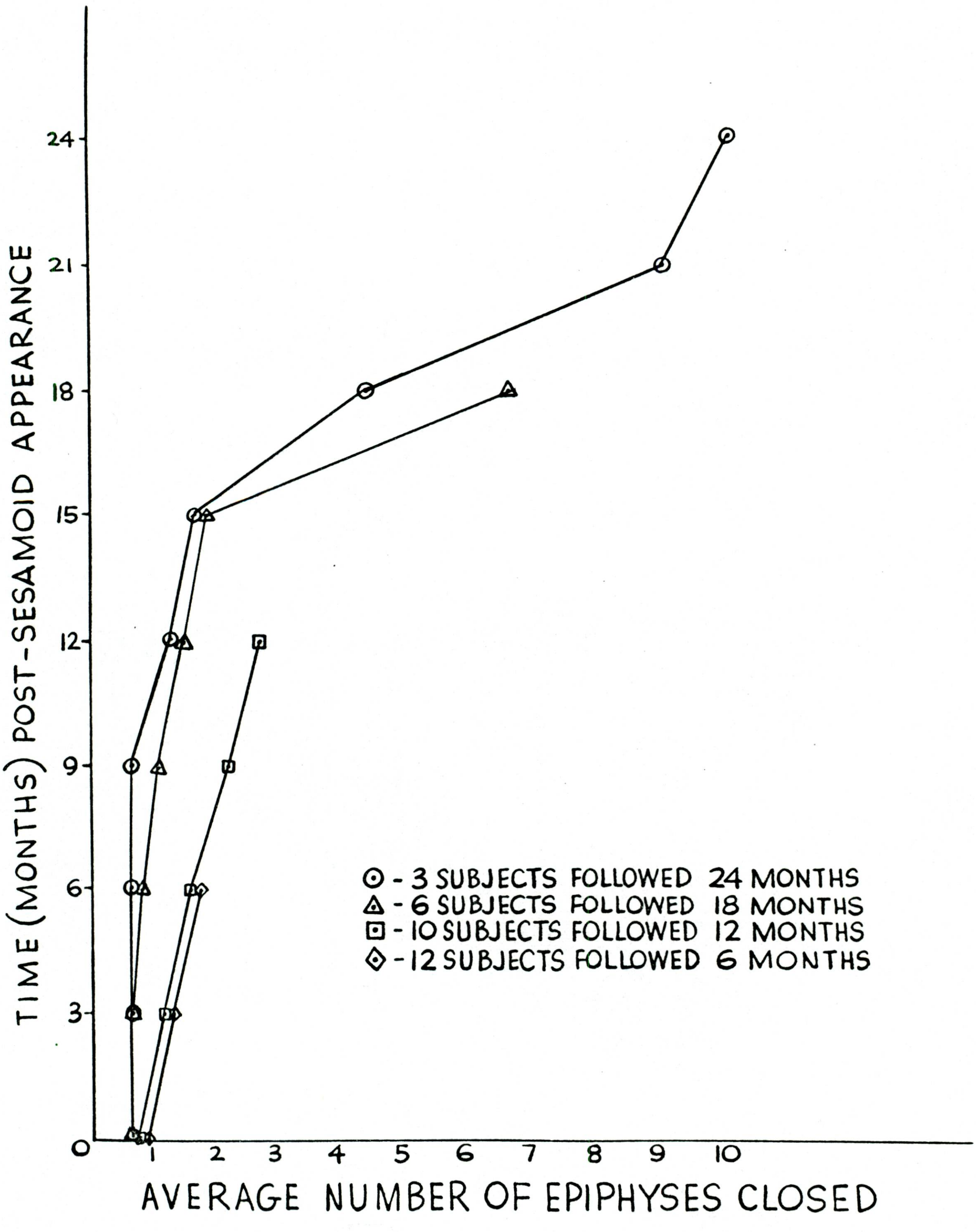


FIGURE 9. AVERAGE NUMBER OF EPIPHYSES CLOSED FOR THE TOTAL PATIENT GROUP AS A FUNCTION OF TIME POST SESAMOID APPEARANCE IN FEMALES

