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QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND

TECHNICAL REPORT
EP-45

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SKELETAL AGE CHANGES IN YOUNG AMERICAN MALES

QUARTERMASTER RESEARCH & DEVELOPMENT CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

MAY 1957 NATICK, MASSACHUSETTS

HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
OFFICE OF THE COMMANDING GENERAL
NATICK, MASSACHUSETTS

31 May 1957

The Quartermaster General
Department of the Army
Washington 25, D. C.

Dear Sir:

This report, "Skeletal Age Changes in Young American Males," is concerned with one of the principal identification methods available to the Army Graves Registration Service: the successful calculation of the age at death of an unidentified soldier. There are a number of bony sites in the body which show successive age changes and which can be used for this calculation. However, the concept of age changes in the skeleton which was initially developed on anatomical collections over thirty years ago has been revitalized recently by a Quartermaster Research and Development effort to establish a new and improved system based on individuals of military age. In response to a request from the Secretary of the Army, Dr. T. D. Stewart of the Smithsonian Institution examined some 450 skeletonized and identified U. S. war dead which were being repatriated from North Korea in "Operation Glory" during the fall of 1954. Detailed recordings, plaster casts and photographs were obtained which have been analyzed for age changes by both Dr. T. W. McKern, Anthropology Branch, Environmental Protection Research Division, and Dr. Stewart.

This report on skeletal ageing was compiled from the results of the above analysis and will serve as both a technical source and a practical tool for age identification. Also, using specific skeletal locations that best show progressive age changes, new and improved methods of age calculation have been introduced. These new methods, along with the general information contained in this report, will make it possible for those individuals who are involved in identification work to arrive at more accurate age estimations.

Sincerely yours,

C. G. Calloway
C. G. CALLOWAY
Brigadier General, USA
Commanding

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Dr. McKern began work on 6 September 1955, and after completing his analysis of the data and preparing a first draft of the manuscript, moved to the R&D Center, Natick, Massachusetts on 15 August 1956 where he completed work on the manuscript.

The present report represents the results of extensive identification research on a thoroughly documented sample of a military population and is concerned specifically with the estimation of chronological age from the maturational status of unknown remains. It provides an efficient training source as well as more reliable standards which will enable future observers to arrive at more accurate results.

AUSTIN HENSCHEL, Ph.D.
Chief
Environmental Protection Research Division

Approved:

JAMES C. BRADFORD, Colonel, QMC
Commanding Officer
QM R&D Center Operations

A. STUART HUNTER, Ph.D.
Scientific Director
QM Research & Development Command

HEADQUARTERS QUARTERMASTER RESEARCH & ENGINEERING COMMAND, U.S. ARMY
Quartermaster Research & Engineering Center
Natick, Massachusetts

ERRATA 29 October 1957

Technical Report EP-45, Skeletal Age Changes in Young American Males, by Thomas W. McKern and T. D. Stewart, May 1957.

Page	Line	
5	21	Change skeletel to skeletal
10	24	Change 25 to 23
11	32,34	Change Caucausoid to Caucasoid
12	1	
13	2	
20	37	Change Montague to Montagu
24	15	Change Grey's to Gray's
37	20	Change 20 years to 21 years
48	7	Change Table 22 to Table 21
50	4	Change persistant to persistent
65	19	Change eschial to ischial
82	33	Change "quiesence" to "quiescence"
84	25	Change symphseal to symphyseal
88	1	Change 22 years to 23 years
90	2	Change 1871 to 1872
90	12	Change (1925) to (1924)
102	30	Change persistance to persistence
108	5	Change Haffziger to Naffsiger
109	5	Change Cervicle to Cervical

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Page	Line	
115	31	Change 22nd year to 23rd year
120	16	Change coarse to course
140) 141)		Transpose photographs on these pages. Photographs on page 140 go on page 141, those on page 141 go on page 140
154	8	Change varies to vary
154	17	Change erroded to eroded
160	21	Change 23 years to 24 years
168	7	Change Table 46 to Table 51
170	5	Change Table 47 to Table 52
170	25	Change page 20 to page 11
170	32	Change 2.9 percent to 4.4 percent
179	15	Add (after Topinard) Trotter, Mildred 1934 Incidence of synostosis between the manubrium and body of the sternum in Whites and Negroes. Am. J. Phys. Anthrop., 18:439-42.

Foreword

When the United Nations military forces retreated from North Korea in 1950 they necessarily left behind a large number of dead, buried in military cemeteries or in temporary graves. During the following years attempts were made to get permission for the Graves Registration Service groups to enter the area and to remove the remains of the American dead. Permission to enter was denied but it was finally arranged that the Communists would disinter the American remains and exchange them for their own dead which we would return from South Korea.

It was realised by the Memorial Division, Office of The Quartermaster General, that this operation (known as "Operation Glory") held possibilities for research in the field of identification. Thus, the initiation of the present research project dates back to late in the summer of 1953. At that time Dr. T. D. Stewart was approached informally by representatives of the Memorial Division regarding the desirability of further research on identification problems in connection with the recovery of the American war dead in Korea. Negotiations with the Communists regarding the return of the American war dead were completed in the summer of 1954. Prior to this time Dr. Stewart perfected plans for recording information on the skeletal evidence of ageing and arranged for a leave of absence from the Smithsonian Institution.

Dr. Stewart arrived in Kokura, Japan on September 18 and was stationed with the American Graves Registration Service Group at the Jono, Japan area. This was the Army Central Identification Laboratory and it was here that the remains of the American war dead from Korea were being processed.

During the following four months, 450 skeletons were thoroughly investigated according to the procedures outlined in succeeding chapters. At the end of this period the completed records were shipped to the Smithsonian Institution in Washington.

In the spring and summer of 1955 Dr. Russell W. Newman, Environmental Protection Research Division, Quartermaster Research and Development Center, Natick, Massachusetts, worked out an arrangement whereby Dr. Thomas W. McKern was detailed to Washington, D. C. to work with Dr. Stewart on the analysis of the data obtained in Japan.

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ABSTRACT

This report of skeletal age changes was compiled from the results of extensive identification research on a series of 450 skeletal remains of U. S. war dead repatriated from North Korea under "Operation Glory" during the fall of 1954. The report is divided into eleven chapters; ten outline the progress of age changes in selected skeletal segments and one, the eleventh, portrays the total pattern of skeletal maturation. To further aid the observer, each chapter includes complete tabular and detailed photographic evidence of the exact nature of skeletal age changes for the particular area concerned. Also, new methods for determining age estimations have been introduced.

The present work can be used as a technical source as well as a practical tool for the age identification of unknown remains.

INTRODUCTION

1. Background of skeletal ageing

The estimation of chronological age from the maturational status of unknown skeletal remains has long been an important problem to the Quartermaster Corps as well as to the federal and local law enforcement agencies. Formerly the information used in this work was obtained mainly from textbooks of anatomy. In these sources unsubstantiated statements are to be found regarding the ages at which maturational events occur. The placing of definite dates on such events is in keeping with the general practice of oversimplifying anatomical descriptions for teaching purposes. Variation was minimized and central tendencies became the working standards.

It was not until the 1920s that some of the anthropologically-minded anatomists began to reexamine skeletal maturation and to restate the terminal ages with more reference to their variability. Perhaps the greatest contribution along these lines was made by T. Wingate Todd and his associates at Western Reserve University, who had access to a large and unusually well-documented skeletal collection. Throughout the present work we will have occasion to refer to these studies.

In spite of the fact that Todd was aware of the role of variation in maturational events, he still tended to fall into the traditional anatomical practice of simplification because he felt the need in this instance to emphasize general biological principles. For this reason it was easy for others to abstract Todd's data and thereby increase the simplification. An example of this is provided by Krogman's "Guide to the Identification of Human Skeletal Material" prepared for the FBI in 1939. To take a typical case, Krogman indicates in his figure 18 that the proximal epiphysis of the humerus unites in males at 19.5-20.5 years, thus implying a variation of only one year for this feature. An indirect comment on this statement was made in 1952 by F. Vandervael of the University of Liege, who served as an identification specialist for AGRS in Europe after World War I. According to his findings on the remains of 225 American soldiers, the head of the humerus unites at 21 years or later. Vandervael indicated many other changes in the terminal dates of maturational events. Also, Singer in 1953 and Cobb in 1955 denied the utility claimed by Todd for suture closure in age identification. More and more, therefore, it has become apparent that better data are needed in this field. Yet, in the absence of better data, identification specialists have been relying perforce on the standards at hand.

When the present project got under way in the fall of 1954 at Kokura, Japan, the anthropologists in the Identification Laboratory there were estimating age on the basis of standards derived ultimately from the work of Todd and his associates. The identification records of these anthropologists thus provide a base line from which to measure future improvements. Realising this, Dr. Stewart made a comparison of the estimated and actual ages for the first 200 identified cases of the sample which he studied.

The results of this comparison showed that although the anthropologists in Kokura, using existing standards, gave remarkably good estimates of age, they had a tendency to overestimate the ages of a large proportion of unknowns.*

From this analysis of skeletal ageing at the time the present project began, the authors feel that the main problems confronting them are the following: 1) to provide a better picture of the range of variation in maturational events in the American population; and 2) to provide a better training method to enable future observers to arrive at more uniform results.

2. Methods of observation

In preparation for the work in Japan Dr. Stewart devised two recording forms which were printed on 8 x 10½" Keysort Cards (QMC Forms T-90 and T-90a). These cards are reproduced here as figures 1 and 2. As will be seen, Card 1 is devoted to eruption of the third molars and to closure of the cranial sutures; Card 2 is devoted to the union of certain epiphyses and to joint changes of an arthritic nature. Space is provided on both cards for explanatory notes, lists of casts and photographs.

Although the two cards thus served different purposes, both contain a certain amount of information in common, namely, military number (really evacuation number), order number (in the series studied), dates of birth and death, age, race, and state of preservation. Data on age and race were not obtained, of course, until identification was complete.

The selection of observations and their arrangement on the cards were determined partly by space limitations on the cards and by a knowledge of the maturational status of the military age groups. Since space on Card 1 did not permit a detailed recording of facial suture closure and Cobb (1955) had shown that closure here has very little significance for identification, it was decided simply to note the

*Since a similar study is to be presented separately and more elaborately, only the main conclusions of Dr. Stewart's analysis are presented here.

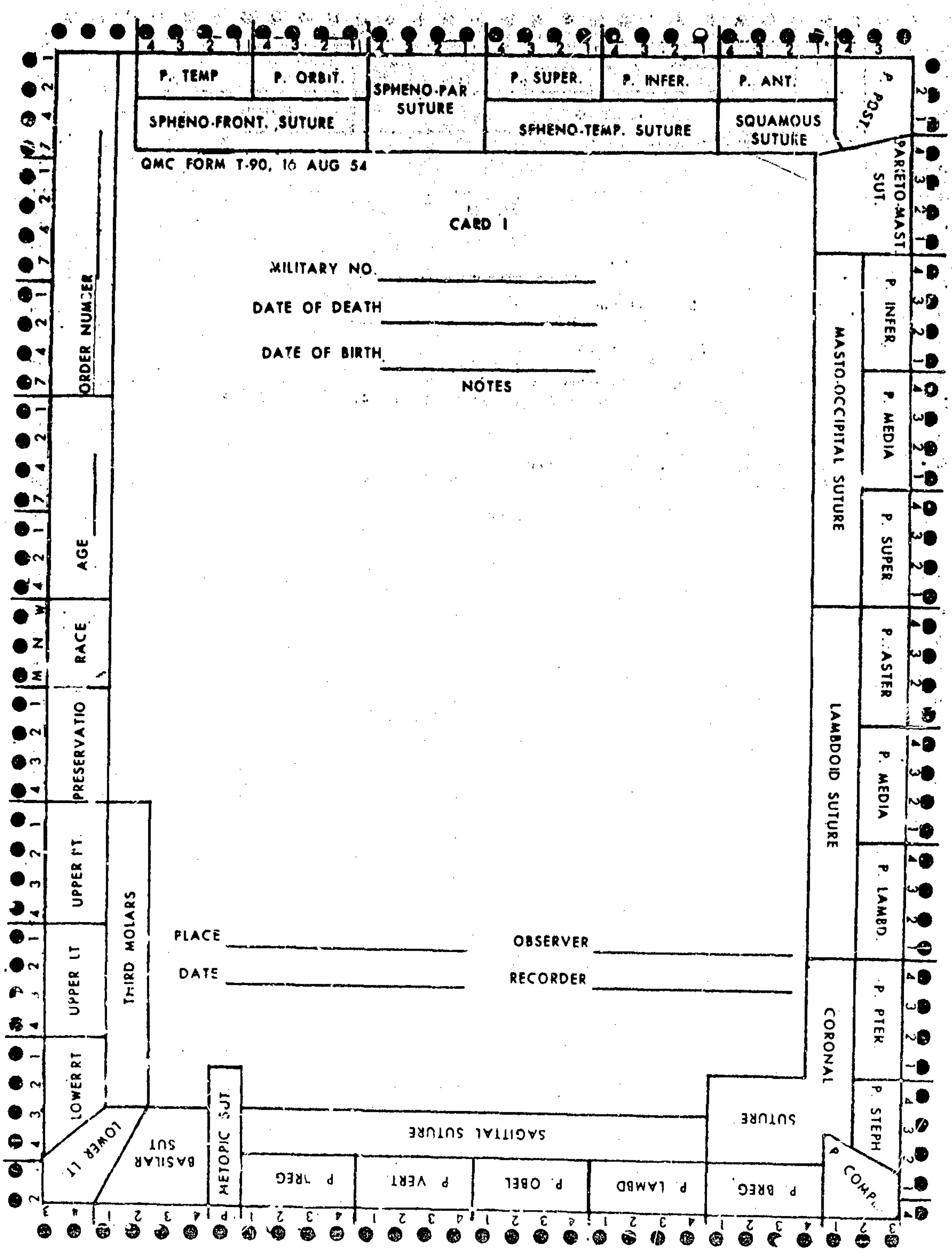
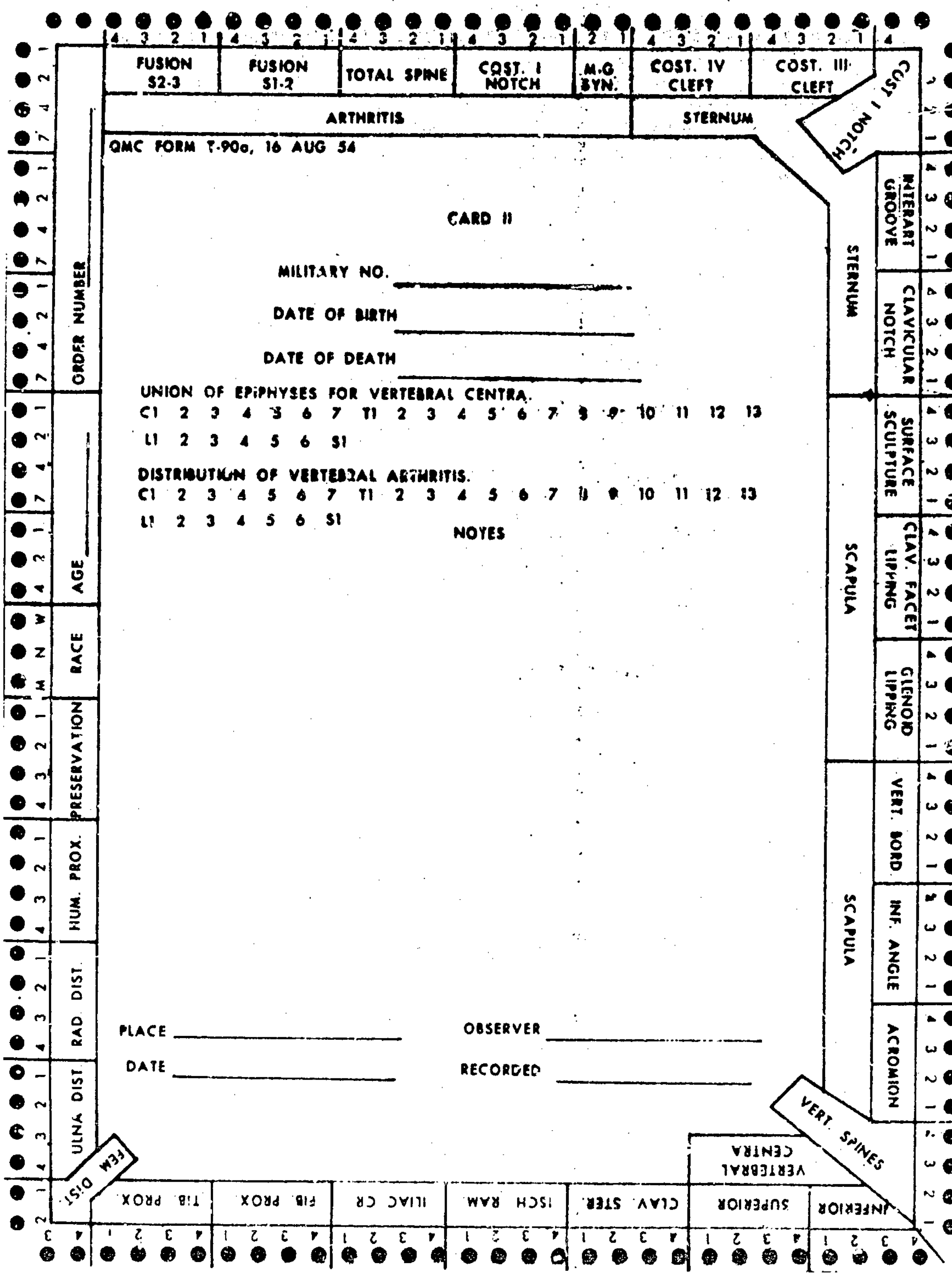


Fig.1 Keysort Card No. 1 for recording the eruption of the third molars and cranial suture closure.



FUSION S2-3 | FUSION S1-2 | TOTAL SPINE | COST. I NOTCH | M.G. SYN. | COST. IV CLEFT | COST. III CLEFT | COST. I NOTCH

ARTHRITIS | STERNUM

QMC FORM T-90a, 16 AUG 54

CARD II

MILITARY NO. ____________

DATE OF BIRTH ____________

DATE OF DEATH ____________

UNION OF EPIPHYSES FOR VERTEBRAL CENTRA.

C1 2 3 4 5 6 7 T1 2 3 4 5 6 7 8 9 10 11 12 13

L1 2 3 4 5 6 S1

DISTRIBUTION OF VERTEBRAL ARTHRITIS.

C1 2 3 4 5 6 7 T1 2 3 4 5 6 7 8 9 10 11 12 13

L1 2 3 4 5 6 S1

NOTES

PLACE ____________ OBSERVER ____________

DATE ____________ RECORDED ____________

ORDER NUMBER | AGE | RACE | PRESERVATION | HUM. PROX. | RAD. DIST. | ULNA DIST. | FEM DIST.

STERNUM | SCAPULA | SCAPULA | INTERART GROOVE | CLAVICULAR NOTCH | SURFACE SCULPTURE | CLAV. FACET LIPPING | GLENOID LIPPING | VERT. BORD. | INF. ANGLE | ACROMION | VERT. SPINES

TIB. PROX. | FIB. PROX. | ILIAC CR. | ISCH. RAM. | CLAV. STER. | SUPERIOR | VERTEBRAL CENTRA | INFERIOR

Fig. 2 Keysort Card No. 2 for recording the union of certain epiphyses and joint changes.

sites of closure in the more readily observable sutures of the face. On the other hand, cranial sutures were arranged on the card in such a way as to permit orderly observation in full detail.

Similarly for Card 2 certain epiphyses had to be selected for detailed recording and others had to be relegated to notes. In the latter group were placed the epiphyses that unite earliest, namely, those of the elbow, hip, and ankle.

Some idea of the work involved in recording the maturational status of a specimen is given by the total number of observations on the two cards, which amounts to about 60. Usually a good many other observations were added in the form of notes.

By using punch cards it was possible to categorize most observations on a scale of 0-5. Zero (no punch) usually indicates absence of the feature in question. For example, in suture closure it means no closure; in epiphyseal union it means lack of union. On the other hand, 5 (4 and 1 both punched) means inability to observe the feature due to damage to, or loss of, the skeletal part. Thus the numbers 1 to 4 were reserved for reporting stages of maturation of the feature. In suture closure this means one-quarter, one-half, three-quarters and complete closure; in epiphyseal union it means beginning, active, recent, and complete union. The only exceptions to this scheme are the following: Preservation (0 = excellent, 1 = good, 2 = fair, 3 = poor, 4 = flesh covered); third molars (1 = deeply imbedded, 2 = partly erupted, 3 impacted, 4 = normally erupted, 5 = not present); synostosis of manubrio-gladiolar joint: (0 = no fusion, 1 = widened joint, 2 = fusion, 3 = not observable).

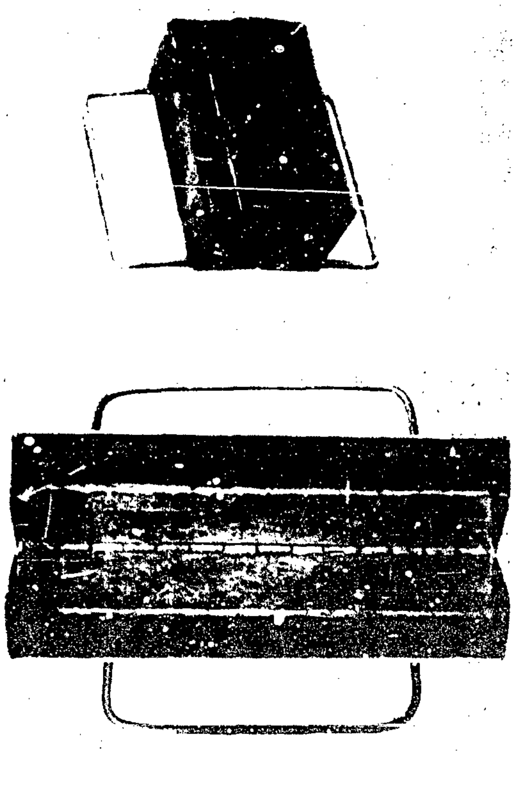


Fig.3 Molding trays used in making the casts. The tray below is partially open to show hinge in base as well as the construction of the interlocking sides.

It will be noted that no space was provided on the punch cards for the pubic symphysis, one of the most important areas

Fig. 4 Preparation of casts of pubic symphyses showing arrangement of equipment (Mr. Doram).

for age identification. The main reason for this is that Dr. Stewart felt he could not take the time to make the observations directly from the bone. Instead, he planned to make plaster casts of the symphysis for later study. Also, he planned to make casts of the sternal end of the clavicle and one border of the manubrium partly in support of the record and partly for further study. In this connection and before going to Japan, Dr. Stewart tested casting compounds and designed metal trays suitable to serve as containers for the molds. Having found that dental molding compound (Trade name: D. P. Elastic Impression Cream) made a satisfactory quick-setting mold, he arranged for a supply to be sent in advance to Japan. Also, he made certain that adequate supplies of plaster of Paris and dental stone were available in Japan. A set of molding trays (Fig. 3), made in the shops of the U. S. National Museum, was taken to Japan.

One of the problems of casting was to work on two or more sets of bones at once without mixing the bones or mislabelling the casts. In order to avoid such errors, one of the staff, Mr. Doram, developed a procedure involving distinct labelling and separate placement of each set of bones and each set of casts. Also, as soon as a cast was available he compared it with its respective bone and inscribed its number and name on the base. Fig.4 shows Mr. Doram working in his section of the laboratory and the arrangement of his work space.

The observations recorded on the punch cards were supplemented further by photographs. For the most part these photographs were regarded simply as evidence corroborating the ratings recorded on the cards. However, in addition certain features, particularly the sculpturing on the blade of the scapula and the lipping of the inner border

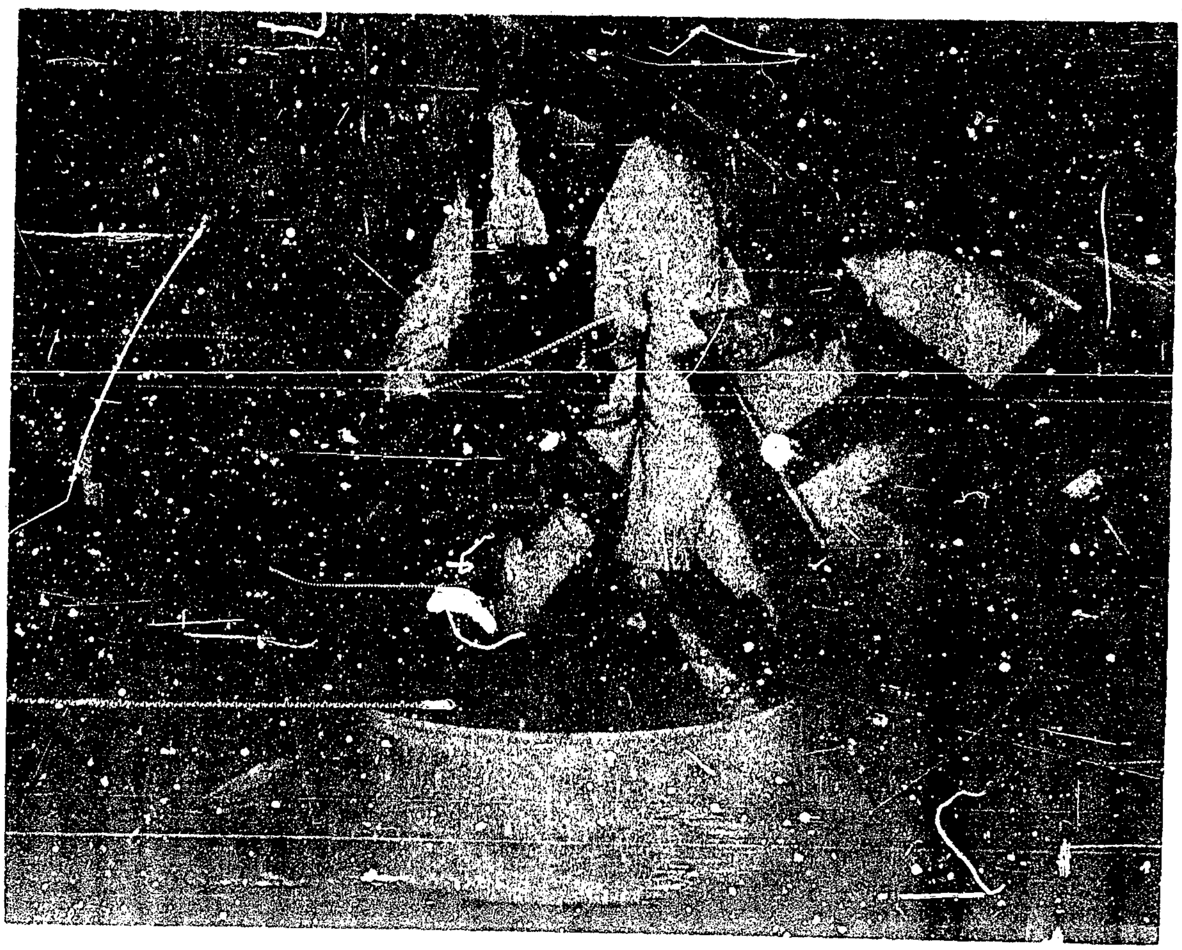


Fig. 5 Arrangement of photographic equipment (Pfc. Bloomenheim photographing skull).

of the ischial tuberosity, were recorded only by means of photography. To avoid errors only one set of bones was photographed at a time, and the specimen number and negative number were made a part of each picture. All photographs were taken with a 4 x 5 Speed Graphic Camera equipped with 127 mm 4.7 Kodak Ektar lens and a Kodak plus No. 2 Supplementary lens. Fig. 5 shows Pfc. Bloomenheim photographing a skull and the arrangement of his photographic equipment.

It should be emphasized here that the observations of the present sample were made by one person (TDS) and that every effort was made to avoid errors of observation. To this end the skeletons were always laid out anatomically in the same way and were viewed always from the same side and with the light in the same position.

3. The sample

The remains of the American soldiers received from North Korea under "Operation Glory" were in varying states of decomposition. In the military cemeteries of this area, burial had been at a depth of 3 to 3½ feet, the remains being wrapped in waterproof shelter halves. Outside of the regular cemeteries, burial conditions had not been uniform. The Communists simply removed the remains in their original wrappings and returned them in sealed rubberized bags. Because the remains were in different states of decomposition, priority groupings were established for processing. Top priority of necessity was given to the remains which were partly flesh-covered. Also high in the priority listing were remains accompanied by good identification media, including those removed from military cemeteries. Lower priorities were given to the remains which were completely skeletonized and which were accompanied by more or less complete identification media; these included the remains from enemy prison camps. At the bottom of the list were incomplete and commingled skeletal remains and all those for which the associated identification media were poor or missing. Under this priority arrangement inevitably some skeletons with poor identification media were studied by Dr. Stewart. Thus, although it had been anticipated originally that the project would utilize only the remains from the military cemeteries, and in general those most likely to be identified, circumstances led to the inclusion in the series of 75 remains which were never identified.

Among the poorly documented remains studied was a series of 158 prisoners of war (POW). Although it was anticipated that a high percentage of these remains would not be identified, actually only 25 (15.8%) had to be excluded for this reason. By contrast, of the 292 individuals killed in action (KIA) 50 (17.1%) were not identified. The sequence in which these categories were studied is shown in Table 1. From what has been said it becomes obvious that the variations in this table are due mainly to factors of priority. Also, attention is called to the fact that the majority of the last 50 cases studied are POW. This is explained by the fact that a

TABLE 1: Categories of Subjects by Order of Study

Order No.	Dates	POW Ident.* (No.)	POW Ident.* (%)	POW Unident.** (No.)	POW Unident.** (%)	KIA Ident.* (No.)	KIA Ident.* (%)	KIA Unident.** (No.)	KIA Unident.** (%)
1 - 50	24 Sep. - 9 Oct.	10	20	3	6	33	66	4	8
51 - 100	9 Oct. - 21 Oct.	0	-	0	-	48	96	2	4
101 - 150	21 Oct. - 3 Nov.	22	44	5	10	21	42	2	4
151 - 200	3 Nov. - 17 Nov.	1	2	2	4	45	90	2	4
201 - 250	17 Nov. - 26 Nov.	33	66	5	10	9	18	3	6
251 - 300	26 Nov. - 13 Dec.	11	22	0	-	32	64	7	14
301 - 350	13 Dec. - 22 Dec.	10	20	0	-	35	70	5	10
351 - 400	24 Dec. - 6 Jan.	13	26	4	8	16	32	17	34
401 - 450	6 Jan. - 20 Jan.	33	66	6	12	3	6	8	16
TOTAL (450)		133	29.6	25	5.5	242	53.8	50	11.1

*Identified
**Unidentified

TABLE 2: Condition of all Remains Studied by Order of Examination (according to status of preservation*)

Order No.	Excellent (No.)	Excellent (%)	Good (No.)	Good (%)	Fair (No.)	Fair (%)	Poor (No.)	Poor (%)	Flesh Covered (No.)	Flesh Covered (%)
1 - 50	14	28	26	52	7	14	2	4	1	2
51 - 100	6	12	33	66	10	20	1	2	-	-
101 - 150	23	46	20	40	7	14	-	-	-	-
151 - 200	4	8	37	74	9	18	-	-	-	-
201 - 250	18	36	25	50	7	14	-	-	-	-
251 - 300	13	26	29	58	5	10	3	6	-	-
301 - 350	14	28	30	60	5	10	1	2	-	-
351 - 400	21	42	23	46	6	12	-	-	-	-
401 - 450	15	30	24	48	10	20	1	2	-	-
TOTAL (450)	128	28.4	247	54.9	66	14.7	8	1.8	1	0.2

*This refers only to the joint surfaces; otherwise the bones were well preserved special effort was made during the last month to get older individuals and these could be found only among the POW. Thus, selection also plays a role.