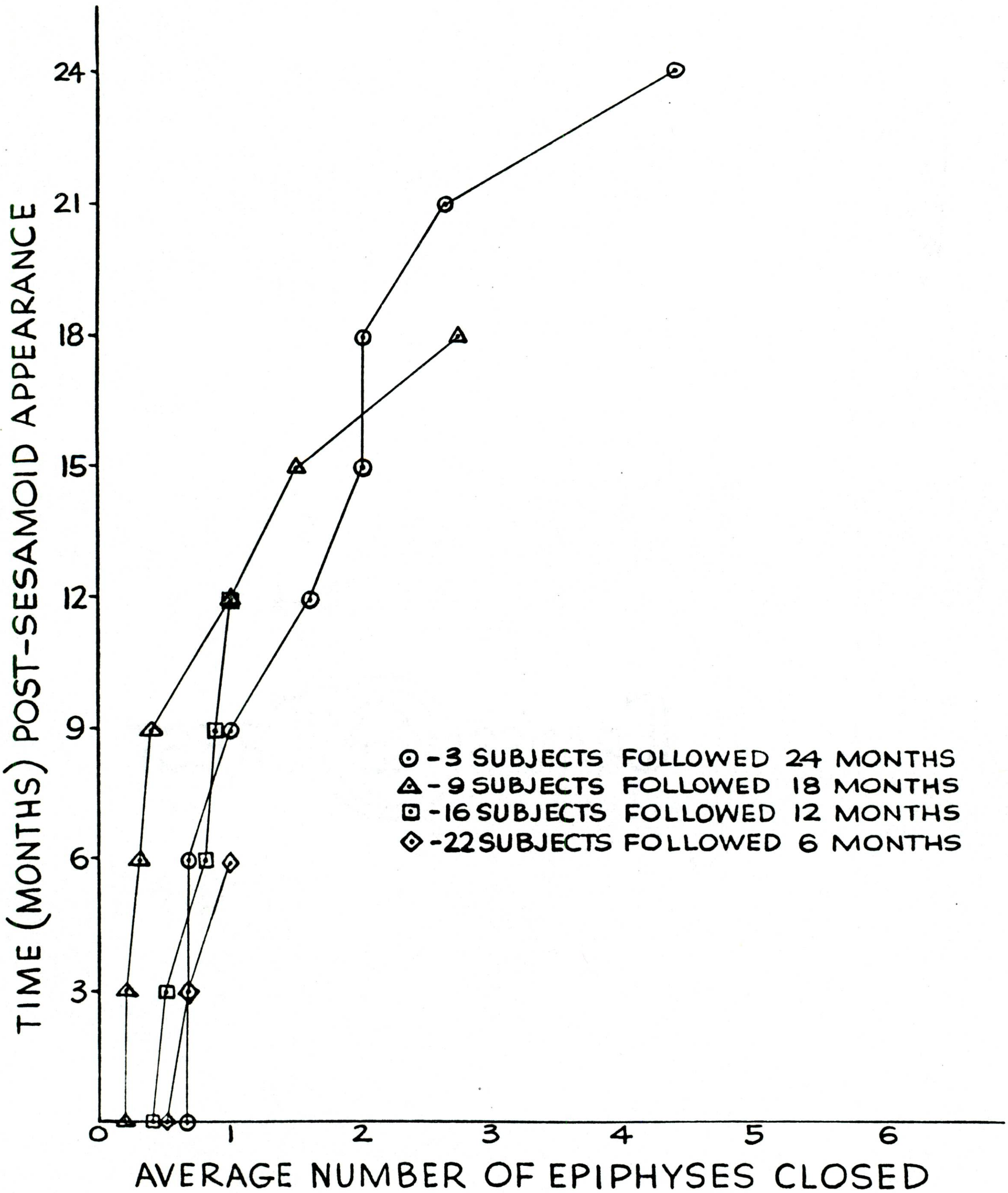


FIGURE 10. AVERAGE NUMBER OF EPIPHYSES CLOSED FOR THE TOTAL PATIENT GROUP AS A FUNCTION OF TIME POST SESAMOID APPEARANCE IN MALES

available in the study for each group. From the appearance of each graph it is obvious one needs more subjects carried for longer time periods to be able to draw useful conclusions.

The graphs in Figures 11 and 12 were placed on normal probability paper. The plotted results show the fraction of epiphyses closed in individual female and male patients as a function of time post sesamoid ossification.

There is a wide individual variation in epiphyseal closure post sesamoid appearance as was also seen in Figures 7 and 8. The fraction is calculated on the basis of nineteen epiphyses. If any of these lines had turned out to be straight or almost so the significance would have been similar to that discussed below for Figures 13 and 14.

The graphs in Figures 13 and 14 record on normal probability paper the average proportion of epiphyses closed over 24 months, at three month intervals. These are an average of the data from the individuals presented in Figures 11 and 12. A graph such as this on normal probability paper would be expected to show a straight line if the times between sesamoid appearance and the epiphyseal closures follow a gaussian or normal distribution.