In general, all of the skeletons seen were in a relatively good state of preservation. However, since the observations being recorded depended largely on joint surfaces being intact, all skeletons were rejected which exhibited extensive damage of these surfaces or which lacked parts critical for the ageing of the particular individual. Occasionally cases were accepted in which parts still had cartilage and ligaments present but only when these structures did not interfere too much with the required observations. Table 2 shows the states of preservation of all the remains studied by the order in which they were studied and Table 3 shows the same stages of preservation for the identified remains alone as arranged by age groups. It is obvious from these tables that "poorly" preserved and flesh-covered remains were seldom included. It would appear also that the category of "excellent" preservation was seldom encountered in the youngest individuals. This is explained probably by the fact that at 17-18 years the many epiphyseal surfaces present are quite vulnerable to weathering.

Naturally very young men predominate in the military population. According to Table 4, in which the number of identified individuals in each category are listed, 18, 19 and 20 were the ages most frequently encountered. From the peak at these years the number of cases per year tapers off, especially after 25. Because some of the ages are poorly represented, it will be our practice in the analyses to combine certain of the poorly represented ages (as for instance in Table 3) in

TABLE 3: Status of Preservation of Identified Remains by Age Groups*

Age	No.	Excellent		Good		Fair		Poor		Flesh Covered	
		(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)
17 - 18	55	1	2	45	82	9	16		-		-
19	53	12	23	30	56	11	21		-		-
20	45	9	20	26	58	8	18	2	4		-
21	39	9	23	23	59	6	15		-	1	3
22	25	10	40	14	56	1	4		-		-
23	27	8	30	13	48	4	15	2	7		-
24 - 25	28	9	32	15	54	3	11	1	3		-
26 - 27	25	11	44	8	32	5	20	1	4		-
28 - 30	29	11	38	15	52	3	10		-		-
31 - 40	43	16	37	22	51	5	12		-		-
41 - 50	6	1	17	4	66	1	17		-		-
TOTAL	375	97	25.9	215	57.3	56	14.9	6	1.6	1	0.3

*See footnote Table 2

TABLE 4: Age Distribution of 375 Identified Remains

Age	No.	Age	No.	Age	No.	Age	No.
17	10	24	14	31	7	38	3
18	45	25	14	32	8	39	4
19	53	26	15	33	4	40	1
20	45	27	10	34	5	41	1
21	39	28	12	35	4	42	3
22	25	29	6	36	4	44	1
23	27	30	11	37	3	50	1

order to make groupings which are statistically more adequate. It should be understood, however, that age was unknown at the time the material was studied. Except during the last month of the project, the material was accepted without respect to age. In the last month, as has been stated, deliberate selection was made of older individuals, but solely on the basis of morphological appearance.

The American soldiers killed in Korea came from all parts of the continental United States as well as from the extracontinental U. S. territories. The origin of an individual was not known at the time his remains were examined. The bulk of the identified group (368) came from the continental United States. A percentage breakdown of the latter figure by sections of the country is shown in Fig. 6.

As will be seen, the highest percentage (25.5) occurs in the East North Central States; the lowest percentage (3.3) occurs in the Mountain section. Pennsylvania was the largest contributor among the states of our series (30). Other states with high representations are: Michigan (29); Illinois (27); California (24); New York (23). These figures suggest a distribution similar to that of the American population as a whole.

As with age and birthplace, race was not known when the remains were examined, although sometimes it could be detected from skull morphology. According to military practice, three racial stocks were recognized: Caucausoid, Negroid, and Mongoloid. Table 5 shows the distribution by age of these racial elements in the identified series. The Caucausoid group predominates (90.4%) and only one Mongoloid is represented. On the other hand, the Negroids are fairly evenly distributed throughout the whole age range. Unfortunately, the number of Negroids (35) is too small to justify separate racial analysis. We will discuss this matter further.

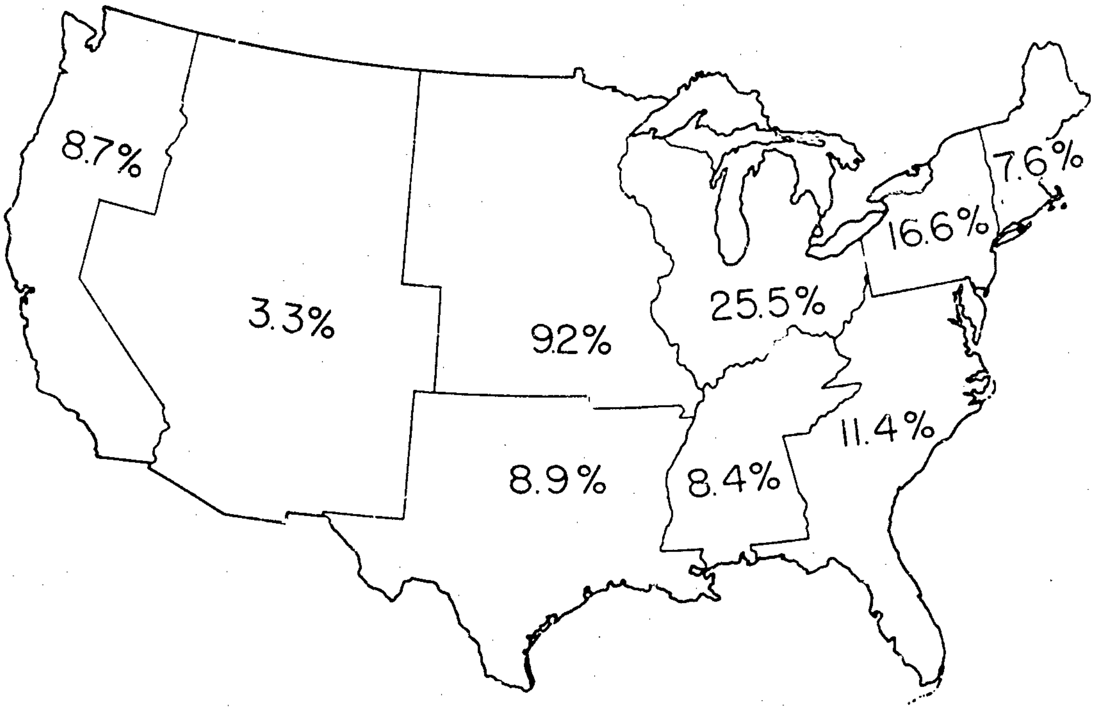


Fig. 6 Sectional distribution of the Army series.

Judging from the names of identified Caucausoids — admittedly a highly subjective appraisal — about 90% had an ancestry stemming back to the British Isles and Northwestern Europe (including Germany). The remainder probably had been derived from Southern and Eastern Europe.

The POWs present a special problem. It was noted immediately that their skeletons were almost invariably free of tissues and complete to the smallest bones. In contrast with the skeletons which had come from the military cemeteries, those of the POWs seemed to have lost most of their organic matter and were light in weight. Although these changes may have been due mainly to differences in mode of burial, taken together with occasional evidence of changes in surface texture (osteoporosis), they suggested that the POW often had suffered from extreme and prolonged malnutrition. This raised the question whether the rate of ageing had been altered in this group. It was important, therefore, to determine whether the POWs should be combined with the KIAs in the analysis, or treated separately.

The POWs had been in captivity for varying lengths of time up to one and a half years before death. Table 6 shows the duration of captivity in relation to age. According to this, the great majority were

TABLE 5: Race Distribution of Identified Remains by Age Group

Age	Total (No.)	Caucasoid (No.)	Caucasoid (%)	Negroid (No.)	Negroid (%)	Mongoloid (No.)	Mongoloid (%)
17 - 18	55	49	89.1	6	10.9		-
19	53	53	100.0	0	-		-
20	45	43	95.5	2	4.5		-
21	39	36	92.3	3	7.7		-
22	25	24	96.0	1	4.0		-
23	27	25	92.6	2	7.4		-
24	14	14	100.0	0	-		-
25	14	10	71.4	4	28.6		-
26	15	11	73.3	4	26.7		-
27	10	7	70.0	3	30.0		-
28	12	10	83.3	2	16.7		-
29 - 30	17	12	70.6	4	23.5	1	5.9
31 - 40	43	39	90.7	4	9.3		-
41 - 50	6	6	100.0	0	-		-
TOTAL	375	339	90.4	35	9.3	1	0.3

TABLE 6: Age versus Duration of Captivity before Death

Age	No.	%	Intervals of captivity (months) 0 - 3 (No.)	0 - 3 (%)	3 - 6 (No.)	3 - 6 (%)	6 - 9 (No.)	6 - 9 (%)	9 - 13 (No.)	9 - 13 (%)	13 + (No.)	13 + (%)
17 - 18	3		2	66	1	34		-		-		-
19	6		3	50	3	50		-		-		-
20	8			-	3	38	3	38	2	24	-	-
21	10	36.1%	3	30	4	40		-	3	30		-
22	8			-	6	76	2	24		-		-
23	13		4	30	7	54	1	8		-	1	8
24 - 25	13		2	15	5	39	4	30	1	8	1	8
26 - 27	17	63.9%	3	18	11	64	3	18		-		-
28 - 30	17		1	6	13	76	2	12	1	6		-
31 - 40	34		5	15	23	67	6	18		-		-
41 - 50	4			-	4	100		-		-		-
TOTALS	133		23	17.2	80	60.1	21	15.7	7	5.2	2	1.5

Fig. 7 Cranial vault showing the porous nature of the cortical bone. (No. 197, 17 years.)

in captivity status from 3 to 6 months. Also, nearly two-thirds of the POWs were 24 years of age or older. This means that only a little over a third were in developmental stages which are apt to show signs of retardation. Incidentally, the high percentage of older individuals among the POWs is explained by the fact that most of them were members of Regular Army units employed during the fluid stages of the Korean action.

The so-called osteoporosis which was observed in some of the POWs was located sometimes on the vault of the skull alone; at other times on the interproximal surfaces of the vertebrae, on the margins of sternum and on the medial surface of the clavicle; and rarely on all these bones in the same individual. As the name implies and as the illustrations show (Figs. 7 to 9), the cortical bone was unusually

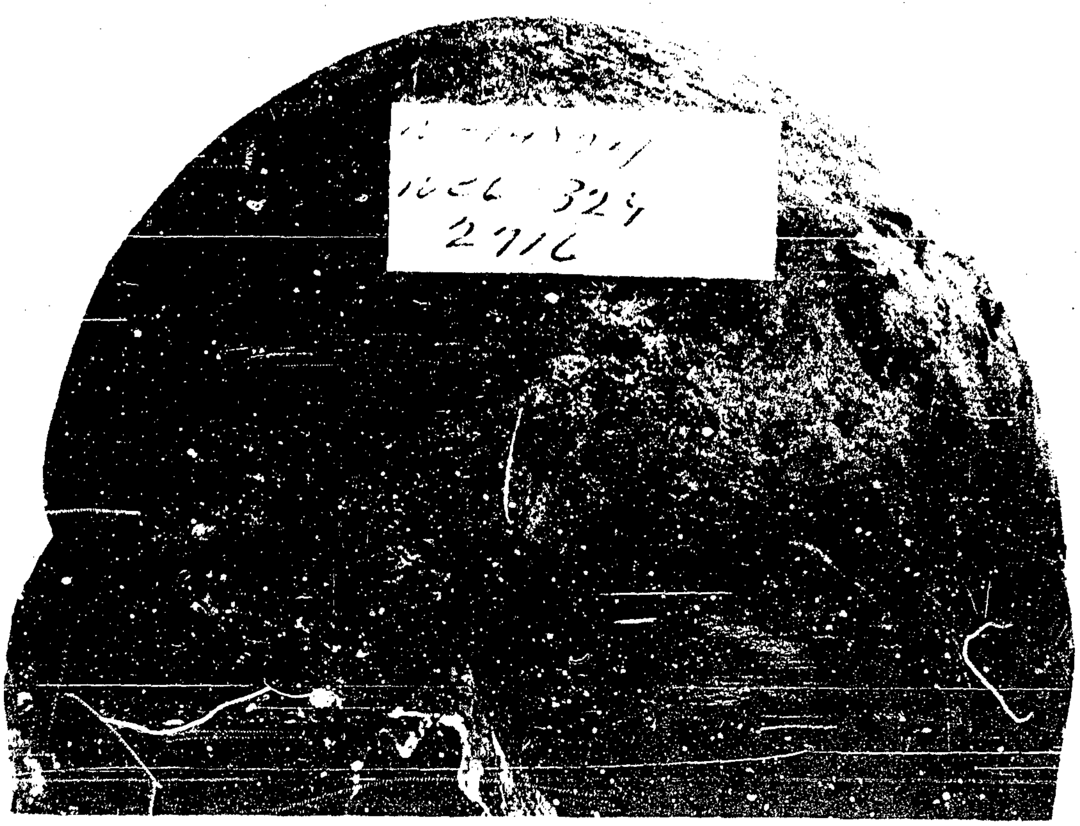


Fig. 8 Supraorbital region of the frontal bone showing the porous nature of the cortical bone. (No. 329, 23 years.)

Fig. 9 Top: Superior surface of the 1st lumbar vertebra showing the porous nature of the cortical bone. (No. 86, 16 years.)
Bottom: Medial surfaces of left and right clavicles showing the porous nature of cortical bone. (No. 73, 20 years.)

porous in such cases. So far as the vertebras and sterna are concerned it was necessary to distinguish between antemortem and postmortem changes. The cranial osteoporosis could not have been confused with postmortem changes.

The 23 cases in which cranial or postcranial osteoporosis was noted are listed by age and category in Table 7. As will be seen, they are about equally divided between POWs and KIAs, but the KIAs are generally below the age of 22 years, whereas the POWs are above this age. Since there is as much evidence of osteoporosis among the KIAs as among the POWs, we feel that this fact, together with the evidence (mentioned above) that the POWs show no signs of retardation, justify combining the two groups for purposes of analysis.

TABLE 7: Analysis of 23 Cases of Osteoporosis by Age and Individual Status

Age	Cranial Osteoporosis	Postcranial Osteoporosis	POW No.	POW Duration	KIA	Race C	Race N	Race M
17	1	-	-		1	1	-	-
18	2	4	-		6	5	1	-
19	1	1	-		1a/	1	-	-
20	2	2	1	4 mo. 29 days	3	4	-	-
21	1	-	1	5 mo. 18 days	-	1	-	-
22	2	1	1	4 mo. 10 days	1	2b/	-	-
23	1	1	2	(6 mo. 21 days c/	-	2	-	-
				(1 yr. 6 mo.	-	1	-	-
24	1	-	1	5 mo. 6 days	-	-	-	-
25	1	-	1	2 mo. 17 days	-	1	1	-
26	-	1	1	5 mo. 6 days	-	1	-	-
27	1	-	1	Unknown	-	-	-	-
30	1	-	1	2 mo. 8 days	-	-	-	1
31	1	-	1	3 mo. 13 days	-	-	1	-
TOTALS	15	10	11		12	19	3	1

a/ The only KIA with both cranial and postcranial osteoporosis.

b/ One POW had both cranial and postcranial osteoporosis.

c/ This POW had cranial osteoporosis.

The following analysis of collected data is divided into an arbitrary sequence of different parts of the skeleton. We could have followed the conventional anatomical sequence or one based on the importance of the parts for age estimation. However, no matter what scheme was used, the reader would still have to use the table of contents to find a particular area. We have therefore decided to follow, in the main, that used on the data cards. Thus, the skull, which is covered in data card #1, will be treated first and the postcranial elements, scored on data card #2, will follow in, more or less, the recorded sequence. Information on the maturation of the ribs was taken only in the form of notes entered on the body of card #2 and will be discussed last.

Since we will be making comparisons with studies from the literature, it is desirable to point out here that the practice varies regarding the concept of when epiphyseal union occurs. Some authors claim that the actual age of union occurs at the age when complete union is actively taking place. For example, Stevenson (1924, p.59) states, "And it is the time at which this significant transition between the major stages of absolute nonunion and complete union respectively takes place that determines the actual age of union of the epiphysis in question." Other authors refer to fusion as the time at which 50 percent or more of their sample show complete union. For instance, Flecker (1942, p.110) in his section on the clavicle, states that, "...the majority of the males aged 19 and 21 years possess epiphyses for the sternal end of the clavicle,..." and on this basis he gives (p.154) the age of fusion for this event as 21.

Even though both procedures may give slightly different age estimates for the same event (as will be seen in Table 20), they are intended to demonstrate time of union as it relates to the general picture of biological maturation rather than to age identification. For age identification it is necessary to know the whole range of occurrence in each age group as well as when the process is in its greatest intensity. For this reason, we will emphasize the total range of maturational activity and define the age of union as that age when all cases are completely united.

CHAPTER I

SUTURE CLOSURE

1. Introduction

Sutures are special serrated and interlocking joints between adjacent bones of the skull. Before the age of 17, these joints are, as a rule, irregular, linear gaps, but later they tend to become obliterated by ossification across the joint lines. Since the progress of suture ossification, or closure, thus is correlated to a certain extent with age, the details of this relationship are of interest here.

Due to the large number of bones that make up the skull (22; 8 paired and 6 un-paired) and hence the equally large number of sutures readily observable (24), observations on suture closure become confusing unless some system of suture classification is used. Most of the emphasis has been on calvarial and facial sutures. For the former we will follow the classification of Todd and Lyon (1924) and for the latter, one of our own devising. In addition, we will differentiate the basilar suture since it is part of the chondrocranium and is usually considered apart from the calvarial and facial sutures.

The result is as follows:

I. Calvarial Sutures

A. Vault sutures
  1. coronal
  * 2. sagittal
  3. lambdoid
  * 4. metopic (when present)

B. Circummeatal sutures (those arranged around the external auditory meatus)
  1. spheno-temporal
  2. squamous
  3. parieto-mastoid
  4. masto-occipital

C. Accessory sutures (those intermediate in their relations to the vault and to the meatus)
  1. spheno-parietal
  2. spheno-frontal

II. Facial Sutures

A. Circumnasal (those arranged around the nasal aperture)
- * 1. internasal
- 2. frontonasal
- * 3. intermaxillary
- 4. frontomaxillary
- 5. nasomaxillary

B. Circummalar (those in which the malar bone participates)
- 1. frontomalar
- 2. temporomalar
- 3. sphenomalar
- 4. maxillomalar

C. Palatal
- * 1. interpalatal
- 2. pterygopalatal
- 3. maxillopalatal
- * 4. intermaxillary (buccal)

*III. Basilar Suture

*Un-paired sutures

Observations of the calvarial sutures are complicated by a further division based on the structural nature of the skull. As housing for the brain, the skull consists of a series of flattened, irregular bones shaped in the form of a hollow sphere and thus presents both outer and inner surfaces. Therefore, each calvarial suture can be viewed from an ectocranial (outside) or an endocranial (inside) aspect. Since endocranial sutures are not visible in the intact skull and can be observed accurately only after the vault has been sectioned, they have received less attention than the ectocranial sutures. The following data were taken from ectocranial observations only.

2. Historical Remarks

As a biological phenomenon, suture closure has been described and discussed since the time of Hippocrates, but as an identification tool, useful for estimating the age of an individual after death, it has a relatively brief history. We do not intend to give a complete historical survey, since Todd and Lyon (1924) and Montague (1938) have published detailed summaries of the subject. According to them, it was not until the middle of the nineteenth century that Gratiolet (1856) first described a sequence of suture closure related to age.

Through the latter half of the nineteenth century and the beginning of the twentieth century many authors contributed to various aspects of the subject. Among the more important names in this period are: Welcker (1862), Pommerol (1869), Sauvage (1870), Ribbe (1885), Topinard (1885), Dwight (1890), Parsons and Box (1905), Frederic (1906), and Zanolli (1908). Their studies included sex and race differences in closure, order and variability of closure, and differentiation between endocranial and ectocranial closure. It is interesting to note that most of these authors concluded that suture closure is extremely irregular and for this reason is of little or no value for age determination.

These early authors worked for the most part, with inadequate samples (Pommerol, for example, referred to only one male skull) and hence their age determinations often were unreliable. In order to correct this deficiency, Todd and Lyon in 1921 started an investigation of the first statistically adequate sample, consisting of 307 male Whites and 120 male Negroes. These crania, which had been documented as to age, sex and race, were from the Western Reserve University collection in Cleveland, Ohio.

For the last thirty years the standards in general use for age identification by suture closure have been those yielded by the investigation of Todd and Lyon. It is therefore desirable to review their work in some detail.

Using Broca's sutural subdivisions and Frederic's scheme for enumerating the amount of closure, Todd and Lyon identified a definite age progression in closure of the vault and circummeatal sutures and illustrated the trend graphically by means of a three-year moving average. They derived dates for the commencement and completion of closure, ectocranially and endocranially, for the individual sutures in both White and Negro males.

In order to give their findings greater clarity, Todd and Lyon tried to eliminate all cases in which suture closure was abnormal. In addition, they felt that since individual differences in closure tended to obscure the age progression, it was necessary to smooth the graphs. They did this in three ways: 1) age intervals of three years were used rather than actual ages; 2) skulls which demonstrated uneven progress in suture closure were eliminated: and 3) skulls were rejected when growth deviations were detected in the postcranial skeleton (Todd relied solely on his earlier analysis of the pubic symphysis for identification of skeletons with growth deviations).

The conclusions of Todd and Lyon have been reviewed by Cobb (1952) and his summary of their data is reproduced in Fig.10.

Endocranial

Suture	Male white C†	Male white T†	Male white Remarks	Male negro C	Male negro T	Male negro Remarks
1. Sagittal	22	35	Slows at 31 at 3.9. Slow to 26	22	31	Slow to 26 complete
2. Spheno-frontal orbital	22	64	Slows at 30 at 3.0. Final burst of act.	30	44	Slow to 26 complete
3. Spheno-frontal temporal	22	65	Same	23	[illegible]	Slow to [illegible] complete
4. Coronal 1 and 2	24	38	Slows at 29 at 3.4	24	38	Slows at 32 at 3.[illegible]
5. Coronal 3	26	41	Slows at 29 at 2.1 rapid to ca. 30	25	44	Slows at 31 at 2.[illegible]
6. Lambdoid 1 and 2	26	43	Slows at 31 at 3.4	23	46	Slows at 30 at 2.[illegible]. Slow to 46
7. Lambdoid 3	26	47	Slows at 30 at 2.2	27	46	Slows at 31 at 2.7
8. Masto-occipital 3	26	72	32–48 at 3.2. Slow progress thereafter	17	30	30 at 3.3. No further progress thereafter
9. Spheno-parietal	29	65	29–46 at 3.0	23	49	Slows at 30 at 2.7
10. Spheno-temporal 2	30	67	Slow at once, 67 at 3.9, grad. progress	40	51	51 at 3.3. Oscillations thereafter
11. Spheno-temporal 1	31	64	31–62 at 2.5, 64 at 2.4. Burst of act. at 6.3	40	41	41 at 1.2, then oscill.
12. Masto-occipital 1 and 2	30	81	32–45 at 1.25, act. bet. 46 & 64, final burst	25	46	46 at 3.5, then oscil.
13. Parieto-mastoid	37	81	Almost inact. till 50, slow thereafter	33	51	51 at 3.6, then oscil.
14. Squamous posterior	37	81	Bursts at 63 & 79, almost inact. till 62	40	49	49 at 1.7, then oscil.
15. Squamous anterior	37	81	Same	40	49	Same

Ectocranial

Suture	Male white C	Male white T	Male white Remarks	Male negro C	Male negro T	Male negro Remarks
1. Sagittal	20	29	3.9 in obelica 2.4 alone 2.9 in gen. Slow to 26	20	32	Slowly to 24–2.9–3.8 in gen., 4.0 in obelica alone
2. Spheno-frontal orbital	28	46	2.3 at 31, 3.8 at 46	21	[illegible]	3.8 at 35, may reach 4.0 at 43
3. Spheno-frontal temporal	28	38	2.1 at 28, may reach 4.0 in old age	25	46	1.9 at 35
4. Coronal 1 and 2	26	29	Bregmatica at 2.3, complicata at 0.0	23	32	Breg. at 2.4, compt. a 1.7
5. Coronal 3	28	50	50 at 3.8, spurious rise at 21	25	35	35 at 2.8, spur rise at 2[illegible]
6. Lambdoid 1 and 2	26	30	Spurious rise at 21. Lambdica 3.3, media 1.9	23	31	Lamb 2.4, media 2.0
7. Lambdoid 3	26	?30	Not more than 1.0	22	?31	Not more than 1.0
8. Masto-occipital 3	26	33	1.4 at 33, may read 4.0 in old age	26	[illegible]	Spurious rise at 21 sec. Act. at 50
9. Spheno-parietal	29	[illegible]	2.0 at 38, 5 at 31, continues to old age	28	46	1.4 at 31
10. Spheno-temporal 2	36	?65	Prob. never closes	50?	0	Prob. never closes
11. Spheno-temporal 1	37	?65	Prob. never closes	50?	0	Prob. never closes
12. Masto-occipital 1 and 2	[illegible]	32	32 at 0.8–1.0, may reach 3.5 in old age	27	31	31 at 2.7, spur. rise ca. 18, sec. act. 50
13. Parieto-mastoid	39	?64	Prob. never closes	50?	0	Prob. never closes
14. Squamous posterior	38	?65	Prob. never closes	50?	0	Prob. never closes
15. Squamous anterior	38	?65	Prob. never closes	50?	0	Prob. never closes

Fig. 10 Summary of the conclusions on ages of cranial suture closure compiled from data of Todd and Lyon. C = commencement, T = termination. (After M. Cobb)

Todd and Lyon were interested primarily in broad biological generalizations and only secondarily in the application of their results to age identification. Forgetting for the moment his junior author, Todd defined the scope of their project as follows (p.326): "I propose to present the facts concerning suture closure and its relation to the racial form and individual contour of the braincase." He concluded (p.380) that, "The real value of this work lies in the light thrown by it upon the nature of suture closure." However, they did attempt to utilize their modal order and dates of suture closure for estimating the actual age of individual skulls and were forced to admit (p.379) that, "... the results in individual cases leave much to be desired ... our work does not justify the uncontrolled use of suture closure in estimation of age." But they added (p. 380) "Our results are of distinct value however when taken in conjunction with indications given by other parts of the skeleton."

Published criticisms of the Todd and Lyon findings are of very recent date. In 1952 Vandervael presented a paper outlining the results of his experience in identifying the ages of American soldiers killed during World War II in the European theater. His sample consisted of 225 individuals between the ages of 18 and 38. Although he does not criticize the standards of Todd and Lyon directly, he implies their limitations for ageing purposes when he states (p. 10), "L'observation des sutures ne nous a été que d'une faible utilité dans le diagnostic de l'âge."

About the same time (1953) Singer published observations on the vault sutures of 100 Cape Coloureds, 190 Bantu, 20 White Germans, 60 North American Indians and 30 Eskimos. He concluded (p. 56) that, "... the age of the individual at death cannot be estimated from the degree of closure of the various cranial sutures, whether taken individually or collectively or whether observed exocranially or endocranially."

Cobb seems to be of much the same opinion, though he has yet to publish his data in detail. As the result of investigating the vault and facial sutures of 2,351 adult skulls of White and American Negro stock (including those used by Todd and Lyon) he stated in an abstract (1955, p. 394) that "... suture closure (both vault and facial) is a variable phenomenon and that age at which each specific suture should be found to have begun and to have completed closure cannot be categorically defined."

The most recent criticism comes from a study by Brooks (1955). Working with a series of 194 male and 177 female California Indian skeletons as well as a "confirming" series of 103 males and 82 females from the Western Reserve collection, she concludes (p. 588) that, "As an age indicator in female skeletons, cranial suture closure is doubtful, in males it should only be utilized as confirmatory to other indicators of adult age."

So much for the critical comments of the findings of Todd and Lyon. Before concluding this review, we want to point out that no detailed study on the closure of the basilar suture has been undertaken. However, references to closure progress appear in most anatomy and some physical anthropology textbooks. The following quotations are probably typical:

> "The basilar portion of the adult skull and the body of the sphenoid bone are united by osseous tissue, but up to the time of puberty they are articulated by the spheno-occipital synchondrosis or fissure." (Sobotta, 1906, p. 45)

> "Between the eighteenth and twenty-fifth years the occipital and sphenoid become united, forming one bone." (Grey's Anatomy, 1930, p. 129)

> "Closure of the basilar suture seems quite regular and bears a rather constant relationship to beginning union of the last three epiphyses of the upper extremity." (Stewart, 1934, p. 451)

> "The basilar part is united to the sphenoid by cartilage which begins to disappear between the eighteenth and twentieth years (earlier in females), and is completely replaced by bone by the twenty-fifth year." (Cunningham's Text-Book of Anatomy, 1937, p.204)

> The sphenoid bone, "... fuses with the basi-occipital before the 25th year." (Grant, p. 622, 1937)

> "Very late, the basioccipital fuses with the basisphenoid." (de Beer, 1937, p. 369)

> "In a normal skull the completion of the pre-adult stage is marked by the closure of the basilar suture." (Hrdlicka, 1939, p. 46) In the 3rd edition, 1947, p. 54, Stewart added to the above sentence the following words: "about 18-19 years of age."