There is some suggestion that within the limits of expected statistical fluctuation this curve might represent a segment of a straight line. The fact that the study has not been continued long enough to observe more than 40 percent closure of the epiphyses, makes it impossible to say whether the time lapse between sesamoid appearance and epiphyseal closure are well approximated by a normal distribution. Studying each patient until most of their epiphyses are closed might resolve this. Assuming that this is a straight line (Figures 13 and

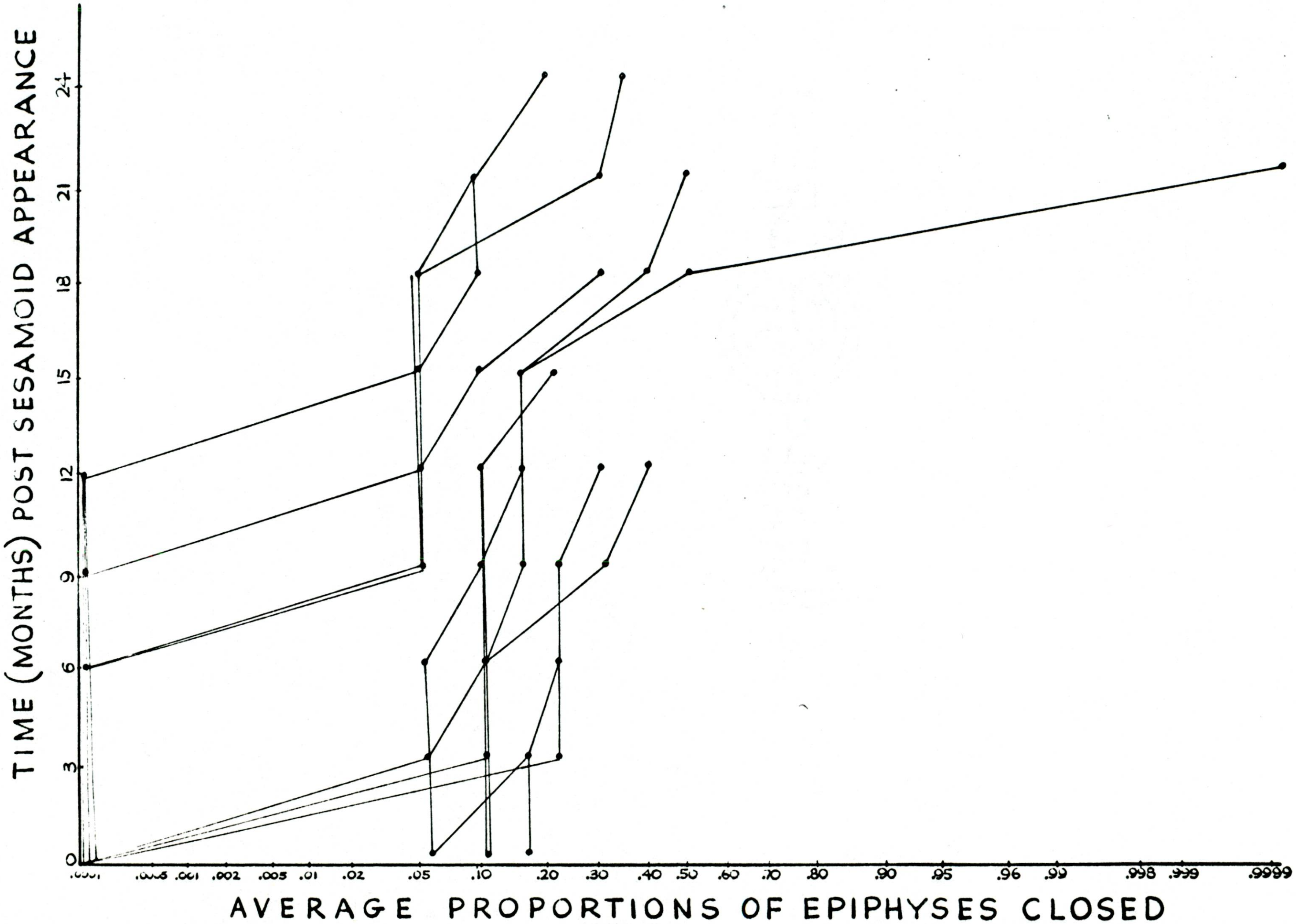


FIGURE 11. FRACTION OF EPIPHYSES CLOSED IN INDIVIDUAL FEMALE PATIENTS AS A FUNCTION OF TIME POST SESAMOID OSSIFICATION (PLOTTED ON NORMAL PROBABILITY PAPER)

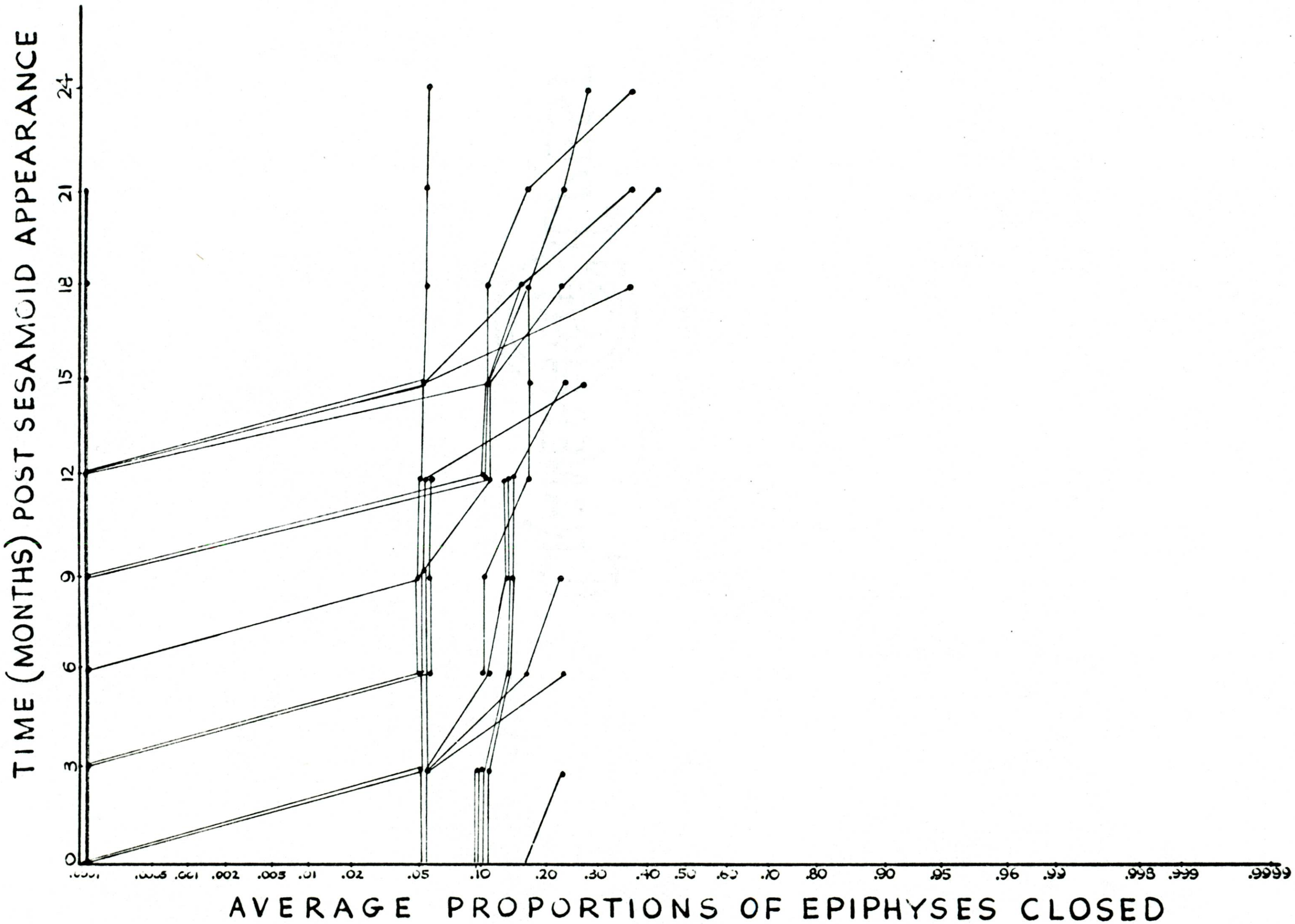


FIGURE 12. FRACTION OF EPIPHYSES CLOSED IN INDIVIDUAL MALE PATIENTS AS A FUNCTION OF TIME POST SESAMOID OSSIFICATION (PLOTTED ON NORMAL PROBABILITY PAPER)