> "Up to the twentieth year the basi-occipital is united to the body of the sphenoid by an intervening piece of cartilage, but about that date ossific union begins and is completed in the course of two or three years." (Morris' Human Anatomy, 1942, p. 127)

"The basi-occipital is united to the basi-sphenoid ... between the age of 20 and 25 years." (Montagu, 1951, p. 489)

"Closure of the basilar suture (basisphenoid with basioccipital) has proved a convenient standard for early adulthood (age 20-21)..." (Cobb, 1952, p. 799)

It is interesting to note the repetition of age 25 in four out of the above ten quotations. Probably this is a reflection of a much earlier statement, credit for which has long ceased to be given. However it is obvious that, as yet, there is no agreement on the age at which the complete closure of the basilar suture occurs.

In view of the above historical survey, there is ample justification for presenting new data based on a well-documented series.

3. Vault sutures

The arrangement and subdivisions of the vault sutures, as treated in the present series, are illustrated in Figure 11 (after Singer, 1953). Though the suture subdivisions of Todd and Singer are actually much alike and are derived ultimately from Broca, we have followed Singer's practice of giving a fourth subdivision to the coronal, namely, the pars stephanica. We had hoped that thereby we might have a better opportunity to test the possible influence of the temporal muscle on suture closure.

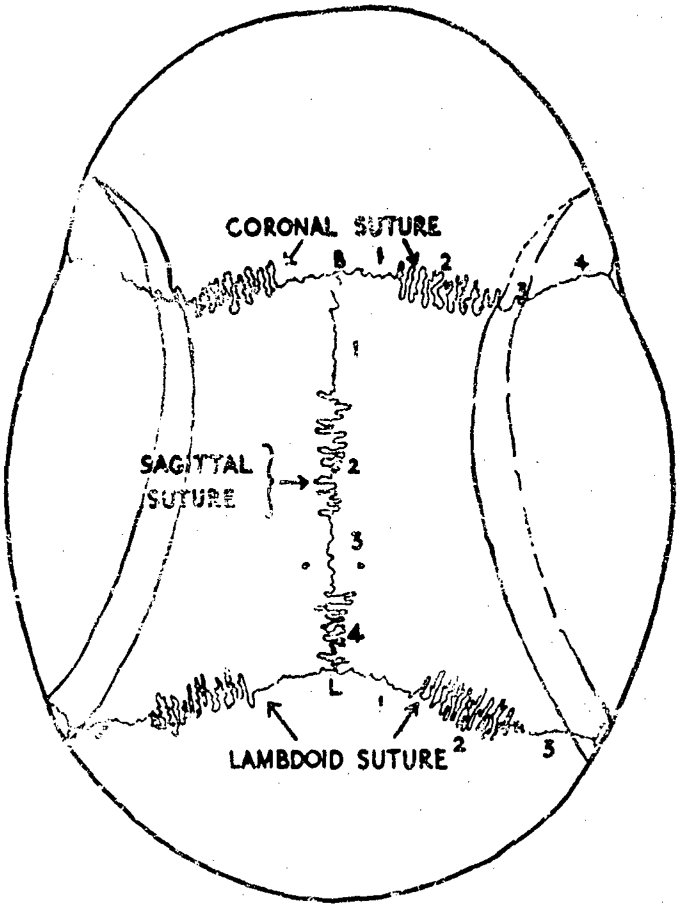
Since suture closure proceeds at varying rates it is usually recorded on a scale of 0 - 4. In other words:

0 = open suture
1 = one-quarter closed
2 = one-half closed
3 = three-quarters closed
4 = completely closed

By this scheme a description of the amount and location of closure in a given suture takes a numerical form. For example, when applied to the closure pattern of the sagittal suture a formula such as 0243 would be translated in the following manner:

pars bregmatica = open
pars verticis = one-half closed
pars obelica = completely closed
pars lambdica = three-quarters closed

Of course, all such appraisals are subjective and individual interpretations may vary slightly among different observers.



B = Bregma.
L = Lambda.

Sagittal: 1 = pars bregmatica.
2 = pars verticis.
3 = pars obelica.
4 = pars lambdica.

Coronal: 1 = pars bregmatica.
2 = pars complicata.
3 = pars stephanica.
4 = pars pterica.

Lambdoid: 1 = pars lambdica.
2 = pars intermedia.
3 = pars asterica.

Fig. 11 Diagrammatic representation of the subdivisions of the cranial vault sutures (after R. Singer).

Time did not permit the recording of both sides of the paired sutures. Usually the left side alone was recorded and when asymmetrical closure was deemed significant, a notation was made. In justification of this procedure we refer to Cobb's detailed study of the cranial sutures (in manuscript) in which he points out that the percentage of suture closure within any one age group for the coronal and lambdoid sutures is practically the same for each side. He feels, therefore, that the pooling of side observations identifies a true progress for total suture closure. Accordingly, we too have pooled the data relating to the two sides.

The gross analysis of the series was begun by arranging the formulae chronologically and plotting them as graphs. As thus viewed, individual differences made an erratic picture in which a trend was scarcely apparent. However, in spite of such irregularities, no cases were eliminated. In other words, since the object of this study is to test the significance of suture closure as a criterion for age determination, we felt obligated to analyze the series as a whole and not merely a refined sample of the series.

In order to present all the data and yet reduce them to a less formidable size, we next grouped together within each age the formulae showing no more than first stage of closure in any part (for example, 0100, 0111, etc.). On the other hand, we combined all those formulae in which the final stage of closure had been reached in one or more parts (for example, 0140, 1344, etc.). All the remaining formulae thus represent an intermediate stage and were combined into a third group. The result, we feel, gives a general picture of the progress of suture closure.

Table 8 shows the extreme variability of suture closure when presented in this manner. However, it is clear that with advancing age the number of skulls with open sutures becomes less while those with advanced closure appear more frequently. But is it possible to place definite dates to the beginning and end of this process? If not, is the observation of any aid to age identification? To establish the age of a given skull from the sutures requires that suture closure have definite and restricted age limits. This is not borne out by the data. For example, in the first age group (17-18), 75 percent show no evidence of closure in the sagittal suture, whereas in the 31-40 age group 10 percent are still open. As taken the other way around, at 17-18 some part of the sagittal suture is already closed in 9 percent of the cases, while at 31-40 this has reached a level of 72 percent. Undoubtedly it is misleading for identification purposes to say that the sagittal suture begins to close at a certain time or is closed at a certain time within these two decades.

The table further shows that the same observations apply to the lambdoid and coronal sutures. Again, on the basis of these data, an individual skull could be assigned any age between 17 and 40 years.

Table 9 shows the locations of beginning closure in the several suture subdivisions and demonstrates in more detail the same erratic progress so apparent in Table 8. In other words, there is no regular increase in the frequency of closure. In the same way, Table 10 shows the locations of the final stage of closure. Again, the irregular pattern does not indicate or support a reliable terminal age of closure within the ages represented.

4. Circummeatal and Accessory Sutures

From tables 11 and 12 which summarize the information on circummeatal and accessory suture closure, it is obvious that the ages at

TABLE 8

A SIMPLIFIED PRESENTATION OF THE STAGES OF SUTURE CLOSURE TO SHOW ITS VARIABILITY: VAULT SUTURES (in %)

		Sagittal				Lambdoid				Coronal			
		Closures*				Closures*				Closures*			
Age	No.	0	1	2,3	4	0	1	2,3	4	0	1	2,3	4
17-18	55	75	4	12	9	92	-	5	3	99	-	-	1
19	52	66	4	10	19	83	5	5	7	84	7	5	4
20	45	54	10	13	23	82	11	3	4	77	17	2	4
21	37	56	9	10	25	72	10	10	8	86	7	2	5
22	24	54	17	5	24	75	17	4	4	72	20	4	4
23	26	42	11	15	32	65	6	23	6	49	34	11	6
24-25	27	34	7	11	48	53	11	18	18	67	12	14	7
26-27	25	12	8	40	40	32	28	16	24	28	16	24	32
28-30	29	18	12	19	51	27	17	35	21	26	25	25	24
31-40	43	10	4	14	72	24	17	20	39	20	20	35	25
41-50	6	2	16	66	16	1	66	-	33	50	33	-	16
Total	369												

* 0: No closure anywhere
1: No more than stage 1 anywhere
2,3: No more than stages 2 or 3
4: Stage 4 in some part

TABLE 9

LOCATIONS OF BEGINNING CLOSURE IN VAULT SUTURES
(in %)

		Sagittal				Lambdoid			Coronal			
Age	No.	Pars breg.	Pars vert.	Pars obel.	Pars lamb.	Pars lamb.	Pars inter.	Pars aster.	Pars breg.	Pars comp.	Pars steph.	Pars pter.
17-18	55	-	4	8	-	4	1	2	4	2	-	2
19	52	11	15	11	6	6	4	4	8	6	4	1
20	45	9	22	15	24	9	11	7	2	13	9	2
21	37	10	16	5	19	16	10	8	2	8	2	2
22	24	20	20	16	25	12	20	4	20	16	8	8
23	26	7	19	11	23	11	11	7	19	19	23	34
24-25	27	26	19	30	26	26	26	26	15	14	19	22
26-27	25	29	1	1	23	3	1	2	3	3	1	37
28-30	29	9	12	9	25	12	29	9	16	29	12	16
31-40	43	11	18	13	17	28	11	18	28	28	18	17
41-50	6	16	16	16	33	50	50	16	33	33	-	16
Total	369											

TABLE 10

LOCATIONS OF FINAL STAGE OF CLOSURE IN VAULT SUTURES (in %)

		Sagittal				Lambdoid			Coronal			
		Parts compl. closed:				Parts compl. closed:			Parts compl. closed:			
Age	No.	1	2	3	4	1	2	3	1	2	3	4
17-18	55	5	-	4	1	-	2	-	-	-	1	-
19	52	7	3	7	2	-	7	-	3	1	-	-
20	45	11	2	4	6	2	2	-	2	-	2	-
21	37	8	2	10	5	-	8	-	5	-	-	-
22	24	8	8	4	4	-	4	-	-	-	4	-
23	26	3	11	7	11	3	-	3	3	-	-	3
23-25	27	15	34	7	16	15	5	5	7	-	-	-
26-27	25	4	8	4	1	8	16	4	12	8	-	8
28-30	29	22	-	9	16	6	16	-	22	-	-	3
31-40	43	26	13	11	26	13	17	2	17	11	-	7
41-50	6	16	36	-	-	33	-	-	33	-	-	-
Total	369											

TABLE 11

A SIMPLIFIED PRESENTATION OF THE STAGES OF SUTURE CLOSURE TO SHOW ITS VARIABILITY: CIRCUMMEATAL SUTURES (in %)

		Spheno-temporal Closures*				Parieto-mastoid Closures*				Masto-occipital Closures*				Squamous Suture Closures*			
Age	No.	0	1	2,3	4	0	1	2,3	4	0	1	2,3	4	0	1	2,3	4
17-18	55	98	2	-	-	100	-	-	-	96	3	-	1	100	-	-	-
19	52	97	3	-	-	100	-	-	-	98	2	-	-	98	2	-	-
20	45	92	4	2	2	98	2	-	-	92	2	2	4	100	-	-	-
21	37	94	2	2	2	100	-	-	-	87	8	-	5	97	3	-	-
22	24	100	-	-	-	96	4	-	-	96	4	-	-	100	-	-	-
23	26	77	23	-	-	100	-	-	-	77	19	-	4	100	-	-	-
24-25	27	97	3	-	-	90	7	-	3	86	11	3	-	96	4	-	-
26-27	25	84	12	4	-	93	-	-	7	76	4	8	12	96	2	2	-
28-30	29	82	9	6	3	100	-	-	-	72	22	-	6	100	-	-	-
31-40	43	69	18	9	4	91	9	-	-	73	9	11	7	94	4	2	-
41-50	6	84	16	-	-	100	-	-	-	50	50	-	-	100	-	-	-
Total	369																

* 0: No closure anywhere
1: No more than stage 1 anywhere
2,3: No more than stages 2 or 3
4: Stage 4 in some part

which advanced closure takes place are not represented. Although there seems to be some evidence that in the accessory sutures active and advanced closure becomes more pronounced in the late twenties, the general pattern of closure progress for both groups of sutures is quite irregular and hence, age limits for beginning as well as completion of suture closure cannot be defined.

TABLE 12

A SIMPLIFIED PRESENTATION OF THE STAGES OF SUTURE CLOSURE TO SHOW ITS VARIABILITY: ACCESSORY SUTURES (in %)

		Spheno-frontal				Spheno-parietal			
		Closures*				Closures*			
Age	No.	0	1	2,3	4	0	1	2,3	4
17-18	55	98	2	-	-	100	-	-	-
19	52	98	2	-	-	98	2	-	-
20	45	98	-	2	-	100	-	-	-
21	37	94	2	2	2	98	-	2	-
22	24	100	-	-	-	100	-	-	-
23	26	92	4		4	96	-	-	4
24-25	27	94	3	-	3	97	-	-	3
26-27	25	68	8	16	8	72	16	4	8
28-30	29	76	6	9	9	82	3	3	12
31-40	43	45	23	7	25	51	17	9	23
41-50	6	34	33	-	33	68	16	-	16
Total	369								

*See footnote Table 11

5. Facial sutures

No provision was made for detailed recording of all the facial sutures of the present series. Nevertheless, observations were recorded for three circumnasal and two circummalar sutures and such restricted observations will at least show the amount of utility of these sutures for age estimation. In Tables 13 and 14 the percentages of cases showing stages of closure by age groups are presented.

TABLE 13

A SIMPLIFIED PRESENTATION OF THE STAGES OF SUTURE CLOSURE TO SHOW ITS VARIABILITY: CIRCUMNASAL SUTURES (in %)

		Intermaxillary				Internasal				Nasomaxillary			
		Parts compl. closed:				Parts compl. closed:				Parts compl. closed:			
Age	No.	1	2	3	4	1	2	3	4	1	2	3	4
17-18	55	97	3	-	-	97	3	-	-	98	2	-	-
19	52	96	3	1	-	87	5	3	5	90	5	2	3
20	45	95	1	-	4	84	4	4	8	93	-	1	6
21	37	84	8	-	8	69	10	-	21	87	5	-	8
22	24	83	-	-	17	75	-	-	25	80	4	4	12
23	26	89	8	-	3	78	11	-	11	89	8	-	3
24-25	27	59	19	19	3	56	3	26	15	72	3	22	3
26-27	25	48	8	32	12	40	12	32	16	40	8	40	12
28-30	29	28	22	41	9	34	19	33	9	31	22	38	9
31-40	43	16	34	46	4	16	34	46	4	16	34	46	4
41-50	6	17	33	50	-	17	33	50	-	17	33	50	-
Total	369												

Closure progress seems to be more regular than that seen in the calvarial sutures and active closure begins, in all facial sutures, in the middle twenties. However, as was demonstrated in the foregoing paragraphs, a reliable trend that could be translated into a workable method for age determination, is absent.

TABLE 14.

A SIMPLIFIED PRESENTATION OF THE STAGES OF SUTURE CLOSURE TO SHOW ITS VARIABILITY: CIRCUMMALAR SUTURES (in %)

		Temporomalar				Maxillomalar			
		Closures*				Closures*			
Age	No.	0	1	2,3	4	0	1	2,3	4
17-18	55	100	-	-	-	100	-	-	-
19	52	99	1	-	-	99	1	-	-
20	45	98	-	2	-	98	-	2	-
21	37	92	-	-	8	90	2	-	8
22	24	92	-	-	8	88	4	-	8
23	26	92	4	-	4	88	4	-	8
24-25	27	89	-	7	4	78	4	11	7
26-27	25	48	12	32	8	44	8	32	16
28-30	29	40	16	38	6	34	16	41	9
31-40	43	15	35	46	4	15	35	46	4
41-50	6	17	33	50	-	17	33	50	-
Total	369								

*See footnote Table 11

6. Basilar suture

Because of the paucity of individuals representing the earlier ages (prior to 17 years of age), the present series lacks the cases that would show the commencing stages of closure in the basilar suture and thus includes mainly the terminal stages. Table 15 gives the percentage of skulls showing stages of closure for each age group and demonstrates active closure up to and including the age of 18 years. In the following age groups (19-20) activity practically ceases and by 21 years the basilar suture is closed.

TABLE 15

THE AGE DISTRIBUTION OF STAGES OF CLOSURE
IN THE BASILAR SUTURE
(in %)

Age	No.	Closure* 0	1	2	3	4
17-18	55	3	2	7	10	78
19	52	-	-	-	3	97
20	45	-	-	-	2	98
21	37	-	-	-	-	100
22	24	-	-	-	-	100

*See footnote Table 11

7. Total pattern of suture closure

For further information on the nature of the relationship between age and suture closure, a regression equation was formulated for all cranial suture closure from 17 to 39 years of age. However, in order to use the recorded observations, a slight change in the scoring scale was made. The standard scale of 0 - 4 was changed to 1 - 5. Also, each of the 11 sutures was treated as a single entity rather than a number of divisions. Thus, using the new 1 - 5 scale, each suture was rescored on the basis of its combined activity. For example, if the original score for a given sagittal suture was 4430 (reading from bregmatica to lambdica) the substituted combined score would be 3, i. e., about one half closed. Then, by adding the scores for the 11 sutures in any individual skull, a single score was given for all individuals in the series. Table 16 summarizes the information resulting from this procedure when applied to the Army series.

On the assumption that a few sutures might produce the same results as all sutures treated together, the method described above was applied to the three main sutures of the vault, coronal, sagittal and lambdoid. However, an r value of .39 showed that there was less correlation between these three sutures and age than between all sutures and age (which showed an r value of .49).

TABLE 16

TOTAL SUTURE SCORE FOR AGES 17-39 SHOWING AGE RANGE, MEAN AGE, AND PREDICTED AGE BASED ON THE REGRESSION OF SUTURE CLOSURE AND AGE.

Score	Age Range	Mean Age	Predicted Age From Regression
15	17 - 38	22.5	20.2
16	18 - 25	22.3	20.6
17	18 - 36	25.5	21.2
18	17 - 23	19.5	21.7
19	17 - 37	21.4	22.2
20	18 - 38	24.7	22.7
21	18 - 34	23.5	23.2
22	17 - 34	23.7	23.7
23	19 - 39	26.6	24.2
24	18 - 31	23.7	24.7
25	18 - 36	23.5	25.2
26	19 - 39	28.3	25.7
27	21 - 27	24.2	26.2
28	17 - 39	28.2	26.7
29	20 - 32	26.5	27.2
30	30 - 33	31.5	27.7
31	20 - 33	26.0	28.2
32	30 - 35	32.5	28.7
33	31 - 33	32.5	29.2
34	26 - 38	32.5	29.7

N = 356
Scores:
Mean: 21.71
S.D.: 5.00
Age:
Mean: 23.58
S.D.: 5.12
r = .4910
Predicted age: .5026 Scores + 12.6655
Standard error of estimate = 4.4614

From Table 16 the following conclusions can be drawn:

1. On the whole, suture closure in the present series seems to progress in a fairly uniform manner.

2. The sutures and their patterns of closure are related to each other but not enough to be reliably applied in cases of individual age determination. If other ageing areas of the skeleton are absent, then crude estimates can be made in terms of decades only.

3. Age estimates based on overall suture closure are more accurate than those based on the combination of coronal, sagittal and lambdoid closure alone.

8. Summary

The foregoing analysis of suture closure illustrates the fact that progress of closure has only a very general relationship with age. So erratic is the onset and progress of closure that an adequate series will provide just about any pattern at any age level. Thus, as a guide for age determination, such a trend is of little use. In other words, suture closure, as either direct or supportive evidence for skeletal age identification, is generally unreliable.

An exception is the basilar suture which is completely closed at the age of 20 years. It has been known that this suture closes rapidly and completely but no evidence has been presented heretofore on the terminal date.

CHAPTER II

ERUPTION OF THE THIRD MOLARS

It is generally recognized that the eruption pattern of the third molars is extremely irregular. Yet, partly because of this irregularity and partly because of the late date of eruption, little specific information is available. Most of the studies on the time of eruption of the permanent teeth in the American population have been based on groups of school children, extending upwards in age to around 20 years (Cf.Bean, 1914, 1917; Cohen, 1928; Hurme, 1948; Suk, 1920). Since the full picture of third molar eruption is not yielded by groups with this upper age limit, the third molar usually has been excluded from such studies.

This situation is reflected in many textbooks where the eruption of the third molars is stated as a time interval rather than a mean age. For example:

Textbook	Age of eruption for third molars.
Cunningham's Text-Book of Anatomy	17 - 21
Grey's Anatomy	17 - 25
Hrdlicka's Practical Anthropometry	18+

On the other hand, although Steggerda and Hill (1942) likewise give an interval of 17 - 21 years, they state that this represents the period in which the greatest intensity of eruption occurs and does not include the upper time limit. Actually, it is not clear that their sample included individuals over 21 years of age. Obviously, such data are of limited use in cases of individual identification.

Besides erupting late and slowly, the third molars often do not erupt normally. This is especially true in the lower jaw where, because of an evolutionary reduction in length, the third molars may be forced out of normal alinement. A frequent result is that the lower third molars abut against the second molars, a condition known as impaction. In other cases the third molars, both upper and lower, may fail to erupt or even fail to form (congenital absence). In such cases during life, gross inspection may not reveal the presence of some or all of the third molars and hence they may be reported as absent when in fact they are only hidden.

Despite these irregularities, the fact that the eruption of the third molars is one of the last maturational events, makes it a possible supplementary age indicator. For efficient use however, we must know not only the true range of eruption time in the American population but just when and how often the third molars appear in an eruptional stage that is meaningful for ageing purposes.

When present, a third molar may be in one of 4 positions: 1) still unerupted; 2) erupting; 3) impacted, and 4) normally erupted. When not present, a third molar may not have formed or may have been extracted antemortem. No attempt was made in the present study to identify the cause of the absence. The frequency of these 5 categories is given in Table 17. Here, we are particularly interested in the unerupted and partially erupted teeth, because they alone indicate immaturity. At 17 - 18 years, 55 - 58 percent of the upper third molars and 32 - 36 percent of the lowers are in these stages. These figures are reduced by nearly half (to 33 - 35 and 18 - 20 percent respectively) by age 19. After the age of 22, eruption has terminated except in a few cases which linger until 35 years.

The difference in eruptional incidence between upper and lower jaws is accounted for by impacted third molars occurring frequently in the lower jaw between the ages of 17 and 21 years. Due perhaps to natural loss of teeth and extractions, few cases of impactions were seen after the age of 21.

The significance of these data is twofold: 1) although the main eruptional period for the third molars is 17 - 22 years, at the peak of eruption (17 - 18 years) only a little over half of the uppers and a third of the lowers give a clue to age; and 2) although, for practical purposes, eruption ceases at 22 years, a few cases may be found in unerupted and erupting stages as late as 35 years. These data bear out our earlier statement that the third molars, particularly in the White race, are merely supplementary age indicators.

TABLE 17

THE STATUS OF THE THIRD MOLARS BY AGE GROUPS
(in %)

		Unerupted				Partially erupted				Impacted				Normally erupted				Absent			
		Upper		Lower		Upper		Lower		Upper		Lower		Upper		Lower		Upper		Lower	
Age		R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
17-18	55	18	20	18	13	40	35	18	14	-	-	18	22	20	19	28	21	22	26	18	25
19	52	6	2	4	-	29	31	16	18	-	-	12	16	40	42	38	37	25	25	30	29
20	45	5	7	5	6	24	20	5	8	-	-	14	15	54	50	54	47	17	23	22	24
21	39	3	-	-	6	8	13	13	11	6	3	11	11	39	58	46	34	44	26	30	38
22	25	-	-	-	-	8	16	8	8	-	-	4	-	52	52	56	48	40	32	32	44
23	27	4	-	-	-	-	-	-	4	-	-	-	4	59	70	67	66	37	30	33	26
24-25	28	4	4	4	4	7	7	7	10	10	-	14	-	27	40	32	43	52	49	43	43
26-27	25	4	-	-	-	4	8	-	-	-	-	4	4	32	36	44	44	60	56	52	52
28-30	29	4	-	-	4	4	7	4	11	-	-	4	-	55	55	56	44	37	38	36	41
31-40	43	2	2	-	2	2	7	2	-	5	-	5	5	45	44	40	45	46	47	53	48
41-50	6	-	-	-	-	-	-	-	-	-	-	-	-	33	17	33	17	67	83	67	83
Total	375																				

CHAPTER III

EXTREMITIES

1. Introduction

The three major bones making up each of the four extremities are called the "long bones." Each long bone is made up of a diaphysis (shaft) with one or more epiphyses at either end. Thus, the long bones grow in two dimensions; in girth and in length (by means of the epiphysis). Growth ceases when the epiphysis joins or fuses with the diaphysis.

Although the long bones of the present series presented 15 observable epiphyses, considerations of space on the data card set a limit on the number that could be recorded in detail. Thus, only those epiphyses with the longest period of activity in the military age range were placed on the card. The status of all other epiphyses was recorded in the form of notes supplemented by photographs. This procedure resulted in a division of the epiphyses into two groups as follows:

Group I. (Epiphyses showing early union)
- Upper extremity
  - Elbow joint:
    - Distal epiphysis of humerus
    - Medial epicondyle of humerus
    - Proximal end of radius
    - Proximal end of ulna
- Lower extremity
  - Hip joint:
    - Head of femur
    - Greater trochanter of femur
    - Lesser trochanter of femur
  - Ankle joint:
    - Distal end of tibia
    - Distal end of fibula

Group II. (Epiphyses showing delayed union)
- Upper extremity
  - Shoulder joint:
    - Proximal end of humerus
  - Wrist joint:
    - Distal end of radius
    - Distal end of ulna

Lower extremity
Knee joint:
Distal end of femur
Proximal end of tibia
Proximal end of fibula

In the 17 to 20 year age groups, 14 percent of cases show unattached epiphyses of the upper and lower extremities. Table 18 shows the distribution of such epiphyses as subdivided into Groups I and II. From this it appears that 20 years is the upper age limit where an observer can expect to find unattached epiphyses of the long bones. Also, the small representation of unattached epiphyses in Group I indicates that this group is the first to mature, thus substantiating the utility of the division.

TABLE 18

THE AGE DISTRIBUTION OF UNATTACHED LONG BONE EPIPHYSES IN THE PRESENT SERIES. (in %)

Epiphyses	Age 17	18	19	20	21
Group I.					
Greater trochanter	-	2	-	-	-
Distal fibula	10	-	-	-	-
Group II.					
Proximal humerus	30	13	5	-	-
Distal radius	50	18	7	4	-
Distal ulna	50	24	7	4	-
Proximal tibia	10	7	2	-	-
Proximal fibula	40	11	4	-	-

2. Historical remarks

The age order of epiphyseal union for the bones of the extremities has long been of interest to anatomists. However, despite a seeming wealth of knowledge, it is extremely difficult to find agreement on ages of epiphyseal union. In a table entitled, "Ages assigned by various authorities for union of epiphyses," Stevenson (1924, p.54) pointed out this lack of agreement among 11 authors and went on to demonstrate the results of his work on 110 skeletons from the Western Reserve collection.

For the purpose of comparing observations made directly on bones, Stevenson's findings are generally considered the standard authority.

More recently, studies giving the age order of epiphyseal union have come from the analysis of roentgenographs (for example, Paterson, 1929 and Flecker, 1942). However, a disparity in results still remains, as is shown in Table 19 where the findings of these authors are compared with those of Stevenson. Actually, the differences shown in Table 19 are not as great as was demonstrated by Stevenson, although a difference of 5 years appears in the case of the medial epicondyle of the humerus. This variability in the stated times of epiphyseal union has made age estimation a difficult if not confusing process.

TABLE 19

AGES ASSIGNED BY THREE AUTHORS FOR UNION OF THE LONG BONE EPIPHYSES.

Epiphyses	Stevenson ('24)	Paterson ('29)	Flecker ('42)
Group I.			
Upper extremity:			
Med. epicond. of humerus	16	18-21	16
Prox. radius	18	18-19	16
Prox. ulna	16-17	19	16
Lower extremity:			
Head of femur	18	18	17
Gtr. troch. of femur	18	18	16
Lsr. troch. of femur	18	18	17
Dist. tibia	18	18	17
Dist. fibula	18	18	17
Group II.			
Upper extremity:			
Prox. humerus	20	21	18
Dist. radius	19	21	19
Dist. ulna	19	21	19
Lower Extremity:			
Dist. femur	19	18	19
Prox. tibia	19	19	18
Prox. fibula	19	18	19

A suggestion of the pattern shown in Table 18 is also seen here in Table 19. It can be calculated from the latter that the average age of union for Group I is 17.5 years while that for Group II is 19.0 years.

3. Upper extremities

Observations on the epiphyses of the long bones are summarized in Tables 20 and 21.

TABLE 20

THE AGE DISTRIBUTION OF COMPLETE UNION FOR THE LONG BONE EPIPHYSES OF GROUP I. (in %)

		Upper Extremity			Lower Extremity				
		Humerus:			Femur:				
Age	No.	med. epicond.	Radius: prox.	Ulna: prox.	head	gtr. troch.	lsr. troch.	Tibia: dist.	Fibula: dist.
17-18	55	86	93	90	88	88	88	89	89
19	52	96	100	100	96	98	98	98	94
20	45	100			100	100	100	100	100
Total	152								

The Humerus:

At 17 and 18 years of age, the distal epiphysis is completely united in all cases. On the other hand, the epiphyses for the medial epicondyle and the head of the humerus are incompletely united in 14 and about 79 percent of cases respectively. The former reaches complete union in all cases by the end of the 19th year and the latter in the 24th year.

The epiphysis for the medial epicondyle unites from below upward, thus leaving a small notch at the superior end as the last site of union (Fig. 12). The last site of union for the proximal end appears as a slight groove, postero-laterally (Fig. 13).