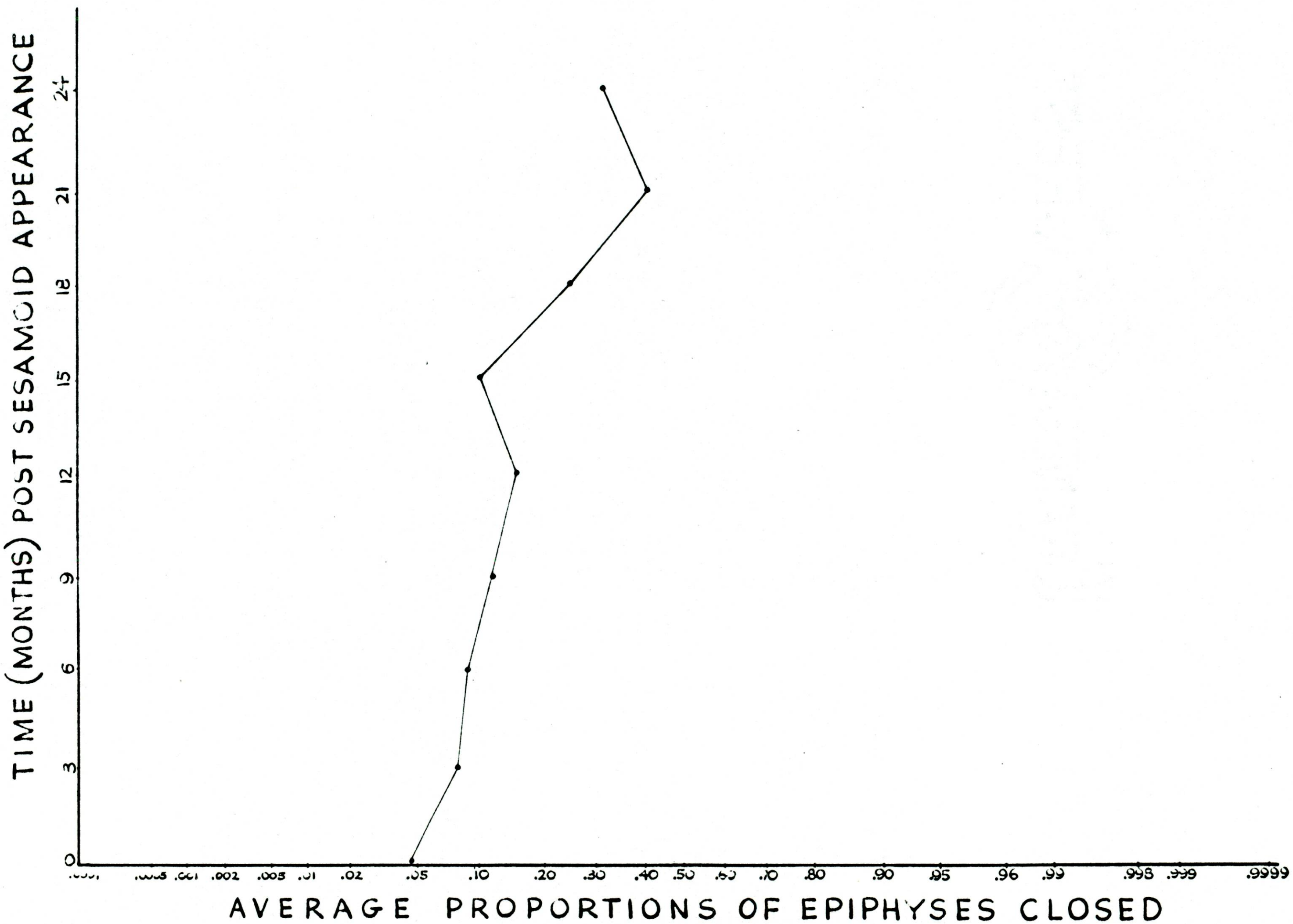


FIGURE 13. THE AVERAGE PROPORTION OF EPIPHYSES CLOSED IN FEMALES AS A FUNCTION OF TIME POST SESAMOID APPEARANCE (PLOTTED ON NORMAL PROBABILITY PAPER)

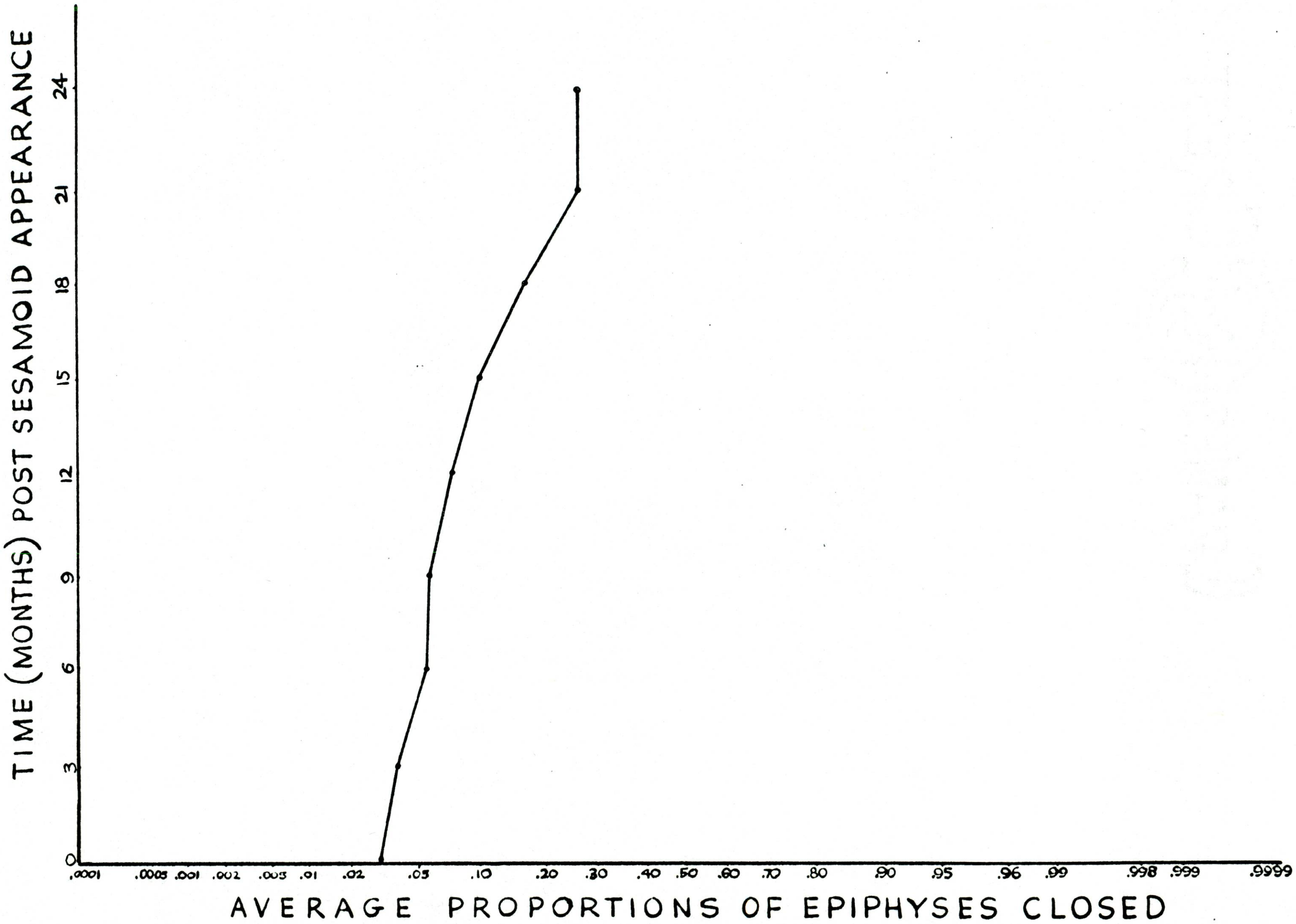


FIGURE 14. THE AVERAGE PROPORTION OF EPIPHYSES CLOSED IN MALES AS A FUNCTION OF TIME POST SESAMOID APPEARANCE (PLOTTED ON NORMAL PROBABILITY PAPER)

14), a visually chosen best fit line was drawn through the data, and parameters were calculated. Such a line gives a mean of 32 months with a standard deviation of 19 months for epiphyseal closure times relative to sesamoid appearance in females. In the males the results are 40 and 21 months respectively. These data are at best provisional and approximate.

Tables I and II represent male and female patients showing the percentage having a certain accumulative number of closures. From these tables one can see how many patients were surveyed at each time point post sesamoid appearance and the number of patients with a particular number of epiphyses closed at this time. These tables show that at a given time there is a wide distribution in the number of epiphyses closed.

It appears that the rate of epiphyseal closure after sesamoid appearance is a little more rapid in females. This might have been foreseen from the fact that females mature more rapidly than males.

At the time of sesamoid appearance many patients did not have epiphyses closed and some continued without epiphyseal closure for as long as 12 months in the case of the females and 21 months in the case of the males. It is also interesting that only one female patient reached complete epiphyseal closure during the study.

Tables III and IV show the anatomical distribution for the epiphyses closed at a given time post sesamoid appearance. The numbers in the left hand column refer to the epiphyses as numbered in Figure 1.

From these tables it can be seen that certain epiphyses tend to close earlier than others. In particular 14 and 18 seem to be early closing epiphyses in both study groups. In Table III number 16 seemed

TABLE I

FEMALE PATIENTS SHOWING THE PERCENTAGE ACCUMULATIVE NUMBER OF EPIPHYSEAL CLOSURES

# Epiphyses Closed	At Sesamoid		3 Mo. After		6 Mo. After		9 Mo. After		12 Mo. After		15 Mo. After		18 Mo. After		21 Mo. After		24 Mo. After	
	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%
0	8	57	4	29	3	25	2	18	1	10								
1	2	14	3	21	3	25	2	18	3	30	3	43	2	33				
2	3	21	4	29	3	25	3	27	2	20	1	14	1	17	2	40		
3	1	7	2	14	1	8	1	9	2	20	2	29			1	20		
4			1	7	1	8	1	9			1	14					1	50
5					1	8	1	9										
6							1	9	1	10			1	17				
7																	1	50
8									1	10			1	17				
9																		
10													1	17	1	20		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19															1	20		
Patient Total	14		14		12		11		10		7		6		5		2	

TABLE II

MALE PATIENTS SHOWING THE PERCENTAGE ACCUMULATIVE NUMBER OF EPIPHYSEAL CLOSURES

# Epiphyses Closed	At Sesamoid		3 Mo. After		6 Mo. After		9 Mo. After		12 Mo. After		15 Mo. After		18 Mo. After		21 Mo. After		24 Mo. After	
	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%	# pts	%
0	15	65	12	52	10	45	9	43	6	38	4	33	1	11	1	17		
1	3	13	5	22	5	23	6	29	3	19	2	17	1	11	1	17	1	33
2	4	17	5	22	3	14	1	5	3	19	3	25	1	11				
3	1	4			3	14	4	19	4	25	1	8	4	44	1	17		
4			1	4	1	5	1	5			1	8	1	11	1	17		
5											1	8					1	33
6													1	11				
7															1	17	1	33
8															1	17		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19																		
Patient Total	23		23		22		21		16		12		9		6		3	