TABLE 21

THE AGE DISTRIBUTION FOR STAGES OF UNION FOR
THE LONG BONE EPIPHYSES OF GROUP II.
(in %)

Upper Extremity

Age	No.	Humerus (prox.) Stages 0	1	2	3	4	Radius (dist.) Stages 0	1	2	3	4	Ulna (dist.) Stages 0	1	2	3	4
17-18	55	14	5	25	35	21	22	3	14	32	29	29	1	11	24	35
19	52	5	2	10	58	25	7	-	5	48	40	7	-	5	32	56
20	45	2	2	4	40	52	4	-	2	24	70	4	2	-	24	70
21	37			2	27	71				19	81				10	90
22	24				12	88				12	88				8	92
23	26				4	96					100					100
24+	136					100										

Total 375

Lower Extremity

Age	No.	Femur (dist.) Stages 0	1	2	3	4	Tibia (prox.) Stages 0	1	2	3	4	Fibula (prox.) Stages 0	1	2	3	4
17-18	55	16	2	3	18	61	2	2	7	23	66	14	-	3	12	71
19	52	4	-	1	9	86	1	-	1	17	81	4	-	6	4	86
20	45			2	9	89				13	87			2	-	98
21	37				8	92				5	95				5	95
22	24					100				4	96					100
23	26										100					
24+	136															

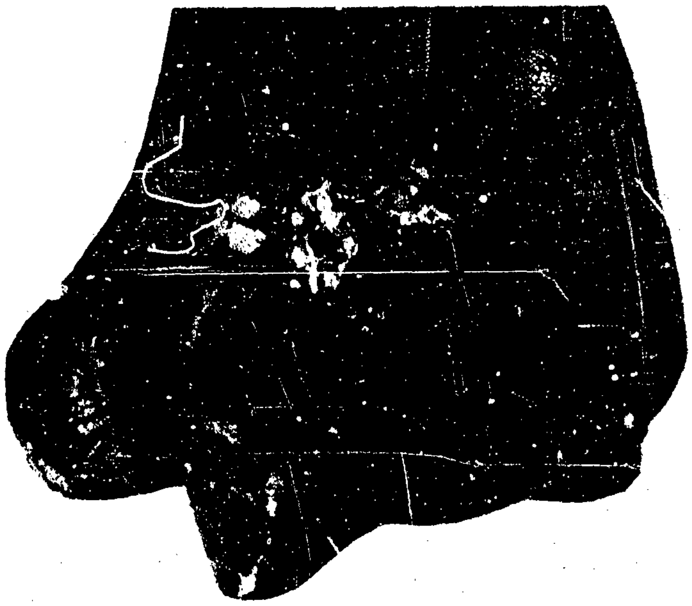


Fig. 12 Distal end of right humerus showing the epiphysis of the medial epicondyle in stage 2 of union. Note that union has begun inferiorly. (No. 44, 18 years).

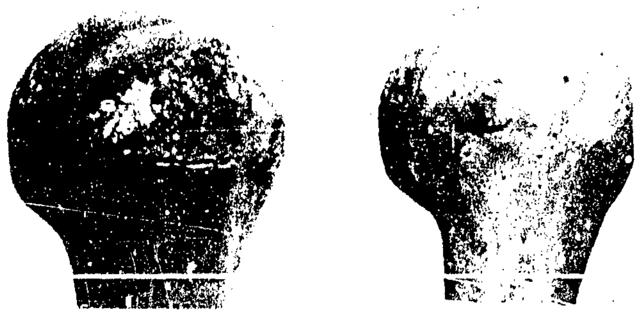


Fig. 13 Proximal end of right humeri showing late stages of union.
Left: Early stage 3 of union. (No. 97, 20 years).
Right: Late stage 3 of union. (No. 174, 20 years).

The Radius and Ulna:

The epiphyses of the radius and ulna can be conveniently treated together since they unite in pairs simultaneously. When first seen in our series, the proximal ends of the radius and ulna are in a late stage of fusion (Fig. 14). Both epiphyses are united in all cases by the 19th year. Early stages of union for the distal epiphyses occur from 17 - 20 years. Thereafter, all cases are either fused or in the last stages of closure. By 23 years, both distal epiphyses are completely united in all cases.

Last traces of the epiphyseal lines are usually located, for the distal ulna, at the base of the styloid process, postero-medially (Fig. 15) and for the distal radius, antero-laterally (Fig. 16).

Fig. 14 Proximal end of right radius (left) and ulna (right) showing recent signs of union. (No. 44, 18 years).

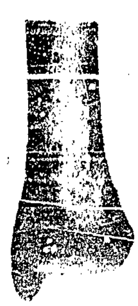


Fig. 15 Distal end of left ulna (posterior) showing stage 4 of union. (No. 99, 17 years).

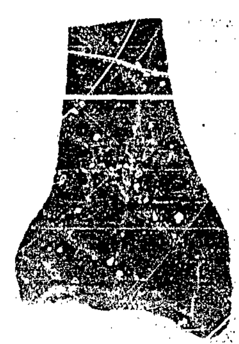


Fig. 16 Distal end of left radius (anterior) showing stage 4 of union. (No. 250, 22 years).

4. <u>Lower extremities</u>

<u>The Femur:</u>

As seen in Table 20, the epiphyses for the head, and greater and lesser trochanters are in the last stages of union for most of the cases (more than 80 percent). Cases of non-union linger on until the end of the 19th year and by 20 the epiphyses for the proximal end of the femur are united in all cases. From Table 22 we find that the last of the femural epiphyses to fuse is at the distal extremity where ossification is still in early stages as late as 20 years and does not become complete for all cases until the 22nd year.

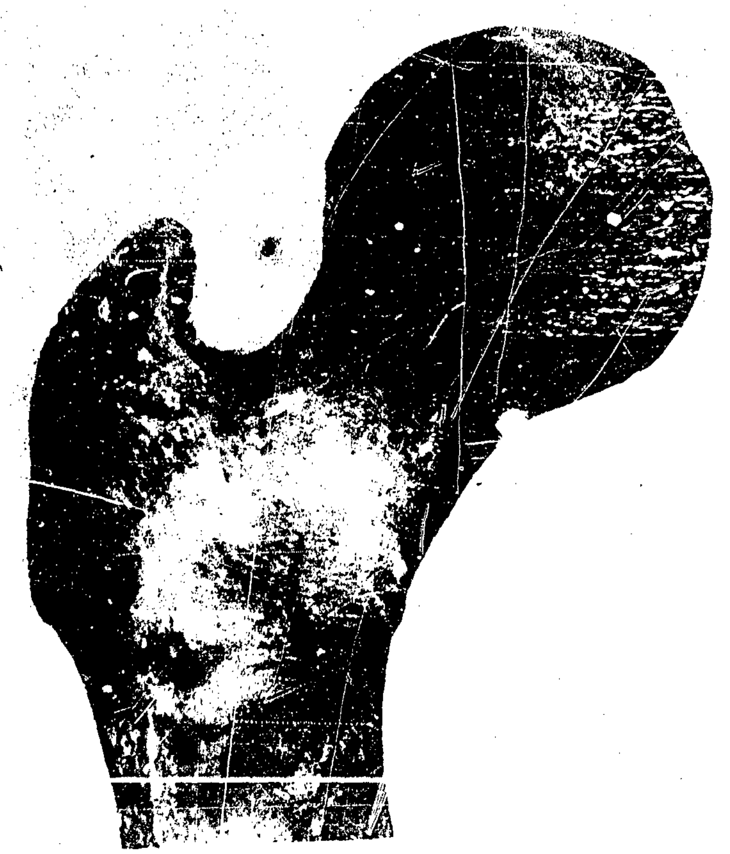


Fig. 17 Proximal end of the left femur showing the epiphyses for the head in stage 3 of union, while those for the greater and lesser trochanters are in stage 2 of union. (No. 72, 18 years.) Note that union begins for the head, antero-laterally; for the greater trochanter, antero-medially; and for the lesser trochanter, superiorly.

At the proximal end of the femur, the last sites of union for the three epiphyses are as follows: 1) head, postero-medially; 2) greater trochanter, postero-medially; and 3) lesser trochanter, inferior margin (Fig. 17). At the distal end, on the postero-medial side (just above the medial condyle), a fissure locates the last site of union (Fig. 18).

Fig. 18 Distal end of left and right femur showing stage 3 of union. (No. 319, 19 years).

The Tibia:

Early stages of fusion were found in the distal epiphysis through the 19th year and complete union for all cases occurs by the 20th year. At the proximal extremity, a few cases show early stages of union in the 17-19 year age groups. Thereafter, progress for completed union is slow and does not occur for all cases until the 23rd year.

Last traces of union at the distal end occur antero-laterally (unfortunately, we are unable to illustrate this feature from our photographs). At the proximal end, the last site of union is found postero-medially (Fig. 19). However, a well-marked groove may persist at this site of last union long after complete fusion has occurred (Fig. 20). Evidence of this groove has been found in tibias as old as 37 years.

Fig. 19 Proximal end of right and left tibia showing stage 3 of union. (No. 153, 20 years).

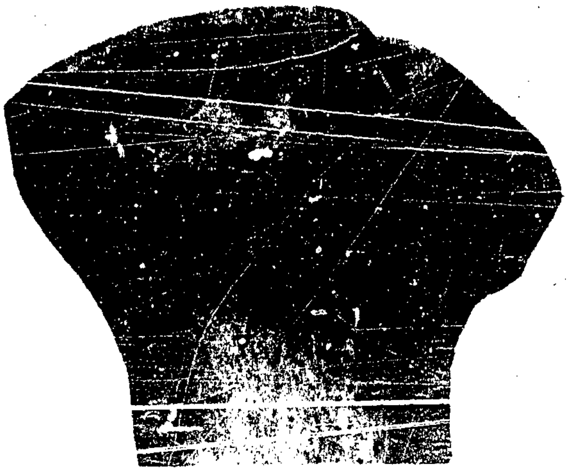


Fig. 20 Proximal end of right tibia showing persistant groove at site of union. (No. 21, 24 years).

The Fibula:

The pattern of maturation for the distal epiphysis of the fibula corresponds with that of the tibia: early stages of union through the 19th year and complete union for all cases by the age of 20. The proximal epiphysis shows early stages of fusion as late as the 20th year and complete union for all cases does not occur until the 22nd year.

The last site of union at the distal end is located medially (Fig. 21); at the proximal end, antero-laterally (Fig. 22).

Fig. 21 Distal end of fibula (left medial and right lateral views) showing- ing stage 2 of union. (No. 2, 19 years).

Fig. 22 Proximal end of right fibula showing stage 3 of union. (No. 89, 18 years).

5. Summary

At 17 and 18 years of age, the epiphyses of Group I are in late stages of union, whereas those of Group II demonstrate early stages of union throughout the late teens and early twenties. For purposes of easier comparison, our findings may be summarized as follows:

Joint	Age of complete union
Group I	
Ankle	20
Hip	20
Elbow	20
Group II	
Knee	23
Wrist	23
Shoulder	24

It will be noted that the general trend is for our ages of union to be slightly later than those shown in Table 19. As we pointed out in Para. 2, the concept of when union occurs is not universally constant. Thus, on the basis of varying definitions of union, differing results are to be expected. In this regard, Stevenson claims that the epiphysis at the distal extremity of the radius unites at age 19, yet his graph (p. 63) shows cases of non-union for the distal radius in the 21-year age group. Our figures show that complete union occurs in only 40 percent of cases at 19 years and that 100 percent of completed union is not reached until 23 years. Flecker (1942, p. 155) agrees with Stevenson's age of union, but his sample includes cases of non-union as late as 23 years (p. 121). In other words, whereas our ages refer to the age at which all cases are united, the above authors have selected from their frequencies of occurrence some kind of average age. We feel that as a practical tool for age identification, ages other than the end age of union can be misleading and hence our emphasis on the total range of occurrence.

CHAPTER IV

THE INNOMINATE BONE

1. Introduction

The innominate or hip bone, when mature, is one of a pair of large irregularly shaped bones which, with the sacrum, make up the pelvis. Before maturity, each innominate is seen to be composed of three main parts (ilium, ischium and pubis) and several epiphyses. At 17 years of age, the three main elements of the innominate are almost completely united and three epiphyses are ununited: iliac crest, ischial tuberosity and ramus. Also, the symphyseal face of the pubis is undergoing metamorphosis.

In this chapter we shall follow the maturation of these three epiphyses and in addition, since the union of the epiphysis at the symphyseal end of the pubis is only a phase of the metamorphosis of the surface, we shall follow symphyseal changes as a whole throughout our series.

2. Historical Remarks

Morphological changes in the innominate bone and their relationship in general to skeletal age have long been recognized. Hunter in 1761, Aeby in 1858, Henle in 1872 and Cleland in 1889, to cite only a few authors, described gross changes in the hip bone taking place during the life of an individual (see Todd's historical summary, 1920, p. 292). Although most of these authors concentrated their attention upon the pubic symphysis, neglecting the epiphyseal areas of the rest of the bone, they failed to relate specific bone changes to age.

The final step was made when Todd (1920) developed a system of symphyseal phases and Stevenson (1924) made a general survey of epiphyseal union. Both studies could be applied to problems of age identification and are still generally considered as the main authorities. For this reason, a brief review of the methods used in and the conclusions resulting from these studies is in order.

Todd's observations on the documented skeletons at Western Reserve U. showed that the symphyseal face of the pubic bone undergoes a regular metamorphosis from puberty onward. In order to represent this transformation he identified a succession of 10 phases involving such bony features as a ridge and furrow pattern, a dorsal margin, a ventral bevel, a ventral rampart, lower and upper extremities, and a rim.

To illustrate each of these phases he selected typical specimens of known age (Fig. 23). The phases, as thus typified, he described as follows (Todd, 1920, p. 313):

Phase 1: Age 18-19. Typical adolescent ridge and furrow formation with no sign of margins and no ventral beveling.

Phase 2: Age 20-21. Foreshadowing of ventral beveling with slight indication of dorsal margin.

Phase 3: Age 22-24. Progressive obliteration of ridge and furrow system with increasing definition of dorsal margin and commencement of ventral rarefaction (beveling).

Phase 4: Age 25-26. Completion of definite dorsal margin, rapid increase of ventral rarefaction and commencing delimitation of lower extremity.

Phase 5: Age 27-30. Commencing formation of upper extremity with increasing definition of lower extremity and possible sporadic attempts at formation of ventral rampart.

Phase 6: Age 30-35. Development and practical completion of ventral rampart with increasing definition of extremities.

Phase 7: Age 35-39. Changes in symphyseal face and ventral aspect of pubis consequent upon diminishing activity, accompanied by bony outgrowths into pelvic attachments of tendons and ligaments.

Phase 8: Age 39-44. Smoothness and inactivity of symphyseal face and ventral aspect of pubis. Oval outline and extremities clearly defined but no "rim" formation or lipping.

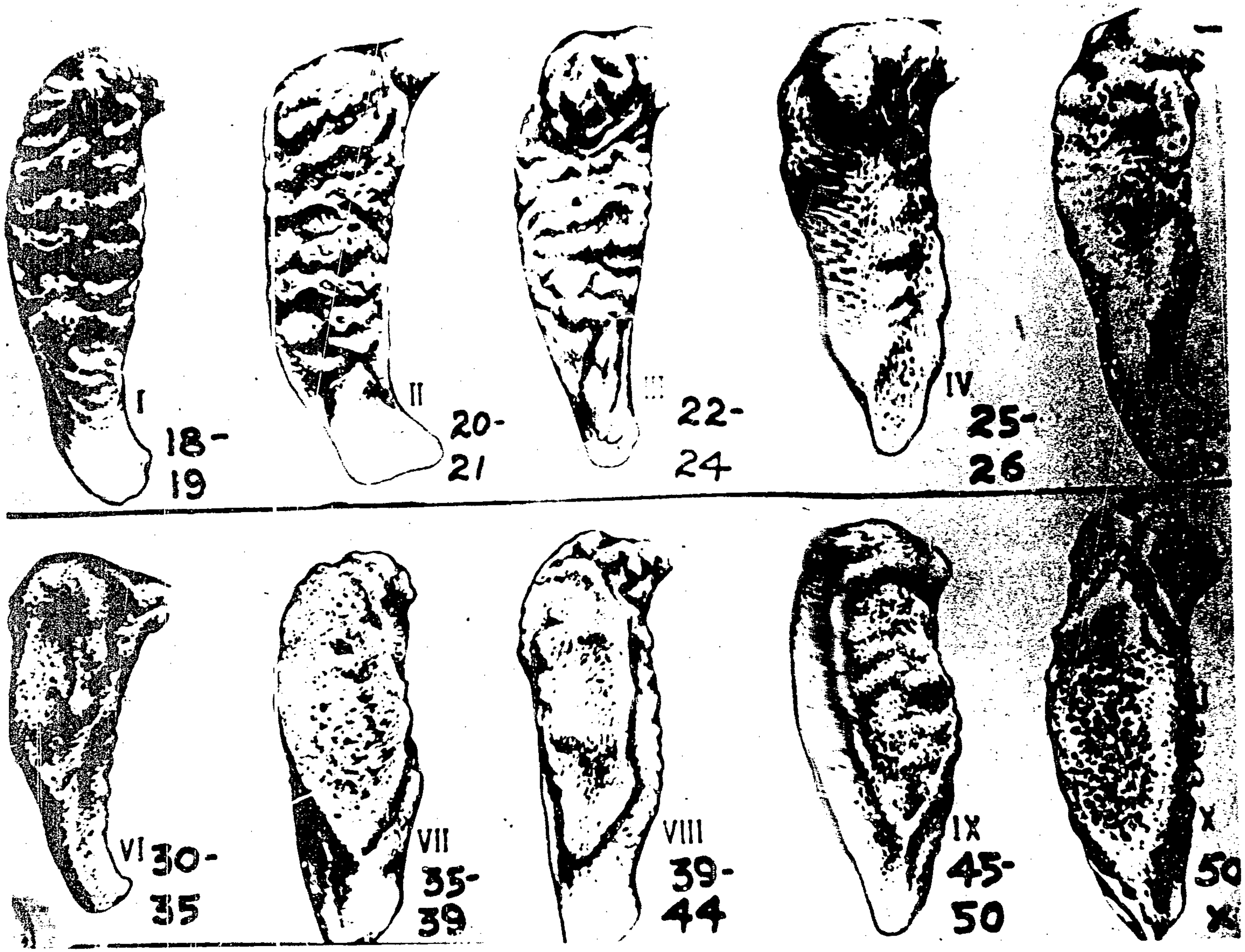


Fig. 23 Modal standards of Todd's 10 typical phases (after G. Neumann).

Phase 9: Age 45-50. Development of "rim" on symphyseal face with lipping of dorsal and ventral margins.

Phase 10: Age 50 and upwards. Erosion of and erratic, possibly pathological, osteophytic growth on symphyseal face with breaking down of ventral margins.

Todd's pubic phases have proved fairly satisfactory for ageing purposes. Recently, however, Brooks (1955) has tested them on a series of 194 male and 177 female California Indian skeletons and a sample of 103 males and 82 females from the Western Reserve collection (the same utilized by Todd). She concludes that for all ages over 20 years the phases consistantly yield a higher than actual age and hence should be modified. Also, she claims that Todd's "extreme deviants" are not necessarily anomalous, but are probably alternative patterns of morphological age changes occurring in the symphyseal surface of the pubis.

It is noteworthy that Todd's pubic phases have also been applied to studies of age changes in the male Japanese pubic bone. Hanihara (1952) investigated a series of 135 male cadavers ranging in ages from 17 to 50+. Although his description of symphyseal metamorphosis follows closely that used by Todd, his emphasis of certain features demonstrates a slightly different interpretation. For example, in the age group 36-39, Hanihara gives a detailed description of the bony outgrowth or swelling on the ventral surface of the pubis just adjacent to the ventral rampart (included by Todd in his account of late marginal projections) and refers to it as one of the primary features of late metamorphosis (p. 250). In our analysis of the present series, we were inclined to agree with Hanihara but because of the paucity of our samples in the age groups over 30 years, the importance of this feature was difficult to interpret. Thus, we have included this feature in the general picture of erratic ossification that is exhibited in the symphysis of older individuals (see par. 7).

Hanihara concludes that, "...the changes (referring to the 10 phases) stated by Todd can be used also on Japanese individuals. However, it (symphyseal changes of Japanese pubic bone) does not always coincide with that of Todd in the division of each age period..." (p. 255). He goes on to state (p. 255) that, "...the age changes of the Japanese people are, generally speaking, 2 to 3 years earlier." He is unable to say whether these differences are due to racial variation or to the differences of opinion on the parts of the examiners. The important point, however, is that Hanihara, like Brooks, finds Todd's phases tending to overage many specimens.

We turn now to Stevenson (1924) and his study of epiphyseal union in general. His series consisted of approximately 110 White and American Negro skeletons of both sexes, and ages ranging from 15 to 28 years, the same material studied by Todd. Among the results of his analysis was a detailed description of the sequence of union for the epiphyses of the iliac crest, ischial tuberosity and ramus.

Criticisms of Stevenson's study have been directed primarily to his sample rather than to his methods. For example, Cobb (1952) points out (p. 799) that the death certificate ages of the majority of the collection are not accurate chronological ages and that actually, these ages "represent both antemortem subjective estimate(s) as well as, in lesser degree, postmortem objective guess(es)". Also, Stevenson's breakdown of age, sex and stock (p. 57) shows the obvious limitations created when 110 cases (each segregated according to age, sex and stock) are spread over an age range of 14 years. That is, the highest total for any one group is 9 cases and most are represented by less than 5 cases.

Such criticisms suggest that there is still something to be learned in this area about growth and especially as observed in the sample of young men represented in the American war dead series.

3. Primary Elements

Th[illegible] terminal stage of union between the primary elements of the innomin[illegible] was observed in only two cases in the 17 year age group and in no[illegible] the 18 year age group. This stage consisted of fissures occurri[illegible] [illegible]wo sites: 1) the posterior superior angle of the obturator foram[illegible] [illegible]rking the line of union between the ischium and the pubis) and 2) [illegible] sciatic notch (marking the line of union between the ilium and th[illegible] [illegible]ium, Fig. 24). The significance of this finding is that 17 years [illegible] [illegible]ents the final age for union of the primary elements of the innomin[illegible]

4. Il[illegible] [illegible]

The [illegible]ysis for the iliac crest is a long slender piece of bone extending [illegible] the anterior superior iliac spine to the posterior superior ili[illegible] [illegible]ine. The epiphysis, when first seen in this series (age 17), is either unattached or in the early stages of fusion and, according to Stevenson (1924, p. 79), should unite in the 22nd year. As usual, we are primarily concerned with variation and thus, with the data collected in the American war dead series, we have attempted to define more accurately the total progress of ossification for the crest.

Observations on the degree of union were recorded on a numerical scale of 0-4 (already described). In addition, the site or sites at which union takes place was recorded in photographs and notes. The

Fig. 24 Left innominate showing stage 4 of union for primary elements. (No. 425, 17 years). Note fissure in the sciatic notch marking the line of union between the ilium and the ischium.

relationship between sites and stages of union can be summarized as follows:

Stage 1. Union begins internally near the anterior superior spine. (Fig. 25)

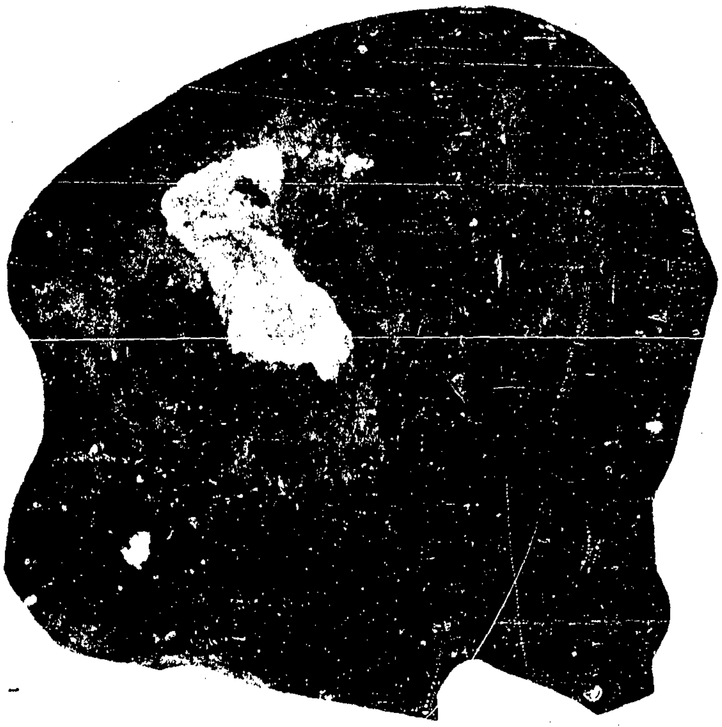


Fig. 25 Right ilium (external surface) showing stage 1 of union for the iliac crest. (No. 319, 19 years). Note beginning union at anterior superior spine.

Stage 2.

Internally: Fused in anterior half and occasionally at the posterior end. (Fig. 26,top)

Externally: Fused at anterior superior spine and in the middle third. (Sometimes also at posterior end, both internally and externally.) (Fig. 26, bottom)

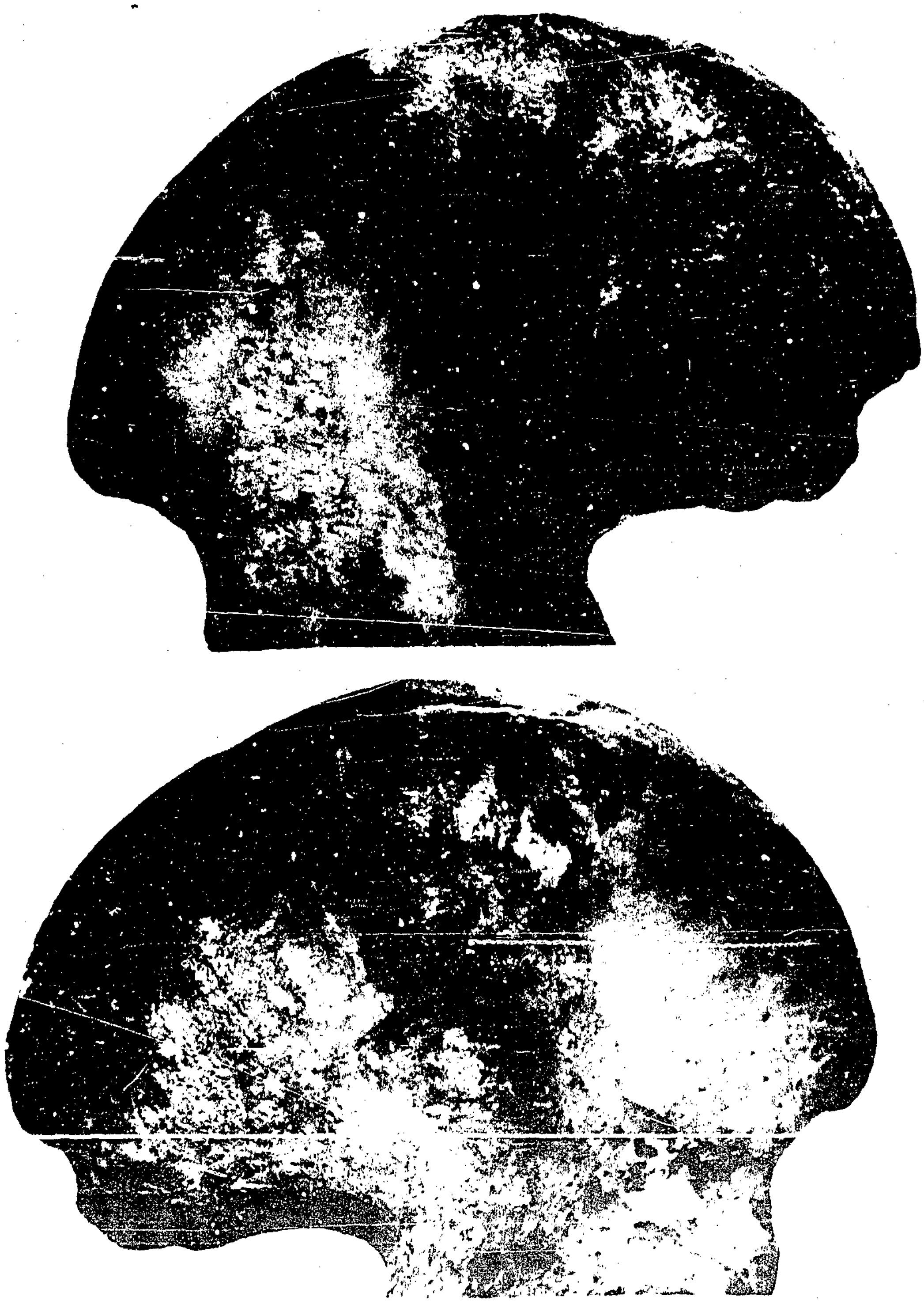


Fig. 26 Top: right ilium (internal surface) showing stage 2 of union for the iliac crest. Bottom: right ilium (external surface) showing stage 2 of union for iliac crest. (No. 348, 19 years.)

Stage 3.
Internally : Ununited only at a point just above the junction of the iliac fossa and articular area. (Fig. 27, top)
Externally: Ununited only at point of greatest anterior thickness. (Fig. 27, Bottom)

Stage 4. Completed union. (The fissures of stage 3 often persist as shallow grooves) (Fig. 28)

Table 22 correlates the above stages with age. From this it is obvious that we are dealing with an epiphysis which in a good many cases has started to unite prior to 17 years; indeed, the majority of crests show some union in both the 17 and 18 year age groups. At the same time, ununited crests appear as late as 20 years while others exhibiting only beginning union appear among the 21 year group. However, in spite of this irregularity, the general picture is one of fairly rapid progress with a period of greatest activity between 20 and 21 years. The crest is completely united at the age of 23 years.

TABLE 22

EPIPHYSIS ON ILIAC CREST: AGE DISTRIBUTION OF STAGES OF UNION (in %)

Age	No.	Stages of Union 0	1	2	3	4
17	10	40	10	10	40	-
18	45	18	16	26	20	20
19	52	5	4	27	28	36
20	45	2	6	4	24	64
21	37	-	5	8	13	74
22	24	-	-	4	4	92
23	26	-	-	-	-	100
Total	239					

Following epiphyseal union, lipping soon begins to appear on the inside of the crest just anterior to the junction of the iliac fossa and the articular area (Fig. 29), which is also one of the last sites of epiphyseal union. Lipping appears externally at the point of greatest anterior thickness (Fig. 30), but its occurrence is too erratic to warrant giving an analysis of the data. Table 23 shows the percentage of cases

Fig. 27 Top: left ilium (internal surface) showing stage 3 of union for the iliac crest. Bottom: left ilium (external surface) showing stage 3 of union for iliac crest. (No. 381, 17 years.)