TABLE III

FEMALE PATIENTS SHOWING THE PERCENT OF SPECIFIC EPIPHYSIS CLOSED

Epiphyses Closed	At Sesamoid 6 pts (43%) with closure out of 14			3 Mo. After 10 pts (71%) with closure out of 14			6 Mo. After 9 pts (75%) with closure out of 12			9 Mo. After 9 pts (82%) with closure out of 11			12 Mo. After 9 pts (90%) with closure out of 10			15 Mo. After 7 pts (100%) with closure			18 Mo. After 6 pts (100%) with closure			21 Mo. After 6 pts (100%) with closure			24 Mo. After 2 pts (100%) with closure		
	# pts	% 6 pts	% 14 pts	# pts	% 10 pts	% 14 pts	# pts	% 9 pts	% 12 pts	# pts	% 9 pts	% 11 pts	# pts	% 9 pts	% 10 pts	# pts	% 7 pts	% 7 pts	# pts	% 6 pts	% 6 pts	# pts	% 5 pts	% 5 pts	# pts	% 2 pts	% 2 pts
1	1	17	7	1	10	7	1	11	8	1	11	9	1	11	10	1	14	14	2	33	33	2	40	40	1	50	50
2	1	17	7	2	10	7										1	14	14	3	50	50	3	60	60	1	50	50
3																1	14	14	2	33	33	2	40	40			
4										1	11	9	2	22	20				3	50	50	3	60	60	1	50	50
5																						1	20	20			
6				1	10	7	2	22	17	2	22	18	1	11	10							2	40	40			
7																						1	20	20			
8										1	11	9	1	11	10				3	50	50	3	60	60	1	50	50
9																						1	20	20			
10	1	17	7	2	20	14	2	22	17	2	11	18	1	11	10				1	17	17	1	20	20			
11																						1	20	20			
12										1	11	9	1	11	10				2	33	33	3	60	60	1	50	50
13																			1	17	17	1	20	20			
14	4	67	29	7	70	50	6	67	50	7	78	64	6	67	60	4	57	57	3	50	50	4	80	80	2	100	100
15																						1	20	20			
16				2	20	14	3	33	25	3	33	27	3	33	30	2	29	29	3	50	50	3	60	60	2	100	100
17													1	11	10							1	20	20			
18	4	67	29	7	70	50	7	78	58	8	89	73	9	100	90	6	86	86	6	100	100	5	100	100	2	100	100
19																						1	20	20			

TABLE IV

MALE PATIENTS SHOWING THE PERCENT OF SPECIFIC EPIPHYSIS CLOSED

Epiphyses Closed	At Sesamoid 8 pts (35%) with closure out of 23			3 Mo. After 11 pts (48%) with closure out of 23			6 Mo. After 10 pts (55%) with closure out of 22			9 Mo. After 12 pts (57%) with closure out of 21			12 Mo. After 10 pts (63%) with closure out of 16			15 Mo. After 8 pts (67%) with closure out of 12			18 Mo. After 8 pts (89%) with closure out of 9			21 Mo. After 5 pts (83%) with closure out of 6			24 Mo. After 3 pts (100%) with closure		
	# pts	% 8 pts	% 23 pts	# pts	% 11 pts	% 23 pts	# pts	% 10 pts	% 22 pts	# pts	% 12 pts	% 21 pts	# pts	% 10 pts	% 16 pts	# pts	% 8 pts	% 12 pts	# pts	% 8 pts	% 9 pts	# pts	% 5 pts	% 6 pts	# pts	% 3 pts	% 3 pts
1																						1	20	17			
2	3	38	13	3	27	13	3	30	14	2	25	14	1	10	6	1	13	8	3	38	33	2	40	33	1	33	33
3																									1	33	33
4																1	13	8									
5																											
6				1	9	4	1	10	5	2	17	10	1	10	6	1	13	8	2	25	22	2	40	33	2	67	67
7																											
8																1	13	8				1	20	17	1	33	33
9																											
10							2	20	9	2	17	10	2	20	13	2	25	17	4	50	44	1	20	17	1	33	33
11				1	9	4																1	20	17			
12																1	13	8				2	40	33	1	33	33
13																											
14	6	75	26	7	64	31	7	70	32	6	50	29	7	70	44	6	75	50	6	75	67	4	80	67	2	67	67
15																											
16																1	13	8	1	13	11	2	40	33	1	33	33
17																											
18	7	88	30	7	88	30	10	100	50	11	92	52	10	100	63	8	100	75	8	100	89	5	100	83	3	100	100
19																			1	13	11	2	20	17			

seemed to be next in frequency of closure followed closely by 1, 2, 6, and 10. Following these the pattern of closure is relatively random, but one patient showed closure of all epiphyses. Excepting this patient, there were no closures in 5, 7, 9, 11, 13, 15, and 19. In the males (Table IV), number 2 was next to close, followed closely by number 6. Beyond this closure seemed to be a relatively random distribution between 10 and 16. There was no closure seen in 5, 7, 9, 13, 15, and 17.