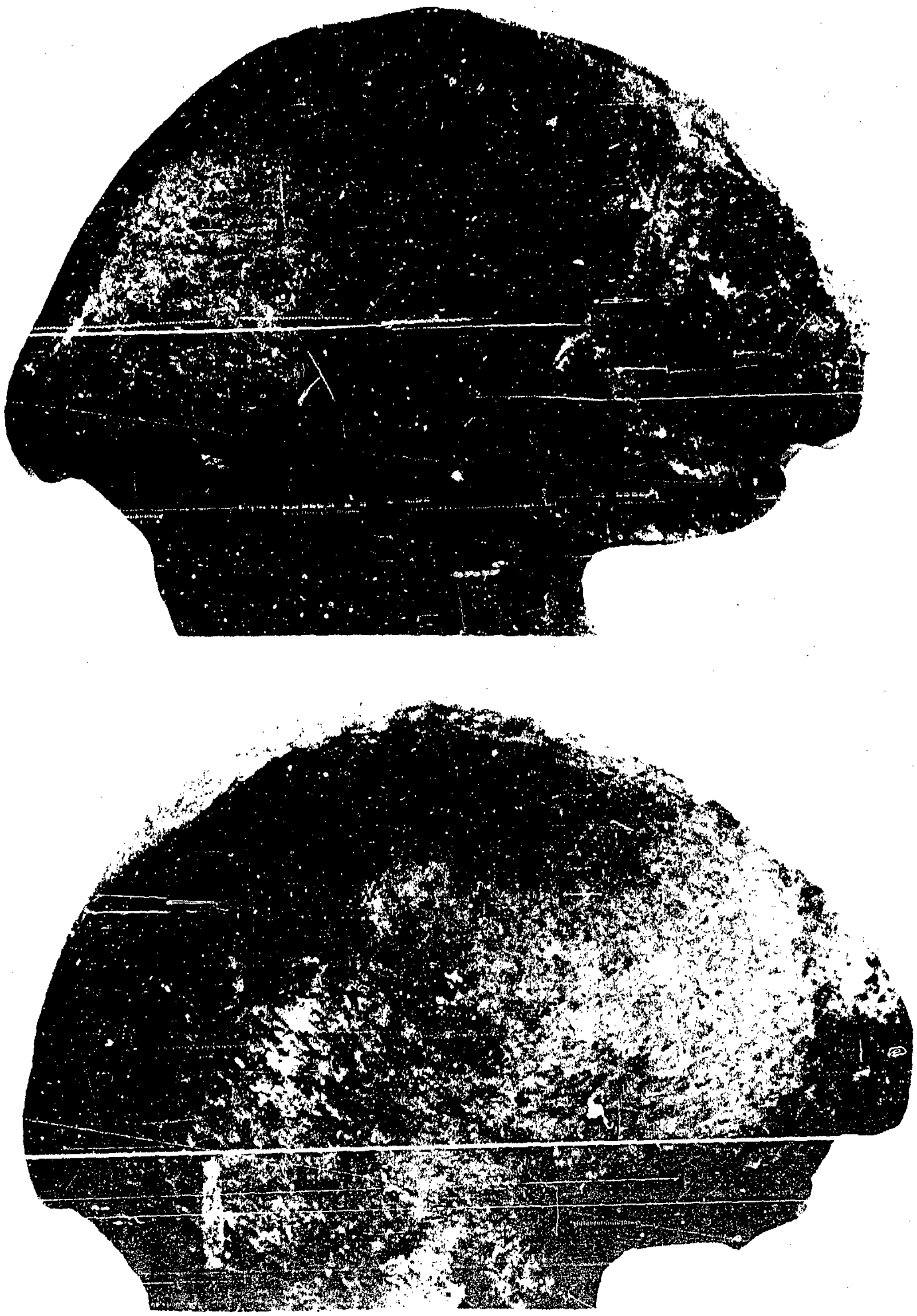


Fig. 28 Top: right ilium (internal surface) showing stage 4 of union for the iliac crest. Bottom: left ilium (external surface) showing stage 4 of union for iliac crest. (No. 324, 19 years).

TABLE 23

ILIAC CREST: LIPPING ON INSIDE AT JUNCTION
OF FOSSA AND ARTICULAR AREA.

Age	No.	Percent of Occurrence
22	24	-
23	26	8
24-25	27	30
26-27	25	30
28-30	29	43
31-35	21	72
36-40	15	64
41-50	6	50
Total	173	

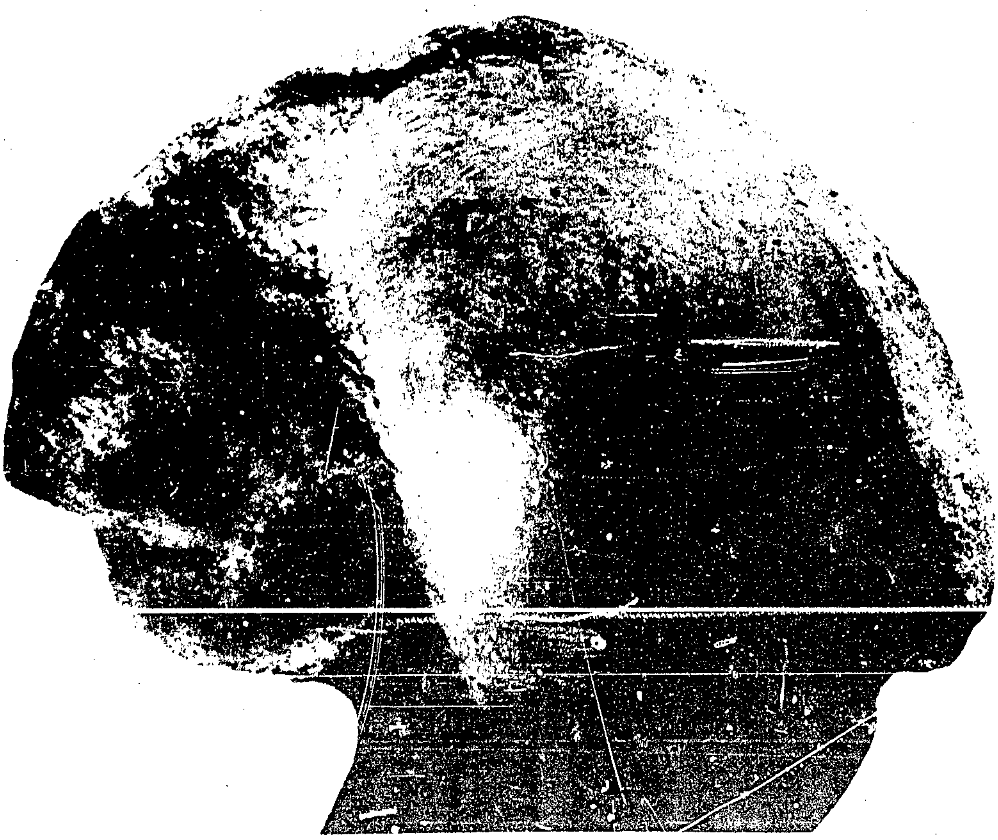


Fig. 29 Left ilium (internal surface) showing area of lipping for iliac crest. (No. 445, 28 years).

Fig. 30 Left ilium (external surface) showing area of lipping for iliac crest. (No. 445, 28 years).

in each age group observed to have lipping on the internal side of the crest. It is interesting to note that lipping does not occur before the age of 23 years, but from that age its frequency rises steadily through the upper age groups. We have no explanation for the peak in the age group 31-35 unless it is due to the small number of samples representing the ages over 35.

5. <u>Ischial Tuberosity and Ramus</u>

The epiphysis for the ischial ramus is a ventral extension of that which helps make up the ischial tuberosity. The length of the ramal portion is variable; it may be almost nonexistent (ending at the level of the border of the obturator foramen, Fig. 31), or long (in some cases extending onto the inferior extremity of the pubic symphysis, Fig. 32). In this last instance the appearance may be misleading. It is unlikely that an ischial epiphysis extended onto the pubis. Probably at an earlier stage of development, a separate ossification center existed for an epiphysis of the descending pubic ramus, and this became conjoined with the epiphysis of the ascending eschial ramus.

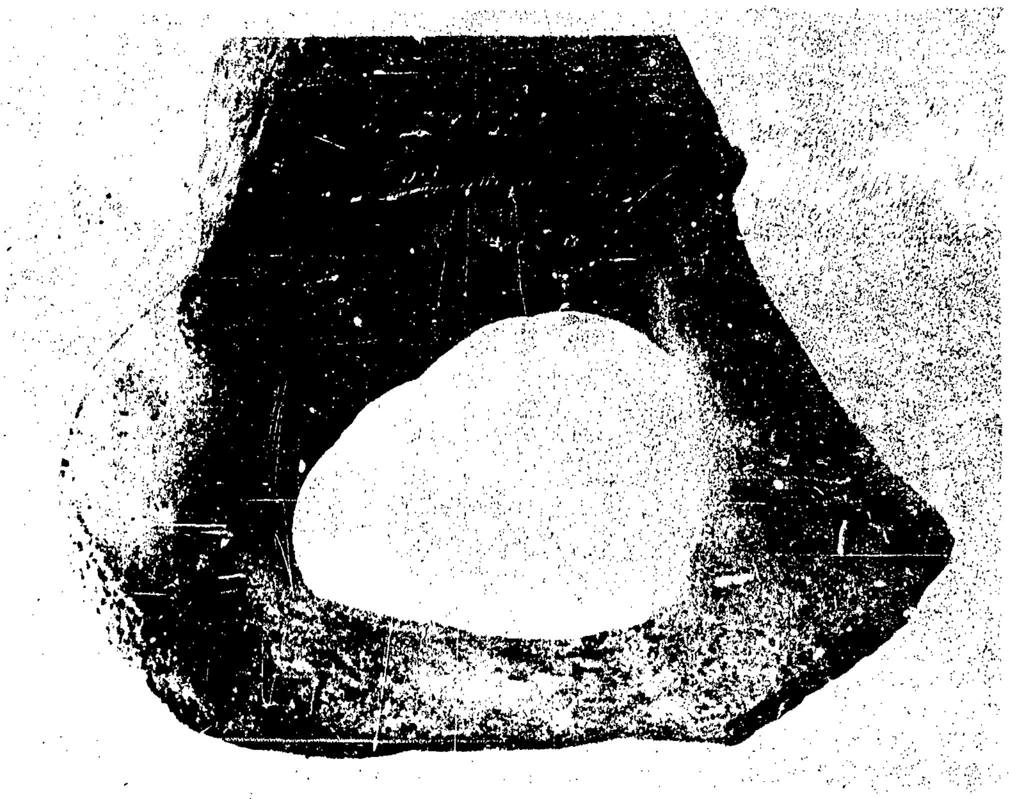


Fig. 31 Left ischium and pubis (internal surface) showing short ramal epiphysis. (No. 118, 32 years).

Regardless of length, this epiphysis follows a pattern of union very much like, but a little more delayed than, that of the iliac crest and, as he did with the crest, Stevenson (1924, p. 79) places complete union at 22 years.

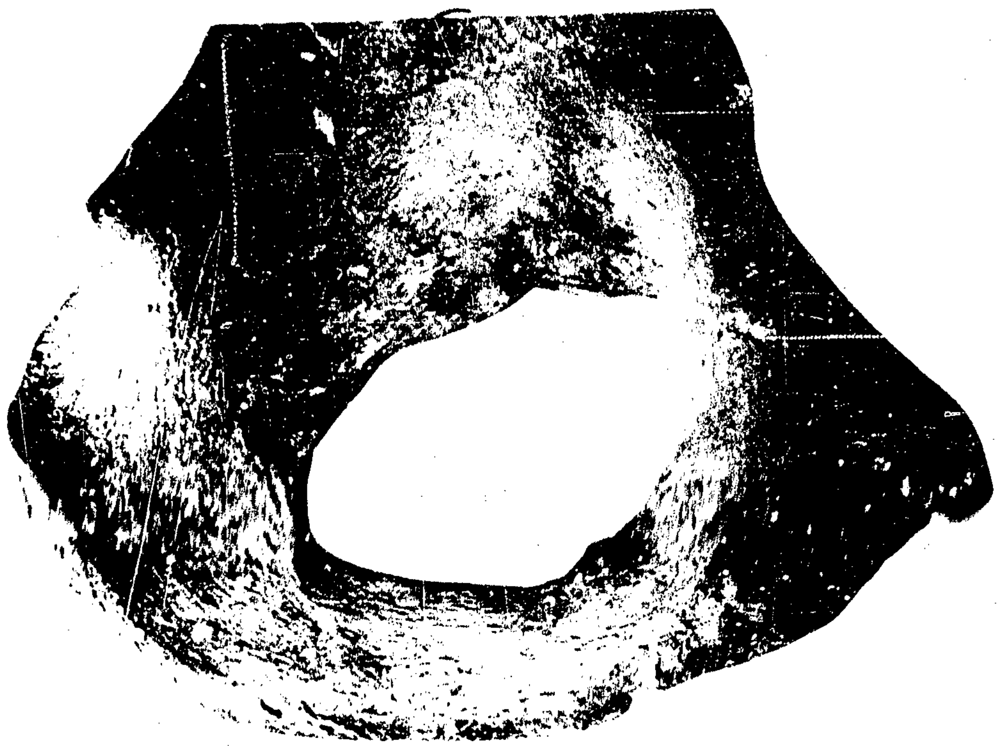


Fig. 32 Left ischium and pubis (internal surface) showing long ramal epiphysis. (No. 82, 20 years)

Our records show that union starts at the posterior end of the tuberosity (Fig. 33) and spreads first along the internal side and then along the external side. After the tuberosity is completely united, the ramal portion is often still unattached. After union of the latter portion, fissures persist for a while (both internally and externally) at the junction of the ramus and tuberosity as well as superiorly on the external side of the ramus. Also, the superior tip of the ramal portion may remain free after the rest has fully fused (Fig. 34).

From Table 24 the progress of union is found to be fairly rapid. Compared to the iliac crest, progress seems to be somewhat more irregular and the final age for complete union is not as distinct. However, after the first half of the 23rd year the ischial epiphysis is completely united in all cases.

Fig. 33 Left ischium showing beginning union of the epiphysis of the tuberosity. (No. 319, 19 years).

Fig. 34 Left ischium and pubis showing free tip of fully fused ramal epiphysis. (No. 198, 19 years).

TABLE 24

EPIPHYSIS ON ISCHIUM: AGE DISTRIBUTION OF STAGES OF UNION (in %)

Age	No.	Stages of Union 0	1	2	3	4
17	10	50	10	20	10	10
18	45	52	13	12	12	11
19	52	14	24	13	17	32
20	45	11	13	9	23	44
21	37	10	6	3	25	56
22	24	4	-	-	4	92
23	26	-	-	4	4	92
24-25	27	-	-	-	-	100
Total	266					

At this stage of maturation of the ischium the inner side of the tuberosity presents a ridge along the line where the epiphysis united. This ridge varies somewhat in prominence but is usually smooth and rounded. After some years the ridge becomes more prominent and roughened. This being the case, it was deemed important to learn whether the change in form of this ridge is a useful ageing criterion. The observation was recorded solely from the photographs.

In Fig. 35, 3 specimens are shown representing early, middle and late stages of lipping for the tuberosity. At age 18 (top specimen), the tuberosity is smooth and rounded. Actually, although lipping is not present, the shadowy outline of a slight ridge along the old epiphyseal line can be distinguished. Also, attention is called to the smooth uninterrupted outline of the obturator foramen. At age 26 (middle specimen), the tuberosity is definitely lipped

Fig. 35 Left ischia showing (top) early, (middle) middle, and (bottom) late stages of lipping for the tuberosity. (No. 284, 18 years; No. 112, 26 years; No. 444, 36 years).

and its border is no longer smooth but has become slightly serrated. Also, the smooth outline of the obturator foramen is now interrupted by small bony nodules (usually found near the anterior and posterior obturator tubercles). At age 36 (bottom specimen), lipping and serration is more pronounced. Here the changes are not confined to the tuberosity, as in the 26 year old specimen but extend along the ischial ramus. The exostoses around the borders of the obturator foramen are also more pronounced (demonstrated also in Fig. 36).

Fig. 36 Right ischium and pubis showing exostoses around the border of the obturator foramen. (No. 379, 32 years).

In general, the formation of lipping and exostoses about the ischium appears to be a gradual and erratic process and such changes tend to become pronounced in the latter part of the fourth decade. However, it should be apparent that they are not accurate age indicators.

6. The Pubic Symphysis: A new system for determining age.

The symphyseal face of the pubis is a nearly ideal area in which to seek evidence on skeletal maturation. Not only are there a succession of changes taking place, but these changes extend into the later decades of adult life, a period for which evidence from other parts of the skeleton is mostly lacking.

Todd may have been essentially right in his selection of cases to typify successive age periods, but the result was a static method of age determination. Since the variability of each feature was lost, only those pubic bones which are close to the typical can be aged with reasonable accuracy.

We feel that the main contribution we can make to this subject is an analysis of our data which takes into account all variations. In order to accomplish this, an approach somewhat different from Todd's is required. Rather than divide the whole course of symphyseal metamorphosis simply into 10 phases, we will make it possible to translate a large number of morphological combinations into chronological terms. Separate components of each symphyseal face can be recognized, and also the fact that each of these undergo transformation by stages. The result may be expressed as a formula, and a review of all formulae by age will provide a basis for judging the position of a particular case relative to the mode.

The idea of summarizing complex morphology by means of a formula is not new to biological science. A well known example is the somatotype formula introduced by Sheldon (1940). In this case a formula, consisting of 3 components of 7 grades each, described the body type of an individual. Such a procedure not only forces the observer to analyze the composition of a structure but, once formulated, enables anyone to visualize what the original structure looked like. Moreover, a formula is a convenient device for comparative purposes.

To serve description most efficiently, a formula must have certain limitations. If composed of too many elements, the significance of each element becomes difficult to remember; on the other hand, if reduced to too few elements, the discriminating function becomes lost. After some experimentation with elements involved in metamorphosis of the symphysis, we felt that the best results were obtained from a formula consisting of 3 components with 5 subdivisions or grades each.

Our search for the main elements began, naturally, with Todd's description of the changes in the pubic symphysis. In the course of this description he introduced 9 "features" in the following order:

1. Ridges and furrows
2. Dorsal margin
3. Ventral beveling
4. Lower extremity
5. Superior ossific nodule
6. Upper extremity
7. Ventral rampart
8. Dorsal plateau
9. Symphyseal rim

Obviously, a formula of 9 digits, which would result if all 9 features were used, would be cumbersome. Therefore, we were faced with the problem of dealing with combinations of previously described features.

At age 17, the starting point of our series, the most prominent feature of the symphyseal face is a pattern of transverse ridges and furrows (Todd's feature 1). The pattern is often interrupted by a semblance of either a longitudinal ridge or groove, bisecting part or all of the symphyseal face and dividing it into dorsal and ventral halves (Fig. 37). We feel that this division is important because it foreshadows events that will be restricted to one or the other side. For convenience in referring to this division, we are using the expressions, "dorsal demi-face" and "ventral demi-face."

Fig. 37 Symphyseal face of the pubis showing the left longitudinal ridge and right longitudinal groove which divides the face into dorsal and ventral halves (dorsal is left and ventral is right). (No. 88, 18 years; No. 139, 18 years).

Since ridge and furrow obliteration is retrogressive in character, gradually disappearing into other features, it seems best to consider it not as a separate feature but as a part of succeeding features.

Next, our analysis of the present series convinced us that the lower symphyseal extremity (Todd's feature 4) occurs in combination with the expansion inferiorly of the dorsal margin, that the upper extremity (Todd's feature 6) is closely associated with the development of the ventral border, and that the so-called ossific nodule (Todd's feature 5) which is found in only a small number of cases and quickly loses its identity, is but the upper part of the ventral rampart. These considerations again led us to believe that such features can be included in the descriptions of the two demi-faces.

Lastly, we combined Todd's features 2 and 8 (dorsal margin and plateau) and features 3 and 7 (ventral beveling and rampart). In further recognition of the essential division of the demi-faces, we feel that the functional relationship of dorsal margin to dorsal plateau, and ventral beveling to ventral rampart are extremely close and thus can be considered as interrelated features. This leaves only one of Todd's features (No. 9 or the symphyseal rim) distinct from the demi-faces. Actually it involves the face as a whole and only after the original subdivision has disappeared. In this way, we have arrived at 3 components that we consider diagnostically reliable in their chronologic behavior: 1) the dorsal plateau, 2) the ventral rampart and 3) the symphyseal rim.

The components do not represent a succession of structural changes which are clearly distinguishable by inspection; instead, they develop gradually and often must be subdivided quantitatively on the basis of experience. After all, the system depends entirely upon what the eye sees and the relationship of the observations with age must be worked out on this basis.

As one would expect, metamorphosis is not always in the same direction. A structure such as the dorsal plateau develops gradually, becomes complete, and then proceeds to break down and disappear. On the other hand, the symphyseal rim, having reached its peak in the mid-thirties, thereafter gradually disintegrates and eventually is replaced. Unavoidably, the numbers used in designating the stages, and hence the formula, ignore the changes in direction. Having the numerical sequence of the stages parallel the direction of the structural changes would only complicate the visual usefulness of the formula. Therefore, since the aim of this analysis is to develop a practical formula for estimating age, we have numbered the active stages of all components from 1 to 5.

In addition to the 5 active developmental stages, a preliminary stage (0), denoting absence of the feature in question, precedes each set of stages. We will now define the 3 components and their developmental stages.

7. The Symphyseal Components

I. Dorsal Plateau. Between the ages of 17-18, the grooves near the dorsal margin begin to fill in with finely textured bone and the ridges show the first evidence of resorption. Coincident with this process, a delimiting dorsal margin appears which eventually outlines the entire demi-face.

Starting in the same general area, the interacting processes of resorption and fill-in spread over the dorsal demi-face until the ridge and groove pattern has been obliterated. Ultimately, this gives to the demi-face a flat, platform-like aspect and for this reason, the component has been given the name, dorsal plateau.

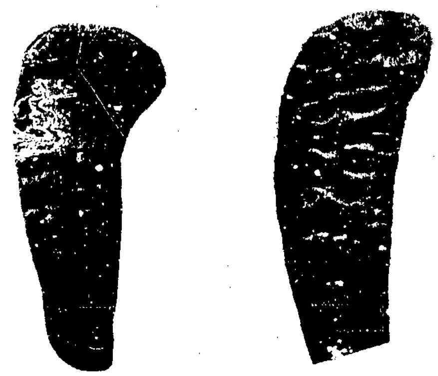


Fig. 38 Symphyseal face of the pubis showing the dorsal nodules on the inferior dorsal demi-face. (No. 183, 18 years; No. 139, 18 years)

Attention is called to the dorsal nodules (not described by Todd), sometimes associated with the early metamorphosis of the dorsal demi-face (Fig. 38). When present, they are found in the lower third of the demi-face. They are not simply enlarged ridges but round lumps of bone incorporated in the ridges. Since they do not aid in delimiting the lower symphyseal extremity and appear in only a small number of cases, we have not regarded them as a distinctive part of Component I.

The 6 (0-5) stages of Component I follow: (Fig. 39)

0. Dorsal margin absent.
1. A slight margin formation first appears in the middle third of the dorsal border.
2. The dorsal margin extends along entire dorsal border.
3. Filling in of grooves and resorption of ridges to form a beginning plateau in the middle third of the dorsal demi-face.

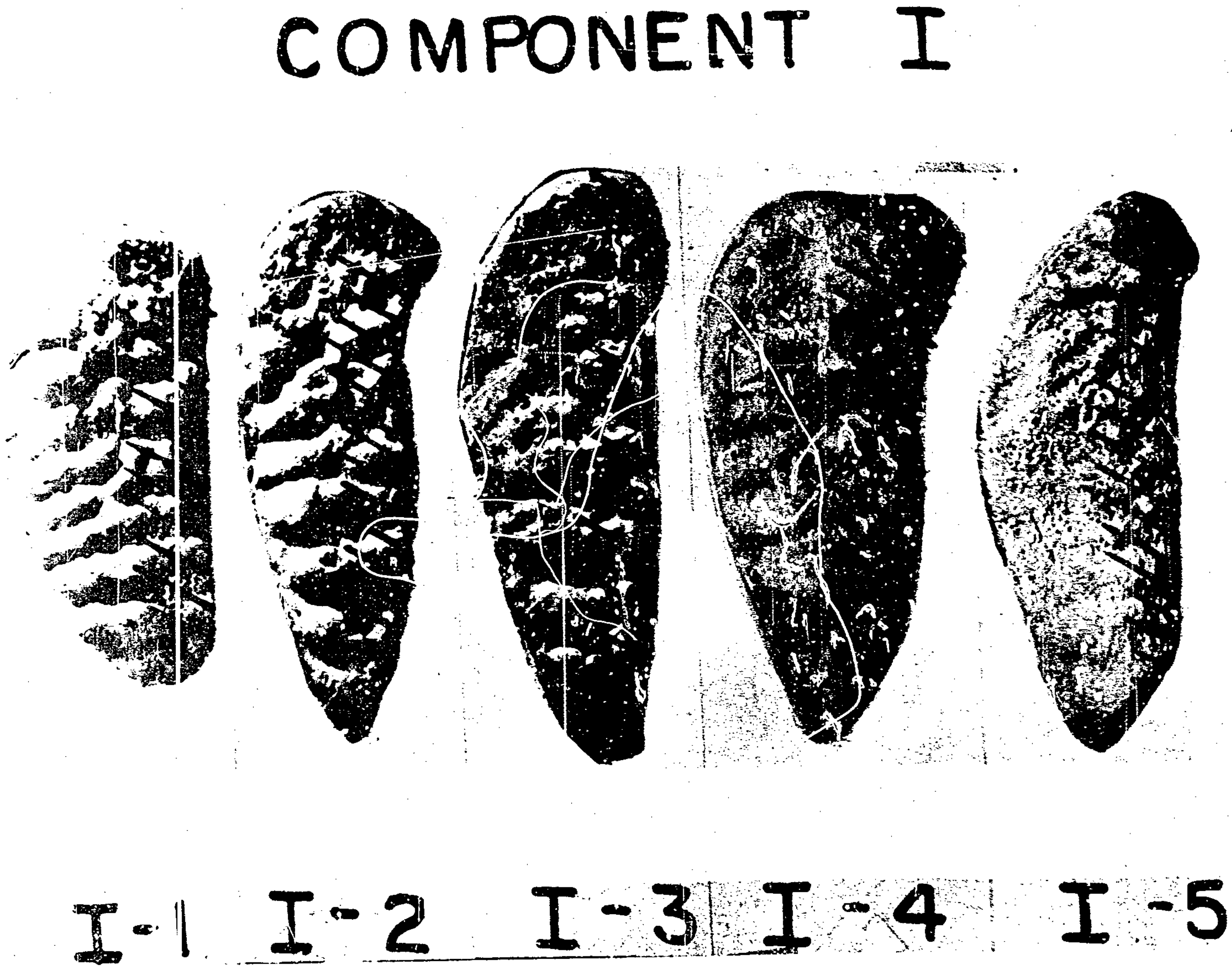


Fig. 39 The 5 active stages of Component I.

4. The plateau, still exhibiting vestiges of billowing, extends over most of the dorsal demi-face.
5. Billowing disappears completely and the surface of the entire demi-face becomes flat and slightly granulated in texture.

II. Ventral rampart. Early in the development of Component I, differentiation of dorsal and ventral demi-faces becomes pronounced due to the breakdown, by rarefaction, of the ventral half. Over this porous, beveled surface, an elongated and more or less complete epiphysis or rampart forms. This rampart is produced by the extension of ossification from upper and lower extremities aided, at times, by independent ossicles along the line of the future ventral margin. Obviously, however, the pattern is variable and the rampart may remain incomplete even in later age groups (the hiatus is usually in the middle two-thirds of the ventral border, Fig. 40) or may bridge only certain portions of the beveled surface.

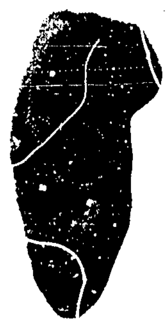


Fig. 40 Symphyseal face of pubis showing ventral hiatus. (No. 239, 29 years).

The 6 (0-5) stages of Component II are as follows: (Fig. 41)

0. Ventral beveling is absent.
1. Ventral beveling is present only at superior extremity of ventral border.
2. Bevel extends inferiorly along ventral border.
3. The ventral rampart begins by means of bony extensions from either or both of the extremities.
4. The rampart is extensive but gaps are still evident along the earlier ventral border, most evident in the upper two-thirds.
5. The rampart is complete.

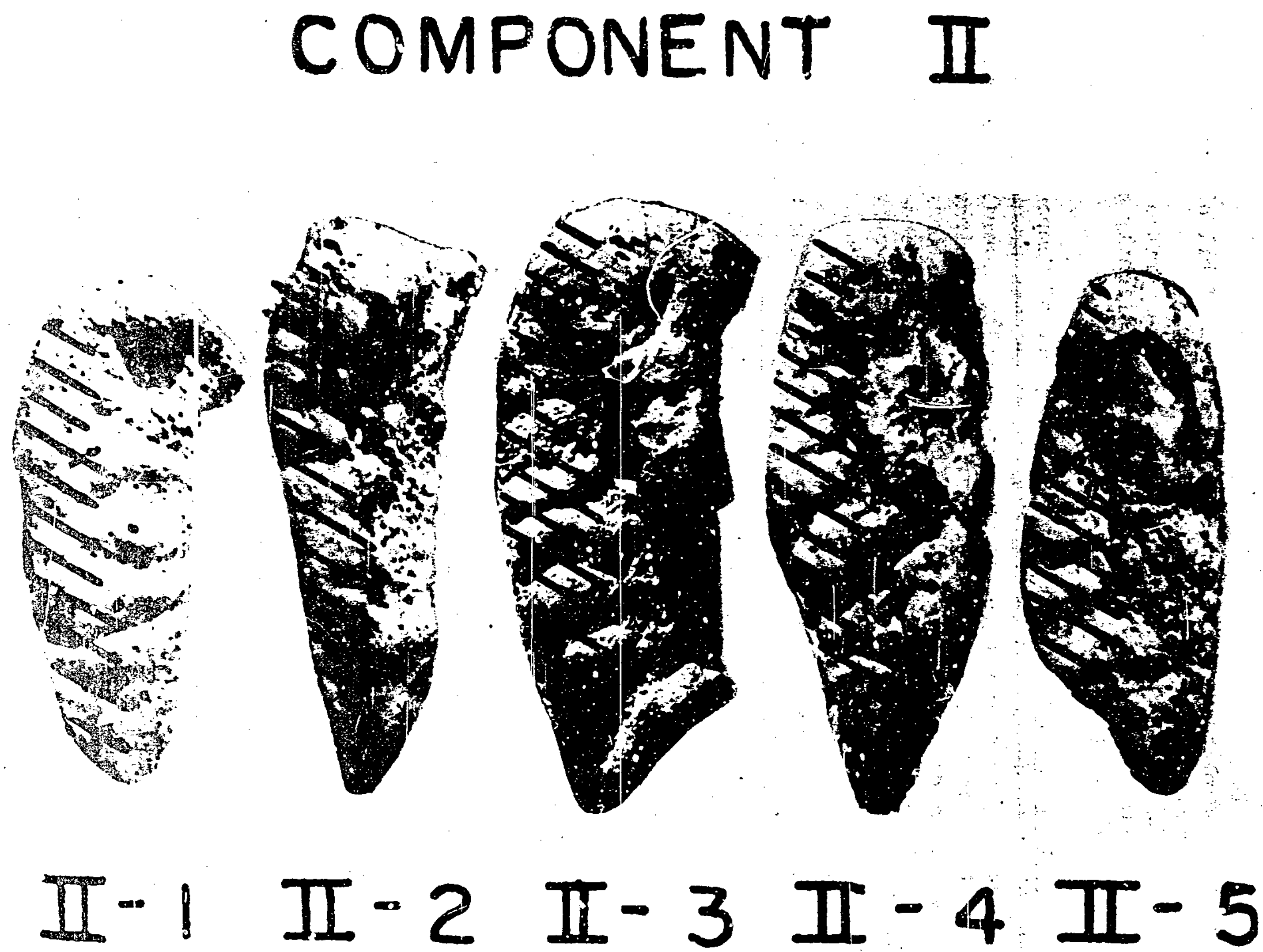


Fig. 41 The 5 active stages of Component II.

III. Symphyseal rim. The final stages of symphyseal maturation are characterized by the formation of a distinct and elevated rim surrounding the now level face. At the same time, the bony texture of the face begins to change from a somewhat granular to a more finely grained or dense bone and, although vestiges of the ridge and groove pattern still may be recognized in the lower third of the dorsal demi-face, it is sometimes difficult to tell whether they are merely regular undulations of the smooth bony surface or true remnants of the earlier ridge and groove pattern.

Following the completion of the symphyseal rim, there is a period during which changes are minute and infrequent. Ultimately the rim is worn down or resorbed and a smooth surface extends to the margins. As the face levels off it undergoes erosion and erratic ossification, the bone becomes more porous and the margins may be lipped.

Metamorphosis of the symphysis in the last decades of life is characterized by further breakdown of the bony tissue. However, because of the small number of older individuals present, the series under discussion does not enable us to define the last stages clearly.

The 6 (0-5) stages of Component III are as follows: (Fig. 42)

0. The symphyseal rim is absent.
1. A partial dorsal rim is present, usually at the superior end of the dorsal margin, it is round and smooth in texture and elevated above the symphyseal surface.
2. The dorsal rim is complete and the ventral rim is beginning to form. There is no particular beginning site.
3. The symphyseal rim is complete. The enclosed symphyseal surface is finely grained in texture and irregular or undulating in appearance.
4. The rim begins to break down. The face becomes smooth and flat and the rim is no longer round but sharply defined. There is some evidence of lipping on the ventral edge.
5. Further breakdown of the rim (especially along superior ventral edge) and rarefaction of the symphyseal face. There is also disintegration and erratic ossification along the ventral rim.

8. Correlations with Age

After having constructed the symphyseal formula and defined the components' changes, our next step was to see whether others could apply

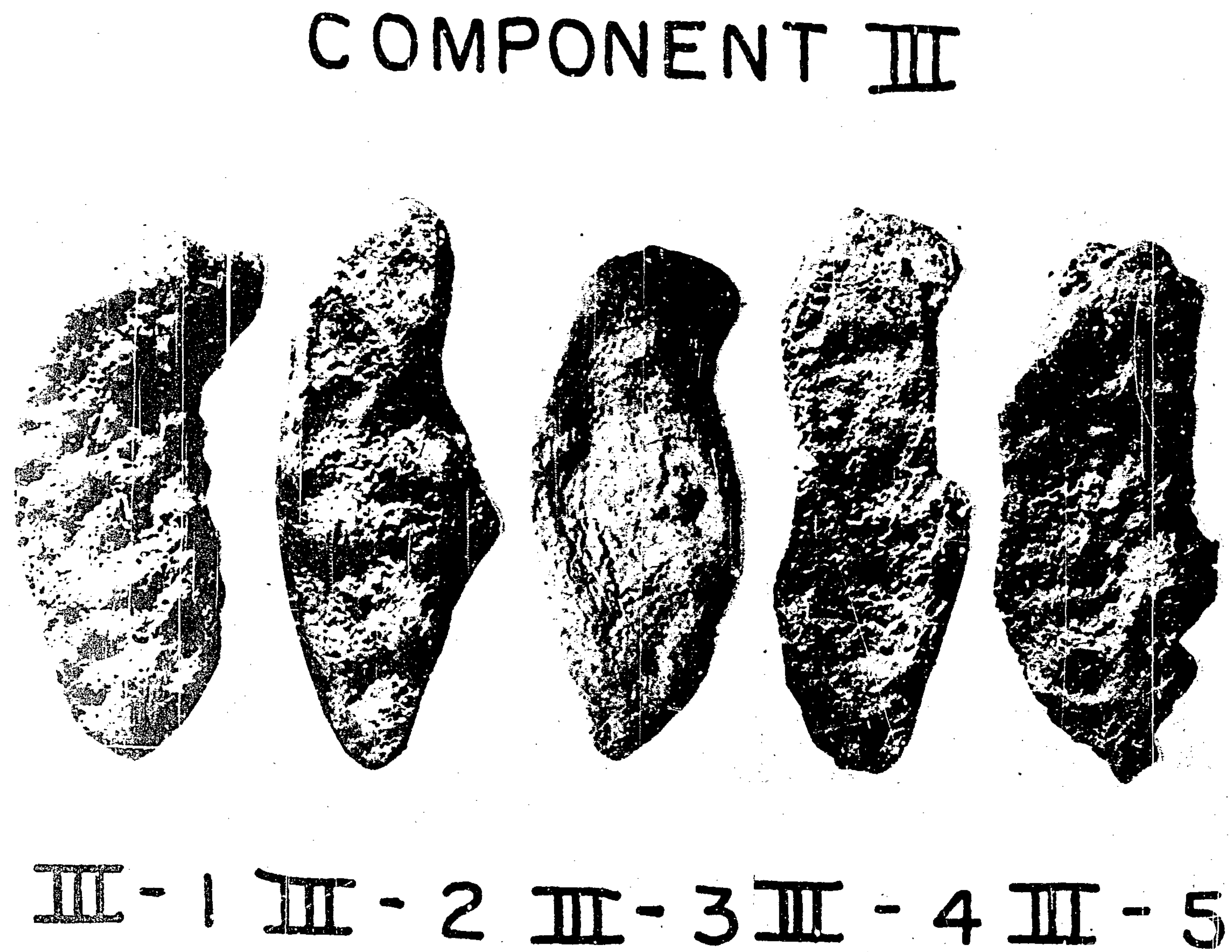


Fig. 42 The 5 active stages of Component III.

TABLE 25

THE AGE DISTRIBUTION OF COMPONENT STAGES

Age*	No.	Component I						Component II						Component III					
		Stages						Stages						Stages					
		0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
17	5	5						5						5					
18	23	2	8	11	2			23						23					
19	57		5	35	16	1		51	5	1				57					
20	52		2	16	26	8		34	16	2				52					
21	33		1	4	20	8		8	13	5	7			31	2				
22	21				7	14		1	7	5	5	3		16	5				
23	29				6	20	3		5	4	12	8		15	14				
24	16				1	8	7			1	7	7	1	3	8	2	3		
25	8					3	5				3	3	2		3	3	2		
26	13					9	4				3	10	0		5	7	1		
27	12					7	5				4	5	3		4	3	5		
28	13					6	7				2	7	4		2	7	4		
29-30	15					1	14					11	4			9	4	2	
31-39	45						45					6	39			5	12	26	2
40-50	7						7						7					5	2
Total	349																		

*Represents age to the nearest year, for example, 17 = 16.5 to 17.4

it with similar results. Such a test was especially necessary since the judgment of component stage and age correlation was based on the subjective observations of one investigator (McKern). Before accepting this judgment as final, several observers not in contact with the project were asked to study the instructions and then to work out the formulae of 10 selected casts. The results of this test demonstrated that after a little practice with the method, observers with only a general knowledge of osteology could formulate normal symphyses with about 90% accuracy. After more experience, the same observers improved further in their formulation.

With this evidence that others can judge the components and their stages on the basis of our descriptions, we proceeded to analyze each symphysis into its formula. For example, a symphysis from the beginning of the series would have the simple formula of 1-0-0, indicating that only the first stage of the dorsal plateau component is present. This stage (I-1) would then be scored as occurring at 18 (the known age of the individual). Later in the series, if we encountered the formula 3-3-0 in a symphysis from a 21 year old individual, we could score the stages I-3 and II-3 under his age. Thus, when all the formulae were scored, an age distribution resulted which is shown in Table 25.

According to Table 25, the first and second stages of Components I and II develop fairly rapidly and are completed in 4 to 6 years, whereas the last stages progress more slowly. In Component III the first stage begins late (21 years) and takes 8 years to complete, whereas the 2nd and 3rd stages take from 16 to 21 years. In our series some stages never reached completion, as 5 of Component I, 4 and 5 of Component II, and 3, 4 and 5 of Component III. Small samples in the age groups over 28 years are reflected in the distributions of stages 4 and 5 of Component III. Necessarily therefore, these final stages are only tentatively defined.

Obviously, this is a picture of deceleration in symphyseal metamorphosis. Component III, in particular, represents a period which Todd characterized as one of "quiesence", when age changes were limited to peripheral outgrowths into attachments of tendons and ligaments.

It will be noted also in Table 25 that the modal age is given up to age 28 whereas all ages over 28 years have been combined into 3 age groups and hence here the position of the mode is masked. For this reason it seems desirable to give the mode and range for each stage in a separate table (Table 26).

The formulae now may be translated into probable ages. For example, reading from Table 26 the formula 3-0-0 has an overall range of 18-24 years (the earliest and latest appearance of any stage of the 3 components) and a modal frequency of 20, 19, and 19 years (the designated modes of each component stage) for the 3 components. Thus, a final judgment of the individual's most probable age at death would be 19¼ years.

TABLE 26

AGE LIMITS OF THE COMPONENT STAGES

Stage	Age Range	Mode
	Component I:	
0	17.0 - 18.0	17.0
1	18.0 - 21.0	18.0
2	18.0 - 21.0	19.0
3	18.0 - 24.0	20.0
4	19.0 - 29.0	23.0
5	23.0 +	31.0
	Component II:	
0	17.0 - 22.0	19.0
1	19.0 - 23.0	20.0
2	19.0 - 24.0	22.0
3	21.0 - 28.0	23.0
4	22.0 - 33.0	26.0
5	24.0 +	32.0
	Component III:	
0	17.0 - 24.0	19.0
1	21.0 - 28.0	23.0
2	24.0 - 32.0	27.0
3	24.0 - 39.0	28.0
4	29.0 +	35.0
5	38.0 +	

Although there are 125 possible formula combinations, only about one fourth of these combinations are likely to occur. In the present series, 21 different formulae were recorded, as follows:

000	320	431	543
100	330	441	552
200	410	442	553
210	420	541	554
300	430	542	555
310			

Obviously, since the components represent a chronological developmental process, certain combinations would be impossible or, at least, pathological. However, this is not to say that the above list includes all the normal combinations. Others will likely appear when the system is applied to more extensive series. However, we believe that if other formulae are found, they will yield age estimates that are in accord with those represented in this study.

Also, it is expected that there may be differences of opinion in the recording of various stages of component development. For example, it is often difficult to determine whether the second component is in stage 4 or 5 and similarly, whether the third component is in stage 2 or 3. The resulting formula could be either 542, 543, 552 or 553. However, these difficulties actually reflect the close interrelations of Components 2 and 3 at this particular period of metamorphosis and the mean ages for all four formulae are practically the same. Thus, the system is flexible to the point where slight deviations in observation will not necessarily produce grave errors in age estimations.

Carrying the analysis a step further, we found that when the figures comprising the formula (300 = 3, 431 = 8, etc.) were added together, the resulting values, when plotted against age, showed distributions exhibiting few, if any, differences from those of the intact formulae. Table 27 thus shows the calculated means and their age ranges for each total score (0-15). Since several of the scores gave similar age estimations, these scores have been lumped into a single category. We can then conclude that once a symphseal formula has been established, the age range and the probable age of the individual at death can be estimated by simply calculating the sum of the 3-digit formula and reading the corresponding age from Table 27.

Attention is called again to the small number of individuals in the upper age groups and to the possibility that they may not give a full picture at the later stages of metamorphosis. Eventually, our observations should be checked on a large sample of older individuals and adjustments made if necessary.

To properly utilize the symphyseal formula, the user must correctly visualize a particular symphysis in terms of the established component stages. Although the stages are described verbally and portrayed photographically, the prime requisite is for realistic and three-dimensional training aids to insure comparability between users and maximum accuracy in assessment. To this end, sets of plastic model symphyseal casts, representing the three components and their 5 developmental stages have been fabricated (Fig. 43). With an enclosed sheet of instructions and in combination with the information contained in the present report the plastic sets become effective tools for ageing unknown skeletal remains.*

TABLE 27

CALCULATED MEAN AGE, STANDARD DEVIATION AND AGE RANGES FOR THE TOTAL SCORES OF THE SYMPHYSEAL FORMULAE

Total Score	No.	Age Range for the Scores	Mean Age	Standard Deviation
0	7	- 17	17.29	.49
1-2	76	17 - 20	19.04	.79
3	43	18 - 21	19.79	.85
4-5	51	18 - 23	20.84	1.13
6-7	26	20 - 24	22.42	.99
8-9	36	22 - 28	24.14	1.93
10	19	23 - 28	26.05	1.87
11-12-13	56	23 - 39	29.18	3.33
14	31	29 +	35.84	3.89
15	4	36 +	41.00	6.22
Total	349			

9. Abnormalities of the Symphysis

Abnormalities of the symphysis complicate age identification and hence have pertinence to the present study. They fall into 2 categories: postmortem erosion and antemortem malformation.

In assembling the series under discussion, poorly preserved skeletons and especially those in which the symphyses were badly eroded, were rejected. The small amount of erosion which was accepted obscures rather than distorts symphyseal features. We believe that such obscuration as existed has not seriously reduced the accuracy of formulation for identification purposes.

*Information on the procurement of the plastic sets may be obtained by writing Dr. Thomas W. McKern at the following address:
HQ QM Research and Development Command
Environmental Protection Research Division
Physical Anthropology Branch
Natick, Mass.

Fig. 43 The set of plastic model symphyseal casts.

On the other hand, there was no conscious or planned selection against local antemortem malformations. As would be expected, however, such abnormalities are rare in this type of population. In Fig. 44, cases #329 and #250 illustrate two distinct types of deformed symphseal faces.

The type represented by case #329 (23 years old) occurs in 3 out of the total series of 371 pelves. Compared to a normal symphyseal face, it is extremely small and exhibits none of the diagnostic features characteristic of its age. The type represented by case #250 (22 years old) was seen in 4 cases. Here a peculiar disintegration of the upper portion of the face (usually indicative of advanced age) accompanies features in the lower portion of the face characteristic of the true age. The other examples of this type have disintegrated in various places and hence the type is to be identified by the breakdown of the face rather than by the location of the breakdown.

In all of our cases of antemortem malformation of the symphyseal face, the rest of the skeleton shows a normal growth pattern. This

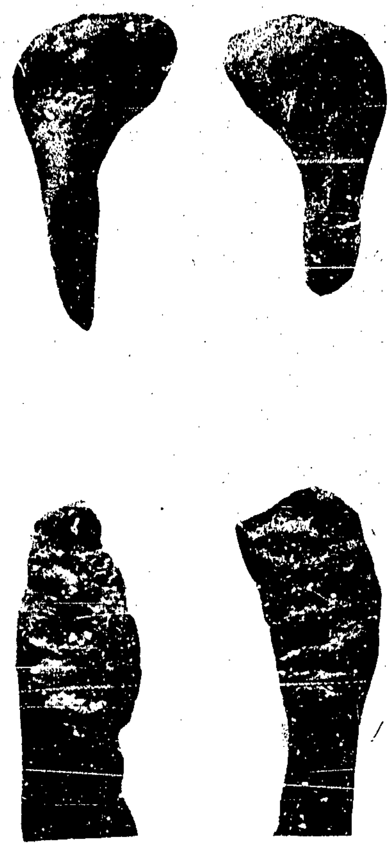


Fig. 44 Symphyseal face of pubis showing types of deformed symphyses. (No. 329, 23 years (above); No. 250, 22 years (below)).

suggests that such malformations may have resulted from trauma to the pubic area. Whatever the cause, it is important to recognize such conditions and to discount them in favor of other more reliable ageing criteria.

10. Summary

Primary elements. Last signs of union for the primary elements of the innominate occur as small fissures at points of union between the ischium, pubis and ilium.

Iliac crest. The early stages of epiphyseal union for the iliac crest are in progress prior to the 17th year. The site of earliest union is at the anterior end of the crest, usually on the medial side and just posterior to the anterior superior iliac spine. The crest is completely fused by the age of 22 years and the last sites of union are at the junction of the iliac fossa and articular area (medially) and at the point of greatest anterior thickness (laterally).

Ischial tuberosity and ramus. The ischial epiphysis is fully united at 23 years and the last site of union seems to be on the external side of the ramus.

Pubic symphysis. Since Todd's system of typical phases serves only those symphyses that conform to his concept of typical, we have proposed a new method of ageing in which symphyseal metamorphosis is evaluated in terms of combinations of its component parts. Thus, we have selected 3 components, each subdivided into 5 developmental stages which, when combined as a formula for any pubic symphysis, will yield an age range and the probable age of the individual. In comparison to Todd's system, the symphyseal formula expresses the true nature of symphyseal variability and does not confine the observer to the narrow limits of typical phases.

CHAPTER V

CLAVICLE

1. Introduction

The medial end of the clavicle articulates with the sternum, and the lateral end with the acromial process of the scapula. Both articular areas are the sites of small and highly variable epiphyses.

The lateral epiphyseal surface is usually small and billowed in the typical fashion. The epiphysis itself is seldom seen and the surface simply glazes over rapidly, around 19 or 20 years, a time when much epiphyseal activity is going on elsewhere in the skeleton. Since the status of this epiphysis is difficult to judge, no provision was made for it on the data card and only occasionally was a cast made of this end of the bone.

On the other hand, the epiphyseal surface at the medial end is relatively rich in detail and matures at a slow rate. Also, extra importance attaches to this epiphysis because of its late time of maturation; it is the last epiphysis to unite. For these reasons, all cases were rated on the usual scale of 0 to 4 and supplemented by a cast and photograph of both sides, taken together.

2. Historical Remarks

Although the clavicle has long been a subject of study, reliable data on the maturation of its epiphyses were not reported until the 1920's when the Todd skeletal collection was formed. Before that time, anatomical text books contained very little about the maturation of the lateral epiphysis and varying statements, based on data of unknown origin, about that of the medial epiphysis.

Age estimations by various authors for the union of the medial epiphysis follow:

Author	Year	Age
Henle	1871	18
Krause	1909	20-21
Dwight	1911	18
Poirier	1911	25
Dixon	1912	25
Bryce	1915	25
Lewis	1918	25
Terry	1921	25
Testut	1921	22-25
Thompson	1921	25

Stevenson (1925) was the first to study the maturation of the clavicle in the Todd collection. On the basis of 50 specimens between the ages of 21 and 27 he was able to say that,

> "The epiphysis in question shows evidence of beginning union in several of the twenty-two year skeletons, and of having only recently united in several of the twenty-seven year individuals. In fact, it is not until the twenty-eight year old group is reached that this epiphysis is found to be united in all the cases. The usual impression that this epiphysis unites more or less constantly at the twenty-fifth year, and the common practice of considering skeletons to be either older or younger than twenty-five according to whether the sternal epiphysis of the clavicle is united or ununited, seems entirely unwarranted. It is impossible to assign any age at which this epiphysis will certainly be completely united below the twenty-eighth year."

Later Todd and D'Errico (1928) were able to expand the series to 166 specimens (including Stevenson's 50) and the age range to 17 and 29 years. Their charts show that union may begin as early as 20 years (1 case) and may still be in the "recent" stage as late as 29 years (2 cases). Nevertheless, they state (p. 37):

> "In both sexes and both races (White and American Negro) union of the sternal epiphysis is practically completed in the twenty-fifth year (R)."

Note that here "practically complete" union is equated with "recent" union. The authors recognize this equation again when they say (p. 37):

> "The loss of all traces of the site of union (C) quickly follows. Of course there are exceptions, mainly in the four years centering on twenty-five."

We will now show how the findings of Todd and D'Errico compare with our own.

3. Medial Epiphysis

Table 28 summarizes the data according to side. At first glance there seems to be some difference in the progress of union between the right and left sides, but these differences occur only in the early age groups and are not large enough to be significant. For example, in the 18 year age group, union in the right clavicle does not exceed stage 1, whereas in the left it has reached stage 2 in 2 percent of the cases. Irregularities of this kind can be seen in the age groups from 18 to 23, after which differences between the right and left sides are absent. Of course, it is easy to displace epiphyseal caps in these early ages and, therefore, differences between sides may arise simply from the loss of one of the caps.

TABLE 28

AGE DISTRIBUTION OF THE STAGES OF UNION
FOR THE MEDIAL CLAVICULAR EPIPHYSIS
(in %)

		Right					Left				
		Stage of Union					Stage of Union				
Age	No.	0	1	2	3	4	0	1	2	3	4
17	10	-	-	-	-	-	-	-	-	-	-
18	45	90	10	-	-	-	86	12	2	-	-
19	52	79	13	8	-	-	73	21	4	-	-
20	45	69	28	11	2	-	56	35	7	2	-
21	37	36	43	13	8	-	47	32	13	8	-
22	24	4	27	39	30	-	1	33	37	29	-
23	26	-	11	43	40	6	-	8	43	40	9
24-25	27	-	3	10	52	37	-	3	10	52	37
26-27	25	-	-	-	36	64	-	-	-	36	64
28-29	18	-	-	-	31	69	-	-	-	31	69
30	11	-	-	-	9	91	-	-	-	9	91
31	54	-	-	-	-	100	-	-	-	-	100
Total	374										

Although beginning union appears first at 18 years in our series, we cannot be sure that this stage does not occasionally appear at 17 years since 10 cases constitute an inadequate sample for this age.

Clavicles with unattached epiphyses may be found as late as 22 years. On the other hand, it is interesting to note that cases of completed union do not appear before the age of 23 years.

Variability of union, as expressed in Table 28 by the distribution of the stages over as many as 6 to 8 age groups, makes it impossible to associate particular ages with stages of union. Only a probable age for beginning union (17 years) and a definite age for the last stage of union (30 years) can be given.

The results do not agree with those of Todd and D'Errico, yet upon closer inspection, the disagreement seems to reflect mainly difference in interpretation. This is shown in a further comparison of the two series (Tables 29 and 30) involving percentages of occurrence for beginning and complete stages of union in selected age groups. For this purpose we have judged beginning union, as recorded by Todd and D'Errico, to be equivalent to our stages 1 and 2, and their complete union to our stage 4.

TABLE 29

THE OCCURRENCE OF BEGINNING EPIPHYSEAL UNION: COMPARISON BETWEEN THE TODD AND D'ERRICO SERIES AND THE AMERICAN WAR DEAD SERIES.

	Todd and D'Errico Series*		American War Dead Series	
Age	No.	%	No.	%
17	2	-	10	-
18	8	-	45	10
19	4	-	52	21
20	12	8	45	39
21	12	58	37	56
22	11	81	24	66
23	14	64	26	54
Total	63		237	

*Whites and Negroes combined (after Todd and D'Errico, 1928, p. 37-38).

In Table 29 the Todd and D'Errico series does not reveal beginning union before the 20th year, the samples representing the preceding years being too small to reveal significant trends. Our data show beginning union as early as 18 years. Yet Todd and D'Errico claim that the sternal epiphysis commences to unite about the 21st and 22nd year (p.49). Obviously, therefore, they are talking about the age when over 50 percent of the cases are in this stage. This is misleading for identification purposes.

Todd and D'Errico also state that complete union does not take place until the 25th year (p. 49). Actually, Table 30 shows that complete union first appears in their series at age 23, just as in ours. However, partial substantiation of their conclusion is exhibited by the abrupt decrease of epiphyseal activity after 25 years. This change is further emphasized in Table 30 where the percentages in Todd's series show a dramatic increase from little or no occurrence of complete union, in ages 24 and 25 respectively, to 36 percent in age 26. In other words, the differences between the two series are not great and could easily derive from the small numbers in each age group. It can be generally stated, therefore, that from the age of 26 to 30, last stages of union are found in only a few cases and complete union occurs in the majority of cases around the age of 25.

TABLE 30

THE OCCURRENCE OF COMPLETE EPIPHYSEAL UNION: COMPARISON BETWEEN THE TODD AND D'ERRICO SERIES AND THE AMERICAN WAR DEAD SERIES.

	Todd and D'Errico Series*		American War Dead Series	
Age	No.	%	No.	%
22	11	-	24	-
23	14	7	26	6
24	14	7	14	21
25	9	-	13	61
26	12	36	15	60
27	12	25	10	60
28	12	50	13	61
29	8	75	6	67
Total	92		121	

*Whites and Negroes combined (see footnote to Table 29).

Unlike most of the limb epiphyses which correspond in size to the surface to be covered, the medial clavicular epiphysis often is reduced in size or does not develop at all. In such cases, Todd claims, "the epiphyseal cartilage disappears and the same waxy textured bone which is typical of the epiphysis glazes over the naked end of the shaft" (p. 49). This seems to be borne out by the fact that Flecker (1942,p.110) could not see the cap of the medial epiphysis in his x-rays in more than 65 percent of the cases. Though Todd and D'Errico have described this character in some detail and emphasized the difficulties met by the observer who must identify the two conditions, they have not revealed how often it occurred in their sample.

In the absence of epiphyseal ossification, how can the end stages of maturation be recognized? Also, can the non-development of an epiphysis lead to an erroneous age estimate? About the only way we can answer these questions is to point out that the mature appearance resulting from epiphyseal glazing alone probably develops slowly. In the absence of a cap to cover the billowed surface we cannot see how such a surface can be smoothed over quickly. This consideration leads us to conclude that under these conditions there is no clear point at which maturation can be said to be complete; cases may appear younger than they are.

Let us turn now to the photographs and casts of the medial end of the clavicle. Out of 77 cases in the age groups 22 to 25 which include the periods of late epiphyseal activity, we were able to detect only one (age 24) where the epiphysis had not developed. The cast in this case has no epiphysis, yet a portion of its superior face is glazed over in marked contrast to the billowed appearance of the remaining surface (Fig. 45). It was recorded on the data card as, "1 or 2(probably 2)" which places the cast at the extreme end of the age frequency for either of these stages (see Table 28). Thus, we can only conclude that: 1) cases of non-ossification can be recognized only in those age groups (22-25) which normally possess epiphyseal caps in late stages of union, and 2) within these age groups, the incidence of recognized cases of non-ossification is low.

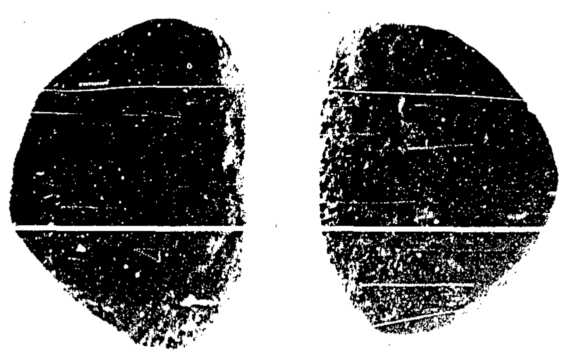


Fig. 45 Left and right surfaces of the clavicle showing example of non-ossification. (No. 231, 24 years). Note glazed surface and absence of epiphysis.

Other than the above observation, epiphyseal caps showing stages of union appear in about 20 percent of the casts in our series. Of these cases, 91 percent show union beginning at the superior margin of the epiphyseal face (Fig. 46). As for the last stages of union, 96 percent of the casts demonstrate fissures at the inferior margin (Fig. 47). Union at the anterior and posterior margins is variable.

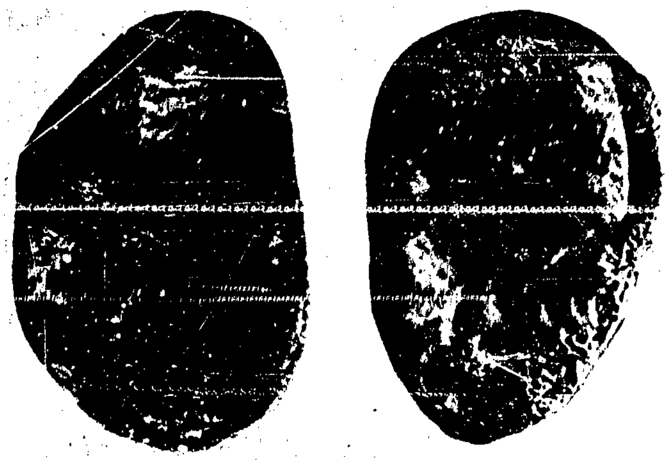


Fig. 46 Left and right medial surfaces of the clavicle showing beginning epiphyseal union at the superior margin. (No. 82, 20 years).

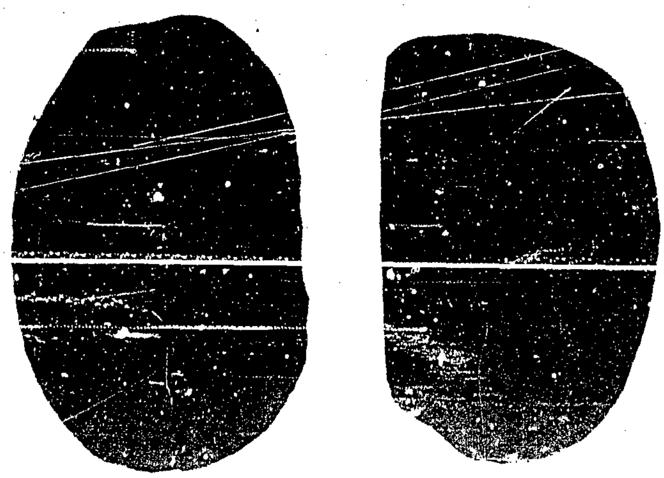


Fig. 47 Left and right medial surfaces of the clavicle showing late stages of epiphyseal union. (No. 111, 25 years).