Tables V and VI present patterns of epiphyseal closure in male and female patients at specific time intervals. Each number represents the closure in this epiphysis since the previous skeletal survey.

It again appears that epiphyses numbers 14 and 18 are early closing epiphyses but not invariably so. The overall distribution is such that it seems to have little specific predictive value.

The smaller the sample size, the less dependable is the data in predicting true population parameters. Thus, the percentages found in Tables I through IV become a less dependable representation of the actual population distribution as one goes from left to right on the tables. Even those followed for a full 24 months did not show more than 37 percent of all possible epiphyseal closures. Thus the length of time they were followed was insufficient to show the full pattern of closure, with the exception of one girl, where all epiphyses closed by 15 years 8 months (21 months post sesamoid appearance).

TABLE V

PATTERN OF EPIPHYSEAL CLOSURE IN FEMALES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
At sesamoid	1	1								1				4				4	
3 months after						1				1				3		2		3	
6 months after						1								1		2		1	
9 months after				1				1				1		1		1		1	
12 months after	1			1													1	2	
15 months after		1	1											1		1			
18 months after	1	2	2	3				3		1		2	1			1		1	
21 months after		2		1	1	2	1	1	1		1	2		1	1	1	1		1
24 months after	1	1														1			

TABLE VI

PATTERN OF EPIPHYSEAL CLOSURE IN MALES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
At sesamoid		3												6				7	
3 months after						1					1			1					
6 months after		1								2				1				5	
9 months after		1				1				1								1	
12 months after										1				3				3	
15 months after		2		1		2		1				1		2		2		2	
18 months after		2				2				3				1		1		1	1
21 months after	1			1		2		2			1	3				2			1
24 months after		2	2					1			1	1				1			

CHAPTER V

SUMMARY AND CONCLUSION

The ability to predict the adolescent growth spurt has been a goal of orthodontists for many years as an aid in treatment planning. Bjork (1967) stated that the onset of ossification of the ulnar sesamoid bone occurs about one year before the maximum puberal growth. It is not always possible to obtain hand radiographs showing the onset of ossification of the ulnar sesamoid bone. If the epiphyseal closure could be correlated with the onset of ossification of the ulnar sesamoid bone, it might be possible to determine the length of time the sesamoid has been present, when time of first appearance is unknown. One might then determine the period of time remaining before the maximum increment of adolescent growth spurt, or if the growth spurt had already taken place.

A study of epiphyseal closure and ossification of the ulnar sesamoid bone was made on twenty-three males and fourteen females for which hand radiographs were available which showed the onset of ossification of the ulnar sesamoid bone.

Starting at the time of sesamoid appearance, the epiphyses most commonly closed in both male and female subjects was number 18 followed closely by number 14. These epiphyses proceeded to close more rapidly than any other in the remaining patients in the study. Except for epiphyses 18 and 14, the patients for the time period studied did not present a uniform pattern of epiphyseal closure. The pattern was too diversified for any significant conclusions.

There is a general trend for rapid increase in closure starting about fifteen months after sesamoid appearance. The limited amount of data suggests that the individual behavior was so variable as to make prediction essentially impossible at this time.

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CORRELATION OF THE EPIPHYSEAL CLOSURE AND OSSIFICATION OF THE ULNAR SESAMOID BONE OF THE METACARPOPHALANGEAL JOINT OF THE THUMB

by

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An Abstract of a Thesis

in Partial Fulfillment of the Requirements

for the Degree Master of Science

in the Field of Orthodontics

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ABSTRACT

The purpose of this investigation was to determine if there is a correlation between the times of closure of the epiphyses of the hand and the time of ossification of the ulnar sesamoid of the metacarpo-phalangeal joint of the thumb.

The time for these events was studied in twenty-three males and fourteen females for which appropriate hand radiographs were available. Radiographs were made every three months and epiphyseal closure was studied in these beginning with the one in which the sesamoid first appeared. The maximum time for study after sesamoid closure was twenty-four months.

Only one subject showed complete closure of the epiphyses of the hand during study. Most subjects were only approaching 40-50 per-cent closure. No really dependable sequence of epiphyseal closure appeared but there were two epiphyses (proximal phalanx of fourth and fifth digit) which closed earliest in a large percentage of the patients. On the basis of the number of subjects followed and the time they were followed it is difficult to make any predictions dependent on which particular epiphyses are closed.

Graphs were made of the average number of epiphyses closed as a function of time post sesamoid appearance. These showed that there is a general trend for rapid increase in closure starting about fifteen months post sesamoid appearance. The limited number of subjects suggests that the individual behavior is so variable as to make prediction unreliable within the time interval covered by the study.