One of the characteristic features of the medial end of the clavicle is its diversity in shape. Todd recognized this fact and divided his series into four types: plane, convex, concave and sigmoid (p. 30). However, on the basis of our observations, the variety of shapes seems to be far greater. For example, the outline of the epiphyseal face may be round, square, triangular or oblong, while the surface varies from deeply concave to convex. This variability tends to discourage any set classificatory procedure. For this reason and also since the shape of the medial end of the clavicle seems to have no influence on the course of the epiphyseal maturation, we feel that a few illustrations will give the reader a sufficient idea of the variability to be found in this area (Fig. 48 and 49).

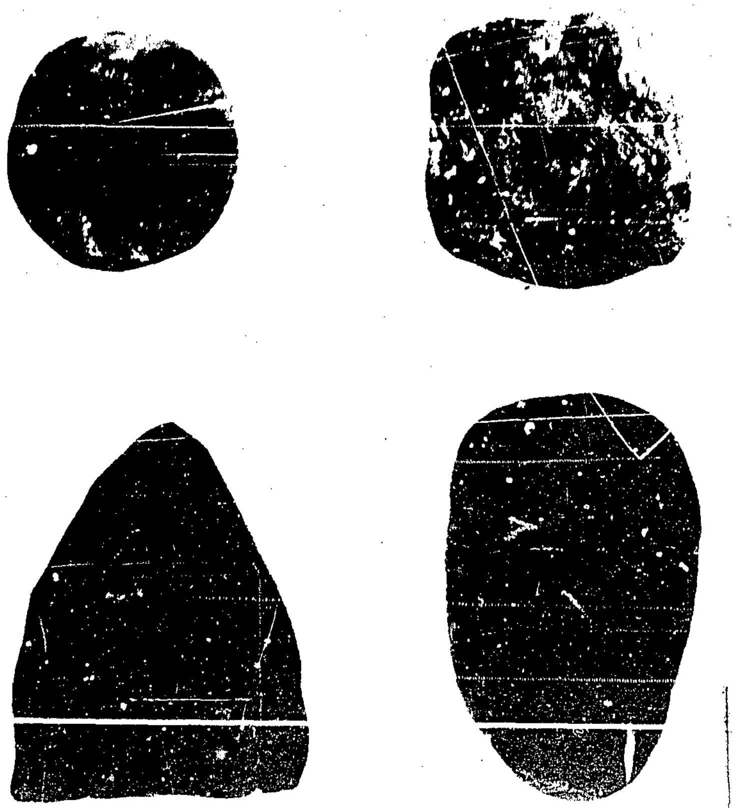


Fig. 48 Medial surfaces of the clavicle showing the variability in shape. Upper left: Round (No. 51, 18 years). Upper right: Square (No. 66, 26 years). Lower left: Triangular (No. 330, 22 years). Lower right: Oblong, (No. 108, 27 years).

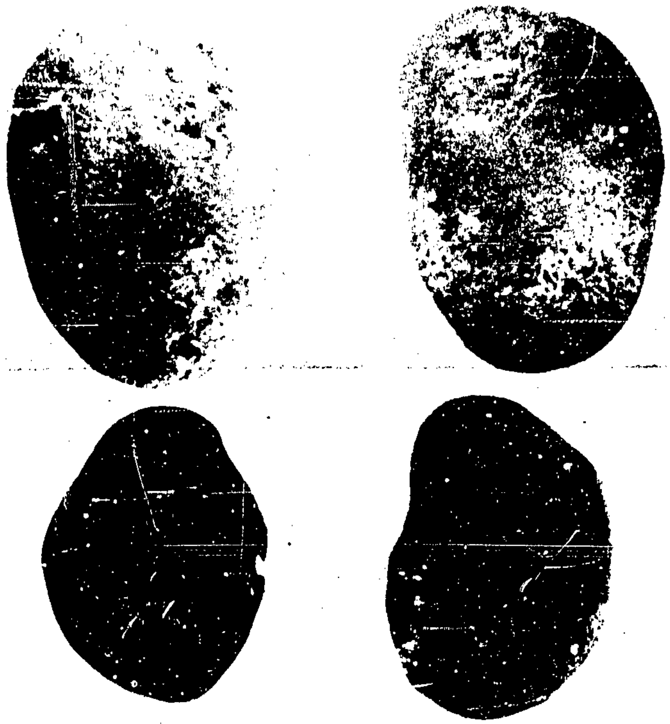


Fig. 49 Medial surfaces of the clavicle showing the variability in surface shape. Upper: Convex (No. 78, 28 years) (left and right). Lower: Deeply concave, (No. 193, 29 years) (left and right).

4. Summary

As early as 18 years but any time between 18 and 25 years, the epiphyseal cap begins to unite to the billowed surface of the medial end of the clavicle. Union begins at the approximate center of the face and spreads to the superior margin where it may progress either anteriorly or posteriorly. From 25 to 30, the majority of cases are undergoing terminal union. The last site of union is located, in the form of a fissure, along the inferior border. With the obliteration of these fissures (at age 31), the epiphysis is completely united.

CHAPTER VI

VERTEBRAL COLUMN

1. Introduction

The presacral vertebral column is composed of 23 to 26 segments which are differentiated functionally into 3 sections: cervical (7), thoracic (11-13) and lumbar (4-6). With the exception of some of the cervical vertebrae, each segment, regardless of its position in the column, presents at least 5 epiphyses: 2 for the centrum in the form of superior and inferior rings, one for the tip of each transverse process, and one for the tip of the spinous process. The progress of union of all these epiphyses is important in skeletal ageing. However, we shall limit our attention to the 2 epiphyses of the centrum (Fig. 50) and to the epiphysis of the spinous process.

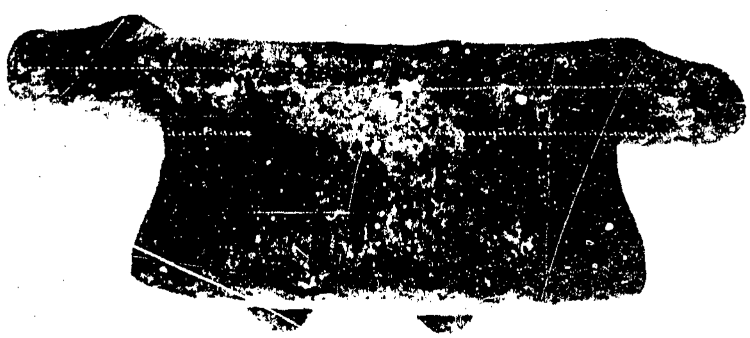


Fig. 50 Anterior surface of L-1 showing unattached epiphyses of the vertebral centra. (No. 139, 18 years).

We are unable to say whether the epiphyses for the transverse processes are already united at the beginning age of our series, for no provision was made for recording them and the photographs are not distinct enough to give us the detailed information.

Age changes in the vertebral column, other than epiphyseal maturation, include lipping of the anterior borders of the centra, the appearance and disappearance of striations on the surfaces of the centra, and spur formations on the superior borders of the laminae. Observations were recorded for these features.

2. Historical Remarks

A review of the literature on the presacral vertebral column reveals a lack of exact knowledge on epiphyseal maturation. Stevenson (1924) did not include these epiphyses in his study and Flecker (1942) limited his attention to the time of their first appearance (probably because his series did not go beyond the age of 17). Anatomy textbooks usually reflect this state of affairs by stating simply that the epiphyses of the vertebrae unite in the 25th year.

TABLE 31

THE AGE DISTRIBUTION OF STAGES OF UNION FOR THE SUPERIOR AND INFERIOR EPIPHYSEAL RINGS OF THE PRESACRAL COLUMN AS A WHOLE (in %)

		Superior Surface					Inferior Surface				
		Stages					Stages				
Age	No.	0	1	2	3	4	0	1	2	3	4
17-18	54	5	22	37	23	13	2	24	37	23	13
19	50		10	30	36	24		8	32	48	14
20	43		7	14	33	46		7	14	37	42
21	35			20	27	63			20	36	44
22	24			4	8	88			4	8	88
23	26				7	93				11	89
24-25	27					100					100
Total	259										

3. Epiphyseal Rings of the Centra

The progress of union for the epiphyses of the centra in the column as a whole is portrayed as a composite rating resulting from a general impression made while viewing the specimen. Table 31 summarizes these observations. Stages 2 and 3 appear most commonly between the ages of 19 and 21, and stage 4 is always present by 24 years. Also, there is no significant difference in the rate of union between superior or inferior

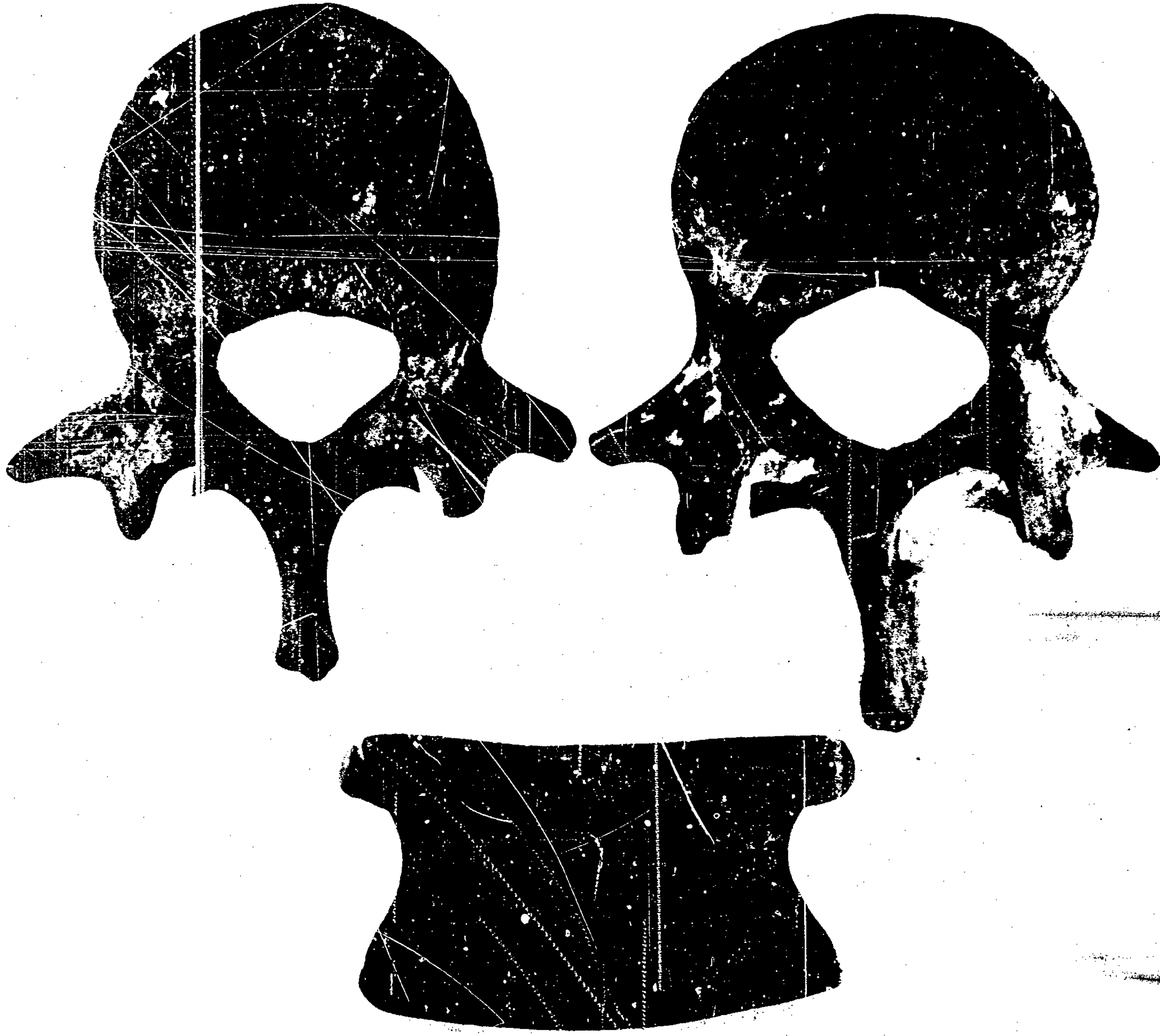


Fig. 51. Various views of the 1st lumbar vertebra showing stages of union.
Upper left: Stage 1 (No. 40, 18 years). Upper right: Stage 2 (No. 284, 18 years).
Bottom: Stage 3 (No. 11, 17 years).

rings. (See Fig. 51 illustrating stages of union).

In Table 32 we have recorded the age distribution of complete union for each of the thoracic vertebrae in order to show the local pattern of maturation. At the age of 20, complete union is seen only in the first and last 5 thoracic segments (T-1, T-8, T-9, T-10, T-11, and T-12). Thereafter, until the age of 24, there is a definite and consistant lag throughout the age groups in the region between T-2 and T-7, but especially in segments T-4 and T-5. Thus, it is important to examine these segments for the last signs of epiphyseal union in the presacral spine.

TABLE 32

AGE DISTRIBUTION OF THE COMPLETE UNION FOR THE EPIPHYSEAL RINGS OF THE INDIVIDUAL THORACIC VERTEBRAL CENTRA (%)

Age	No.	Thoracic Vertebrae 1	2	3	4	5	6	7	8	9	10	11	12
17-18	54	13	13	13	8	4	4	8	13	13	13	13	13
19	50	24	22	14	6	8	8	22	24	24	24	24	24
20	43	100	86	77	70	68	77	96	100	100	100	100	100
21	35	100	92	83	86	83	89	95	100	100	100	100	100
22	24	100	96	84	67	71	91	96	100	100	100	100	100
23	26	100	97	93	81	85	97	100	100	100	100	100	100
24-25	27	100	100	100	100	100	100	100	100	100	100	100	100
Total	259												

4. Vertebral Spines

Because the spinous processes were often damaged, thus making doubtful the status of epiphyseal union there, detailed observations were not attempted. However, on the basis of what could be seen, Table 33 shows that maturation for the epiphyses of the spinous processes parallels that for the epiphyseal rings of the centra. Active union occurs between the ages of 19 and 21 while union is completed in all cases by 24 years of age.

TABLE 33

AGE DISTRIBUTION OF STAGES OF UNION FOR THE EPIPHYSES OF THE VERTEBRAL SPINES (in %)

Age	No.	Stages 0	1	2	3	4
17-18	52	21	16	20	18	25
19	51	7	10	15	27	41
20	42	4	3	7	14	72
21	34			11	12	77
22	23				4	96
23	26				3	97
24-25	27					100
Total	255					

5. Vertebral Striations

The immature surfaces of the vertebral centra have an appearance which recalls the billowed epiphyseal surfaces elsewhere in the skeleton, and especially the symphyseal faces of the pubis. In the centra, the billowing takes the form of striations, which radiate from the center of the surface out toward the borders. These striations disappear in time and the surface becomes irregular and pitted (Fig. 52).

Table 34 shows the occurrence of striations on the thoracic and lumbar centra for ages 22 to 50 and thus demonstrates the areas of concentration as well as their rate of disappearance. As is seen, striations are highly variable and are confined to the lumbar and low thoracic centra. They occur in about 30 percent of the lumbar centra in the middle twenties and persist only in low percentages in the age groups beyond 31 years. Although striations were observed in the 41-50 age group, we feel that exact age at which striations finally disappear cannot be stated.

The persistance of vertebral striations into the fifth decade denies their utility for purposes of age identification. They constitute an additional feature supporting age determinations derived from the symphyseal surface of the pubis.

Fig. 52 Superior surfaces of first lumbar vertebrae showing: Left: billowed striations (No. 44, 18 years). Right: older surface minus striations but irregular and pitted (No. 360, 32 years).

TABLE 34

AGE DISTRIBUTION DEMONSTRATING THE OCCURRENCE OF STRIATIONS ON THE SURFACE OF THE VERTEBRAL CENTRA.
(in %)

Age	No.	Thoracic 1	2	3	4	5	6	7	8	9	10	11	12	Lumbar 1	2	3	4	5
22	25												16	28	32	32	32	32
23	26										4	8	15	30	30	30	30	30
24-25	26												15	30	30	30	30	30
26-27	25											5	20	28	20	16	16	16
28-30	29												6	20	13	13	13	13
31-40	43											2	11	11	8	8	8	8
41-50	6													-	-	-	-	-
Total	162																	

6. Vertebral Lipping

As seen in Table 35, the degree of lipping in the present series is mostly limited to stage 1. However, this stage increases in frequency

TABLE 35

AGE DISTRIBUTION FOR STAGES OF VERTEBRAL LIPPING FOR THE PRESACRAL COLUMN AS A WHOLE.
(in %)

Age	No.	Stages 0	1	2	3	4
17-18	55	93	7			
19	52	96	4			
20	43	95	5			
21	27	95	5			
22	25	92	8			
23	26	89	11			
24-25	26	77	23			
26-27	25	64	36			
28-30	29	40	60			
31-40	43	20	76	4		
41-50	6		100			
Total	367					

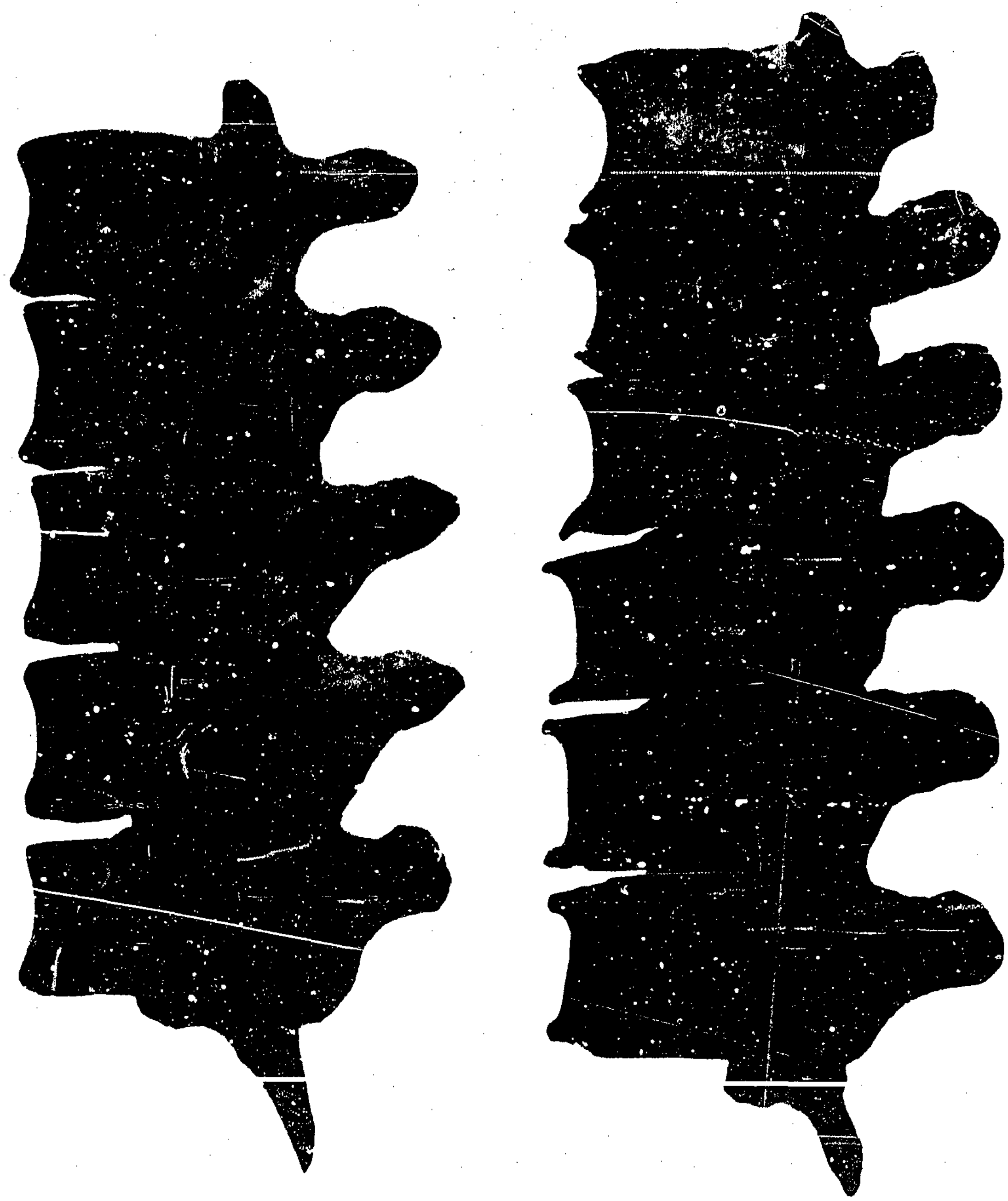


Fig. 53 Lateral anterior view, as articulated, of selected vertebrae showing: Left: no lipping at anterior margins, T-3 to T-7 (No. 118, 22 years). Right: marked lipping at anterior margins, T-4 to T-9 (No. 360, 32 years).

from the age of 22 and reaches 60 percent at 30 years of age. Above 30 years, lipping extends in a few cases to most of the cervical and all of the thoracic and lumbar vertebrae (Fig. 53).

The distribution of vertebral lipping, as shown in Table 36, is rather erratic, especially in the age groups up through 22 years, but the highest percentages are concentrated in the lower thoracic region (T-10 and T-11). It must be pointed out, however, that much of the erratic nature of the data in Table 36 is probably due to cases where lipping was caused by local injury. Without reliable medical histories or without better evidence of injury, it is seldom possible to separate evidence of local trauma from injury caused by normal mechanical stress.

Lipping was also observed on the facet for the dens of the first cervical vertebra (Fig. 54) and was found to be too variable for useful age association. For example, in each age group from 17 to 50 the occurrence ranges from no lipping to extreme lipping and seems to be more of an individual characteristic than an orderly age change.

In general, the occurrence of lipping in the presacral vertebral column, though progressive and somewhat localized to the areas of greatest mobility, exhibits a high variability that cannot be adequately or usefully applied to estimations of age.

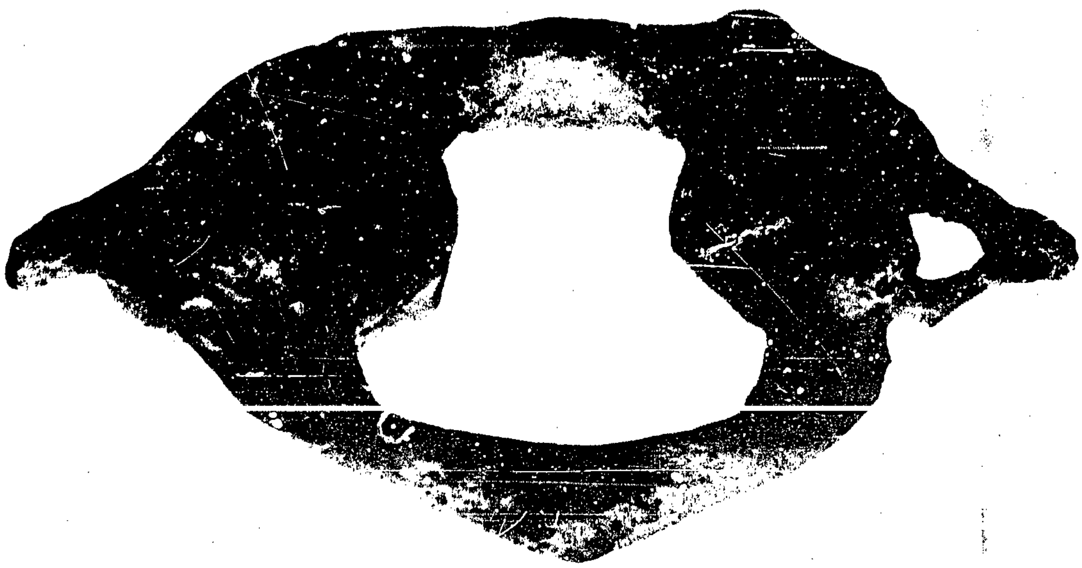


Fig. 54 Posterior superior view of the first cervical vertebra showing lipping of the facet for the dens. (No. 440, 31 years).

TABLE 36

AGE DISTRIBUTION OF VERTEBRAL LIPPING FOR THE SEPARATE ELEMENTS OF THE PRESACRAL COLUMN
(in %)

		Cervical							Thoracic												Lumbar				
Age	No.	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
17-18	55													4	4	2	2	2	2	4					2
19	52																2		2						
20	43								2	2	2			2		2	2		2						
21	37															3	3	3	5						
22	25														4				4				4	4	4
23	26									4	4	4	4	4	4	8	4	8	4	4	4				
24-25	26											4			4	4	4	8			4				
26-27	25					4	4			4	4	12	4	8	8	12	8	12	4						
28-30	29				3	3					6	13	10	20	20	33	30	23	13	23	3				
31-40	43			2	4	11	9	4	4	9	20	40	43	30	32	46	43	51	46	34	23	16	11	19	20
41-50	6					16				16	16	66	33	33	50	50	50	50	50	66	33	66	66	66	66
Total	367																								

7. Laminal Spurs

Bony spurs are often observed projecting from the laminae of the thoracic vertebrae (Fig. 55). These spurs have been described in detail by Le Double (1912) and Shore (1931). However, the reason or reasons for their occurrence was not known until 1938 when Haffziger, Inman and Saunders pointed out that they represent normal ossifications functionally associated with the interlaminar ligaments. Allbrook (1954) and Davis (1955) have also investigated various aspects of spur formation but no one has correlated this phenomenon with age.

Laminal spurs were observed in a large portion of the series under discussion and, although present on both superior and inferior borders, only those on the superior borders were recorded. The results are summarized in Tables 37 and 38.

Fig. 55 Posterior.superior view of two thoracic vertebrae showing: Left: slight projecting bone spurs of the 7th thoracic (No. 51, 18 years); Right: extreme projecting bone spurs of the 8th thoracic (No. 314, 21 years).

From Table 37, two conclusions are immediately evident: 1) with the exception of a few cases, the cervical vertebrae do not seem to be involved, 2) the amount of individual variation makes it impossible to correlate the occurrence of spurs with age. We can state only that with advancing age, the spurs are more frequently present and especially in the lower thoracic region.

TABLE 37

AGE DISTRIBUTION OF THE OCCURRENCE OF LAMINAL SPURS FOR THE PRESACRAL COLUMN AS A WHOLE. (in %)

		Cervicle							Thoracic												Lumbar				
Age	No.	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
17-18	55								9	14	18	25	30	29	25	27	27	34	40	30	10	9	3	1	1
19	52								9	19	25	30	28	28	36	36	30	40	38	19	13	13	7	3	2
20	43								11	18	29	39	49	39	46	51	53	58	55	49	16	14	4		
21	37							3	13	24	40	40	40	45	51	51	45	48	55	32	8	10	8	3	3
22	25								24	36	32	36	40	44	44	48	48	52	52	52	36	20	5		
23	26						4	4	30	46	53	53	53	53	61	61	69	69	61	53	34	30	15	11	4
24-25	26							4	11	46	61	65	69	80	73	84	73	80	84	77	46	50	19	15	7
26-27	25								12	28	48	52	56	60	60	56	56	68	68	60	28	24	8	8	12
28-30	29							3	36	46	56	63	63	56	66	70	73	73	76	70	36	30	23	20	16
31-40	43							4	14	44	58	74	65	67	67	69	74	74	74	74	49	30	20	20	14
41-50	6								33	50	50	66	66	50	66	83	83	93	100	66	50	33	16		
Total	367																								

To determine the area of most pronounced expression, the age distribution for the two most extreme stages of development (3 and 4) are summarized in Table 38. Again, individual variation makes it difficult to extract any significant trend. Since examples of the pronounced development of spurs can be found in all age groups from 17 to 50 and the occurrence of this feature ranges from T-3 to T-12, there seems to be no practical correlation between the bony spurs and age.

TABLE 38

AGE DISTRIBUTION FOR STAGES 3-4 OF VERTEBRAL SPURS IN THE THORACIC VERTEBRAE. (in %)

		Thoracic Vertebrae											
Age	No.	1	2	3	4	5	6	7	8	9	10	11	12
17-18	55						2	2	2	2	3	2	2
19	52			2	2	2	5	3	5	3	2	7	2
20	43				2								2
21	37							3	5		3	3	
22	25								8	8	16	14	5
23	26					4	11	8	8	11	11	18	
24-25	26					4	4	11	11	11	15	15	8
26-27	25							5	14	8	16	20	8
28-30	29			3	3	10	10	6	6	10	6	6	3
31-40	43			2		4	11	14	16	16	20	23	7
41-50	6						16	33	33	33	33	50	16
Total	367												

8. Summary

The presacral vertebral column is completely ossified by the 24th year. Noteworthy is the sequential pattern of ossification which shows the last signs of complete maturity occurring in the upper thoracic vertebrae (specifically, T-4 and T-5).

Striations tend to disappear from the surface of the centra, starting at 23 years of age, but may persist in the lumbar region for many years. Other age changes, in the form of lipping of the anterior borders and the formation of spurs on the laminae of the dorsal arches, show a progressive increase in their occurrence and gross development. However, all are too variable to be of much assistance in age identification.

CHAPTER VII

SCAPULA

1. Introduction

The scapula is a triangular-shaped bone forming the posterior end of the shoulder girdle. It is held in place largely by muscle but also by articulations with the head of the humerus at the glenoid fossa and with the clavicle at the acromial process.

Normally the scapula presents 6 epiphyses: two for the coracoid process and one each for the margin of the glenoid cavity, the acromion, the inferior angle, and the medial or vertebral border. However, since the epiphyses for the coracoid process and glenoid fossa usually unite before the beginning age of our series (Fig. 56), only the remaining 3 were observed and their union recorded.

The acromial epiphysis and the epiphysis of the inferior angle are easily seen and recorded. On the other hand, the epiphysis of the medial border presents an observational problem; it is either a long, narrow and very fragile strip of bone, or reduced to small segments (Fig. 57), and is frequently damaged, especially before union is complete. We feel, therefore, that our recordings of stages of union for this epiphysis may, in some cases, be incorrect and the results should be viewed with this in mind.

In addition to the above information, direct observations were made on age changes in the surfaces of the acromial facet and glenoid fossa.

2. Historical Remarks

The majority of studies on the scapula emphasize the comparative morphology or pathology and few, if any, consider the pattern of ossification. This scarcity of information on ossification is reflected in the anatomy textbooks (Grey, Morris and Cunningham, to mention a few) where it is simply stated that the epiphyses of the scapula are joined by the 25th year.

It was not until the 1920's, when the Western Reserve collection was formed, that the subject of epiphyseal maturation in this bone could be adequately analyzed. Using this collection of documented skeletons, Graves, in 1922, and Stevenson, in 1924, reached practically the same conclusions. Graves observed the age changes in 139 pairs of scapulae

Fig. 56 Proximal end of left scapula showing last stages of union for the epiphysis of the glenoid fossa (only case found in our series). (No. 317, 18 years).

Fig. 56 Proximal end of left scapula showing last stages of union for the epiphysis of the glenoid fossa (only case found in our series). (No. 317, 18 years).

Fig. 57 Right scapula showing the epiphysis of the medial border reduced to small segments. (No. 328, 38 years.)

ranging in years from 18 to 88 and concluded (p. 21) that the several epiphyses unite at different ages, "...finally producing an adult scapula in every detail by approximately the 22nd year of life..." Two years later, Stevenson, working with a sample of 110 pairs from ages 15 to 28, concluded (p. 70) that, "The date of union for these (epiphyses) varies in different individuals between the nineteenth and twenty-second years."

We will now add our observations for comparison.

3. Epiphyses for the Acromion, Inferior Angle and Medial Border.

Table 39 summarizes the 4 stages of epiphyseal maturation for the 3 epiphyses under consideration. With the exception of 6 cases in which the acromial epiphysis was united on one side but not on the other, significant differences in stages of maturation between right and left scapulae were not found. Thus, side is disregarded in this table.

TABLE 39

AGE DISTRIBUTION OF STAGES OF EPIPHYSEAL UNION FOR THE ACROMION, INFERIOR ANGLE AND MEDIAL BORDER OF THE SCAPULA. (in %)

		Acromion					Inferior Angle					Medial Border				
Age	No.	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
17	10	50	-	-	10	40	50	10	-	-	40	60	-	-	10	20
18	38	20	4	4	8	64	38	8	2	12	40	46	10	8	10	26
19	51	10	2	2	4	82	21	-	4	11	64	30	-	10	15	46
20	43	4	-	2	11	83	9	-	-	4	87	7	5	5	13	70
21	37	-	-	-	5	95	5	-	2	2	91	-	6	10	13	71
22	24	4	-	-	-	96	-	-	4	-	96	-	4	4	4	88
23	26	-	-	-	-	100	-	-	-	-	100	-	-	-	-	100
Total	229															

From Table 39, it is evident that union commences for all three epiphyses prior to the starting age of the present series (17 years) and finishes in the 22nd year. The progress of union is irregular throughout the age groups owing, perhaps, to the difficulties of observation mentioned. Graves and Stevenson also noted this irregularity. However, in spite of irregularity and rapidity of union, there is some evidence indicating a sequence. Even though all three are completely fused at the same age, the epiphyses for the acromion and inferior angle show concentrated activity in the ages of 18 to 20 whereas the epiphysis for the medial border demonstrates a lag in progress that lasts through the age of 22.

Infrequently the acromial epiphysis fails to unite altogether. Earlier reports of separate acromial bones by Symington (1900), Vallois (1932) and Gray (1942) give frequencies of occurrence of 6.2, 2.7 and 3.3 percent respectively. This feature is represented in our series by a single case in an individual 37 years of age (Fig.58). It is necessary to be aware of this anomaly in order to avoid mistaking it for evidence of immaturity.

4. Changes in Joint Surfaces

As already noted, the scapula presents 2 joint surfaces: a facet on the acromion for articulation with the clavicle, and the glenoid fossa for articulation with the head of the humerus. Normal wear to these surfaces during the life span of the individual produces various changes, but mainly lipping of the joint margins (Fig. 59). Since lipping is often taken into consideration in estimating skeletal age, observations on its frequency at these sites are presented in Table 40.

TABLE 40

AGE DISTRIBUTION OF STAGES OF LIPPING FOR THE CLAVICULAR FACET AND GLENOID FOSSA. (in %)

		Clav. Facet Lipping					Glenoid Lipping				
Age	No.	0	1	2	3	4	0	1	2	3	4
17	10	90	10	-	-	-	30	70	-	-	-
18	38	84	16	-	-	-	72	28	-	-	-
19	51	75	23	2	-	-	44	54	2	-	-
20	43	66	32	2	-	-	46	54	-	-	-
21	37	55	40	5	-	-	51	44	5	-	-
22	24	55	41	4	-	-	50	50	-	-	-
23	26	54	42	4	-	-	32	57	11	-	-
24-25	27	51	45	4	-	-	55	41	4	-	-
26-27	25	20	44	28	8	-	40	28	24	4	4
28-30	29	54	37	9	-	-	41	43	16	-	-
31-40	42	28	57	11	2	2	16	52	23	9	-
41-50	6	33	16	51	-	-	-	34	33	33	-
Total	358										

Fig. 58 Left scapula showing failure of acromial epiphysis to unite. (No. 122, 37 years).

Fig. 59 Left scapula showing lipping of the glenoid margin. (No. 360, 32 years).

As will be seen, beginning lipping is present in both joints throughout the series. In the glenoid fossa this amounts to very little more than a slight angulation of a previously rounded margin. Although the percentages in Table 40 are erratic (due in some part to subjectivity of observation), they show a general increase with advancing age. It should be noted also that 2nd-degree lipping does not begin until the late teens and high frequencies of this stage do not appear until the middle 20's. We can conclude therefore, that lipping of the scapular joints progresses too slowly to be of much help in age identification except as it may substantiate or support other ageing criteria.

5. Summary

Since the epiphyses for the caracoid process and glenoid margin usually unite before the beginning age of our series, stages of union were recorded only for the acromion, inferior angle and medial border. Though the epiphysis for the medial border lags in the early twenties, fusion for all three is completed by the 23rd year.

The occurrence of lipping on the acromial facet and glenoid fossa cannot be used for other than supportive age evidence.

CHAPTER VIII

STERNUM

1. Introduction

Morphologically the sternum is the most variable bone in the body. According to Ashley (1956), a very definite relationship exists between the shape of the adult sternum and the number and arrangement of the ossification centers from which the bone develops. Most of this variation involves the middle portion of the bone, the corpus sterni; the form of the superior portion, the manubrium sterni, is much more constant; that of the inferior portion, the xiphoid process, is inconstant (it has been largely disregarded in the present study). At the beginning age of the Army series (17-18 years) the sternum usually consists of a manubrium and a still-subdivided corpus sterni (with as many as three parts and sometimes with traces of other previously separate parts).

The joint between the manubrium and the corpus sterni, known as the manubriogladiolar or superior intersternal joint, is, of coarse, unpaired (although the second pair of ribs are attached here). Otherwise there are usually 8 paired joints formed by the clavicles and the first 7 ribs. Although there are thus 17 joint areas providing age indications, only 5 (one unpaired, 4 paired) have been utilized in the present study. The observed paired joints are the sternoclavicular and the first, third and fourth chondrosternals. In addition, the so-called interarticular groove between the sternoclavicular and first chondrosternal joints on each side was observed. Each feature was rated on the usual scale of 0-4. These readings were supplemented with a photograph of the whole sternum (usually only the anterior surface) and by a cast of one lateral side of the manubrium (both sides were cast when they were asymmetrical, and sometimes a cast was made of one side of the corpus sterni).

Attention is called to the fact that the superior intersternal joint and the paired first chondrosternal joints are usually synchondrodial in type: that is, they lack joint cavities, cartilage being joined directly to bone. The paired sternoclavicular and other chondrosternal joints are diarthrodial, having well-defined joint cavities. It is noteworthy also that (Stewart 1954, p. 521) "on each side the joints for the clavicle and first rib, which differ in type (see above), are contiguous, whereas the joint for the second rib is located at the junction of the manubrium and corpus and hence in close relationship with the superior intersternal joint (again 2 joints of different type in juxtaposition)".

2. <u>Historical Remarks</u>.

In 1890 Thomas Dwight, Professor of Anatomy at Harvard University, investigated the sternum from the identification standpoint. He concluded that, "The sternum is of little value as an index of age" (p. 532). Perhaps because of this discouraging report, no one else seems to have studied age changes in the sternum until 1954, when Stewart published his preliminary report on "Metamorphosis of the joints of the sternum in relation to age changes in other bones." The latter study was undertaken to explore the possibility of including the sternum in the present work on the remains of American soldiers. In order to evaluate the findings on the soldiers, the summary of the 1954 findings, which was stated in very tentative terms, is quoted here:

> 1. <u>Up to the time the proximal epiphysis of the humerus is uniting (up to 17-18? years)</u>.
>
> Component elements of the corpus sterni are still identifiable, although those in the inferior two-thirds may have fused. Joint surfaces here and in the manubrium are rounded, dimpled or billowed, and exhibit a matte-like surface texture.
>
> 2. <u>Coincident with, and somewhat following, the union of the proximal epiphysis of the humerus (about 19-20? years)</u>.
>
> Epiphyseal plates can be found in all stages of union on the clavicular facets. At the end of this period epiphyseal plates are beginning to unite on the rib facets, or failing the formation of plates, the articular surfaces are beginning to glaze over. Also, in most cases, the superior element of the corpus is fusing with the element next below.
>
> 3. <u>Coincident with the union of the epiphyses for the iliac crest and ischial ramus (about 20-23? years)</u>.
>
> The eminence marking the boundary between the articular areas of the clavicle and first rib gives way to a sharp transverse ridge. The last step in the formation of this ridge is the filling-in of a ventral interarticular notch. At this time the facets for the third ribs are usually divided by a transverse cleft, the last remaining

sign of the recent fusion of the superior element of the corpus.

4. Coincident with and immediately following union of the epiphysis at the sternal end of the clavicle (about 20-30? years).

Raised rim is formed around the articular areas of the first and second ribs and those of the superior intersternal joint. By this time the superior intersternal joint has broadened so that the articular surfaces are rectangular. Facets for first ribs become slightly more porous. Clefts in facets for third ribs are being bridged across ventrally and dorsally.

5. Just before or coincident with the appearance of arthritis in the vertebrae (about 35 years).

Hypertrophic bone spurs appear around the margins of the facets for the first ribs, particularly ventrally and dorsally and more above than below. The other rib facets develop spurs much more slowly. Also, there may be progressive, disorderly break-down of the joint surfaces.

3. Fusion of primary elements

As pointed out in the introduction, the corpus sterni at 17 years of age usually is still in two or more parts. Thereafter the fusion which has taken place in the lowermost segments moves upwards to bring about the incorporation of the remaining segments. Table 41 shows the progress of fusion between the second and third segments (at the level of the attachment of the fourth ribs)* during the interval from 17 to 25 years. The distinction between recent (stage 3) and complete (stage 4) fusion is often difficult to determine. In general, stage 4 was assumed to have been reached when no cleft remained at the bottom of the costal notch, or when such a cleft, although present, was bridged over and otherwise looked mature. Evidence of immaturity often is more visible posteriorly than anteriorly. Figure 60 shows such a case involving the next highest level. As will be seen from the table, 72.7% of the 17-18 year group had reached the third and fourth stages of fusion. Not until 23 years were 100% of cases in these stages. In view of this situation perhaps an equally significant finding is that nonunion at this level may exist up to the age of 22. Figure 61 shows an example of such nonunion at this age.

Fusion of the primary elements of the corpus at the next highest level, that is, between the first and second segments (level of attachment of the third ribs) follows a later and slower course. Table 42

*The segments, like the ribs, are numbered from above downward.

TABLE 41

PROGRESS OF FUSION BETWEEN SECOND AND THIRD SEGMENTS OF THE CORPUS STERNI (AT LEVEL OF ATTACHMENT OF FOURTH RIBS). (in %)

Age	No. of Cases	No Fusion	Beginning Fusion	Active Fusion	Recent Fusion	Complete Fusion
17-18	44	9.1	9.1	9.1	68.2	4.5
19	42	11.9	-	4.8	69.0	14.3
20	36	5.6	-	-	55.6	38.9
21	37	8.1	2.7	2.7	48.6	37.8
22	22	4.5	-	-	45.4	50.0
23	24	-	-	-	50.0	50.0
24-25	24	-	-	-	8.3	91.7

TABLE 42

PROGRESS OF FUSION BETWEEN FIRST AND SECOND SEGMENTS OF THE CORPUS STERNI (AT LEVEL OF ATTACHMENT OF THIRD RIBS). (in %)

Age	No. of Cases	No Fusion	Beginning Fusion	Active Fusion	Recent Fusion	Complete Fusion
17-18	46	45.6	2.2	13.0	34.8	4.3
19	43	27.9	-	13.9	51.2	7.0
20	38	13.2	5.3	7.9	52.6	21.0
21	38	13.2	-	7.9	52.6	26.3
22	23	8.7	-	4.3	56.5	30.4
23	24	16.7	-	-	58.3	25.0
24-25	24	-	-	4.2	41.7	54.2
26-27	25	12.0	-	-	36.0	52.0
28-30	29	3.4	-	-	37.9	58.6

summarizes the progress of fusion at this level during the interval from 17 to 30 years. Fusion here makes the corpus sterni one piece of bone. As will be seen from this table, the combined stages of recent and complete fusion has been reached in 39.1% of the cases by 17-18 years. Thereafter the percentage rises but does not reach 100%, because unlike in the preceding table there is evidence in Table 42 of persistence of nonunion in a few cases. Figure 62 shows such a case persisting to the age of 27 years. On the other hand, some of these cases of nonunion at the level of attachment of the third ribs are to be accounted for by the presence of an anomaly in which the segment that would normally fuse with and form

Fig. 60 Anterior and posterior views of the corpus sterni in case No. 386 (unidentified) showing that union of the top segment may be delayed posteriorly.

the uppermost part of the corpus instead fuses with the bottom of the manubrium, thus producing an unusually long manubrium. Examples of such anomaly are shown in Figure 63. Except for anomalous cases which can often be identified because of signs of advanced maturation elsewhere in the bone, it would seem that nonunion is absent after 22 years of age. On the other hand, attention is called to the fact that signs indicative of stage 3 can be found throughout the third decade (Fig. 64).

Normally the joint between the manubrium and corpus sterni, the so-called superior intersternal joint, does not fuse. However, in the preceding paragraph it has been pointed out that the manubrium sometimes captures the uppermost segment of the corpus. Also, occasionally there is fusion between the manubrium and the corpus as a whole. Trotter

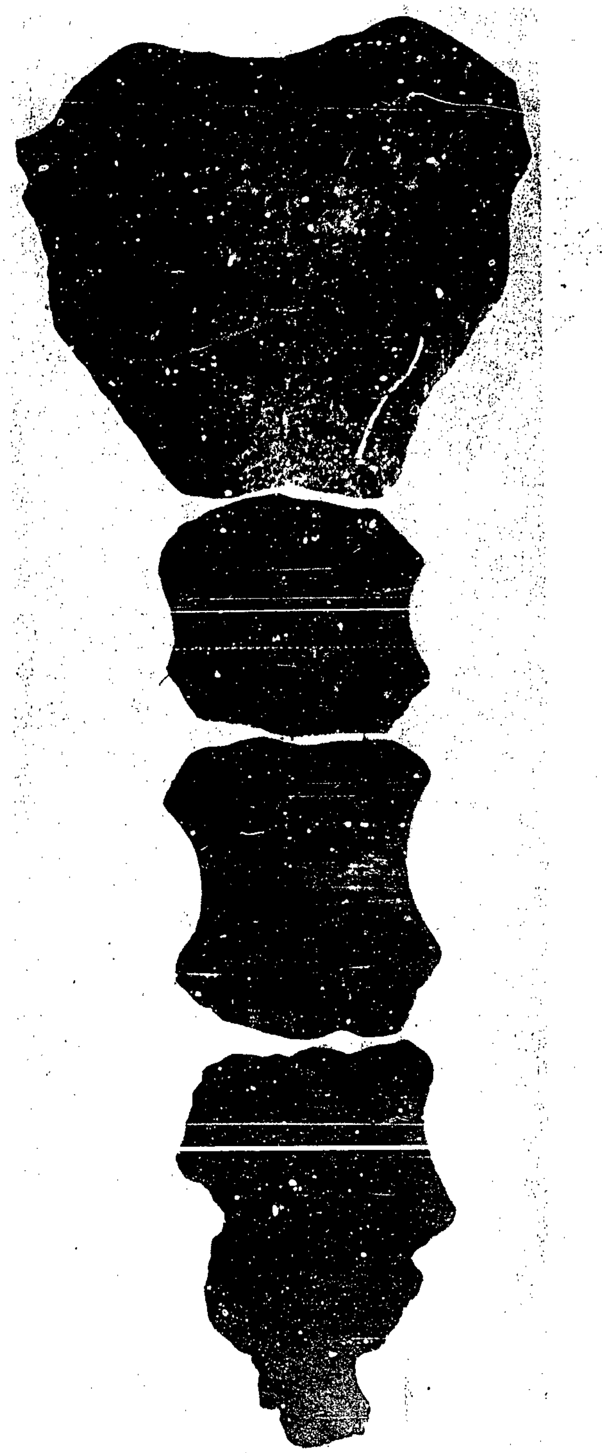


Fig. 61 An example of delayed union of the segments of the corpus sterni. (No. 83, 22 years.)

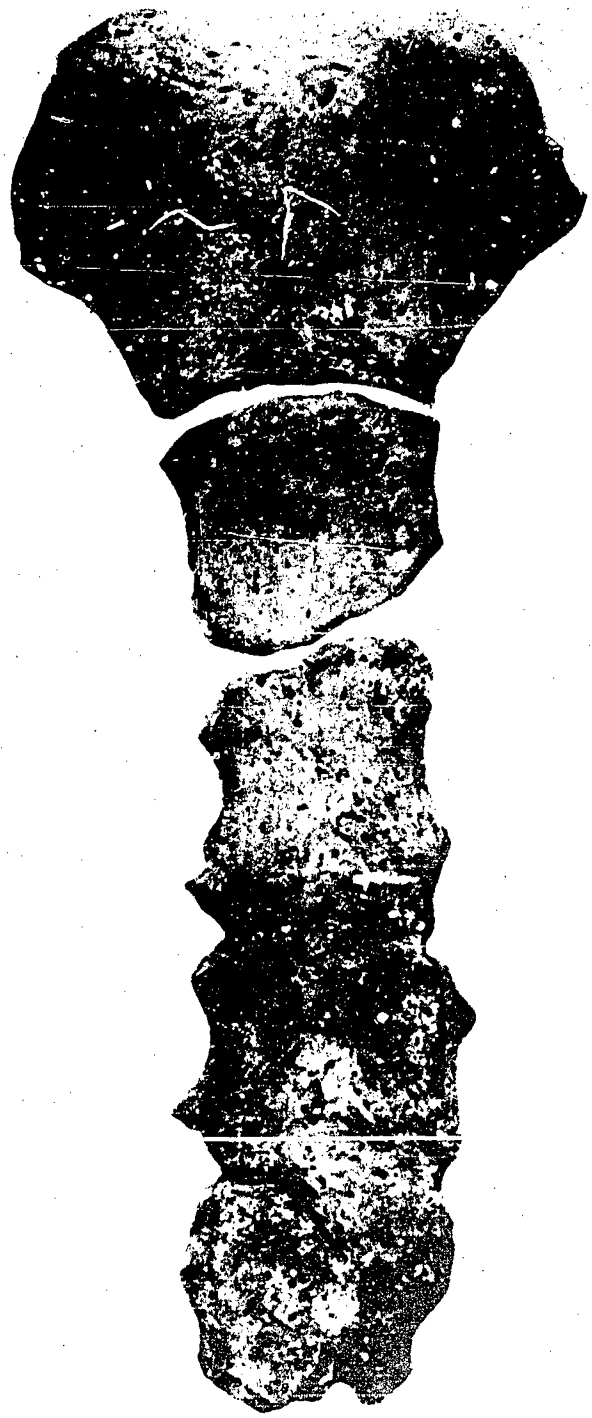


Fig. 62 Example of delayed union of the top segment of the corpus sterni. (No. 420, 27 years).

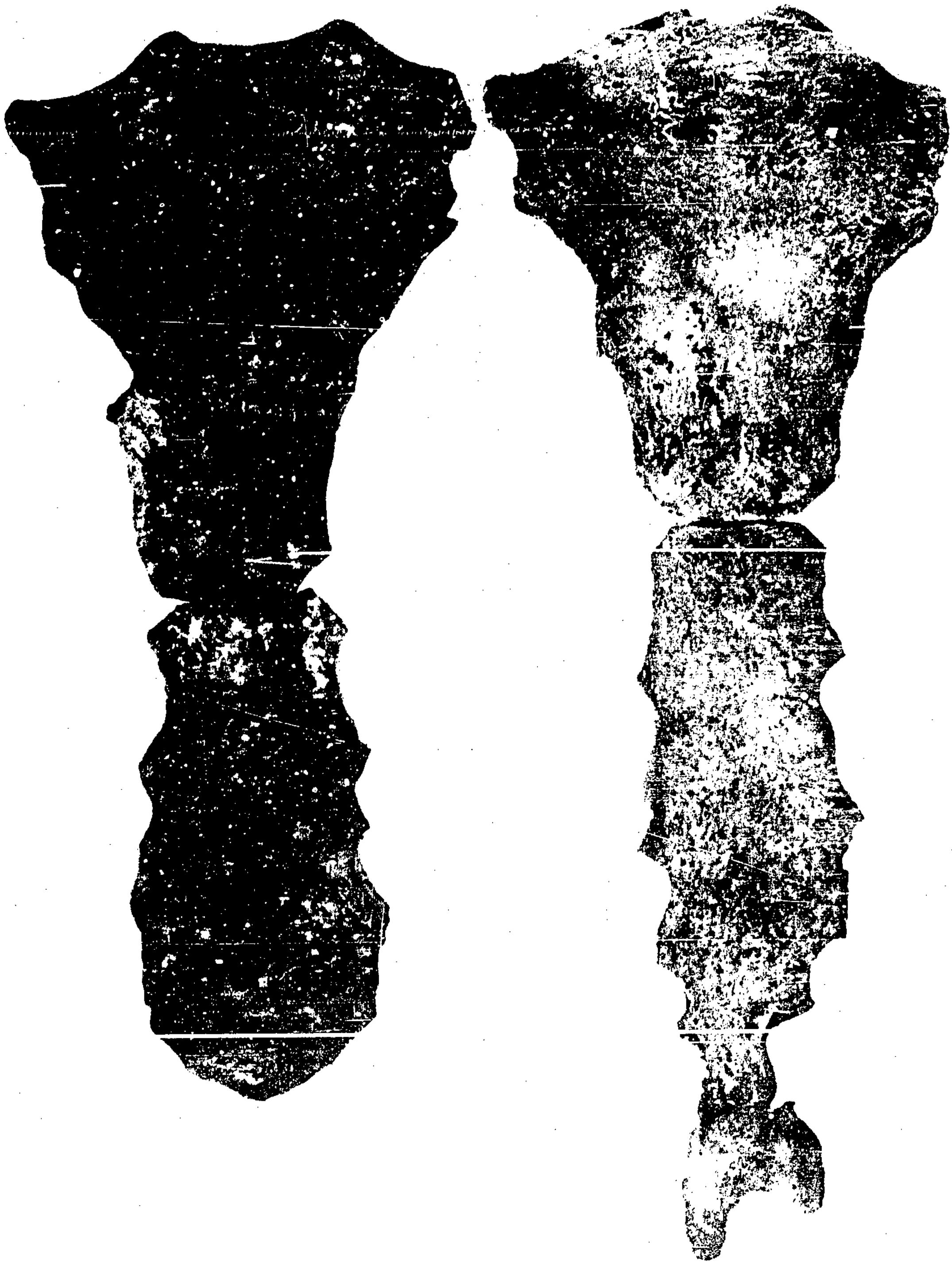


Fig. 63 Examples of extra long manubria in which it appears that the segment that normally fuses with and forms the uppermost part of the corpus instead has fused with the bottom of the manubrium. (Left: No. 413, 28 years; Right: No. 109, 30 years).

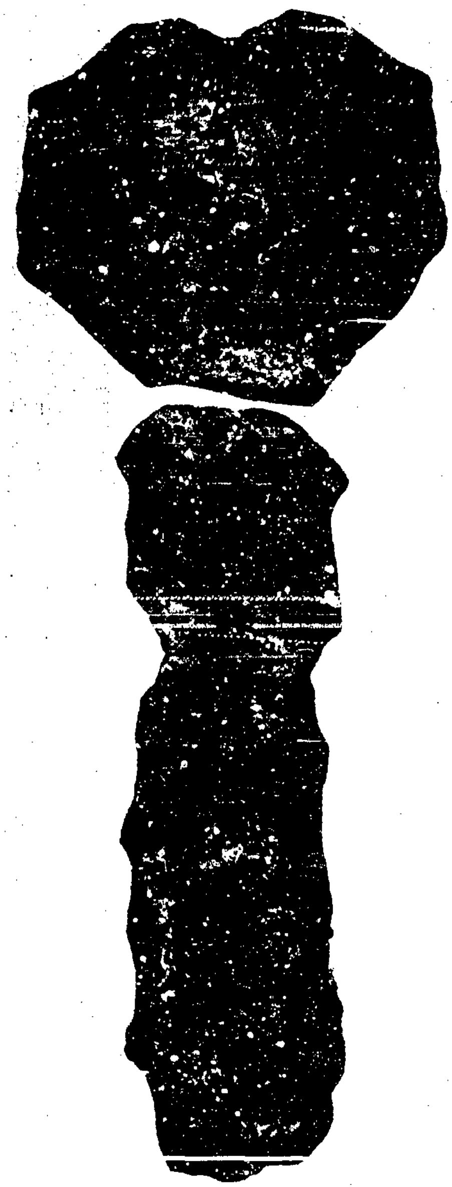


Fig. 64 Signs of recent union (stage 3) of the first and second segments of the corpus sterni in an individual 25-28 years of age. (No. 424, POW, exact date of death uncertain).

(1934) found that such fusion occurred in 5.7% of cases up to the age of 30 and in 10.3% of cases between 30 and 60. Thus the correlation with age is very low. As will be seen from Table 43, our total series yields a frequency of 5.2% of such fusions. According to this table also a thickening of the joint surface, usually with a breakdown of the surface (Fig. 65, middle), occurs in 13% of cases. In none of these, of course, is the joint fused. However, since most fused superior intersternal joints are thickened (Fig. 66), it would seem likely that thickening and surface breakdown are preliminary stages of fusion at this level. We feel that when no thickening can be detected in a fused superior intersternal joint, the manubrium could have been of the anomalous type described earlier. Joint thickening does not seem to occur at other segmental levels (Fig. 65, right).

TABLE 43

THICKENING AND FUSION OF SUPERIOR INTERSTERNAL JOINT BY AGE (in %)

Age	No. of Cases	No Fusion	Joint thickened but not fused	Fusion
17-18	52	90.4	9.6	-
19	46	84.8	13.0	2.2
20	44	86.4	9.1	4.5
21	38	84.2	10.5	5.3
22	23	82.6	17.4	-
23	24	66.7	25.0	8.3
24-25	26	76.9	7.7	15.4
26-27	25	88.0	4.0	8.0
28-30	30	80.0	6.7	13.3
31-40	43	62.8	32.6	4.6
41-50	6	66.7	33.3	-
Unknown	72	87.5	8.3	4.2
Means		81.8	13.0	5.2
TOTAL	429			

4. The Clavicular Notch

As pointed out by Stewart in 1954, an incompletely attached epiphysis sometimes is to be seen on the surface where the clavicle articulates (Fig. 67). This epiphysis may be so thin and scale-like that its presence is not readily detected. Also, since this feature is seen infrequently, the possibility exists that, like the epiphysis on the medial end of the clavicle, it may be greatly reduced in size or may not develop at all in some cases. Be this as it may, before epiphyseal union or its equivalent,

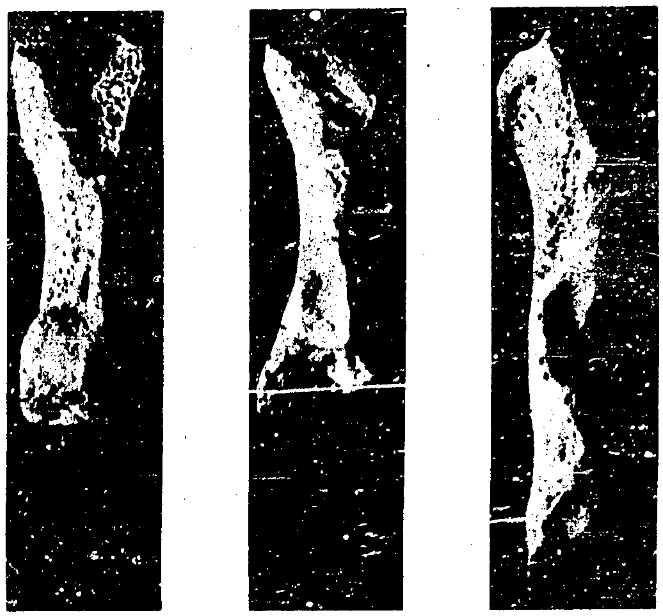


Fig. 65 Casts of the left side of 3 manubria showing variations at the level of the costal I notch. Left and middle: Normal and thickened superior intersternal joints, respectively. Right: A manubrium with a captive upper segment of the corpus but no thickening at the level of fusion. (Nos. 445, 81 and 413, respectively, all 28 years).

the surface is somewhat irregular, being dimpled or billowed, but seldom quite as much so as most other such surfaces (Fig. 68). Thus, in scoring the notch, any suggestion of billowing was rated as stage 1, and a visible epiphysis was rated as stage 2. Originally an effort was made to distinguish also stages 3 and 4 (that is, nearly and completely mature notches), but it was soon realized that these stages are not distinguishable and any opinion thereon is based on a knowledge of maturation events in other parts of the skeleton.

Table 44 shows the progress of maturation, as thus defined, in the clavicular notch from 17 to 23 years. It should be borne in mind that these results represent scorings made over a period of several months without any opportunity for reassessment. If the specimens had been available for review, it is possible that more individuals might have

Fig. 66 Three cases of synostosis between the manubrium and the body of the sternum showing different degrees of joint thickening. (Left: No. 314, 21 years; Middle: No. 396, unidentified; Right: No. 361, 39 years).

Fig. 67 Example of large epiphyses attached to clavicular notches of manubrium. In this case also, the manubrium is extra long and like those shown in Fig. 63. (No. 2, 19 years).

Fig. 68 Cast of the right side of the manubrium (No. 317, 18 years) showing the clavicular notch in the billowed stage prior to epiphyseal union. The billowing in this case is more prominent than usual.

been judged to be in the stage prior to epiphyseal union. Nevertheless, it seems likely that the date of the union of this epiphysis centers around 19 years. This opinion is supported by four other cases which have remained unidentified but which show stages of skeletal maturation comparable to those found in the 19-20 year group. Since the presence of an epiphysis was noted in such a small number of cases (and it was looked for specifically), it appears to have rather little utility in age identification. Examples of clavicular notches with epiphyses present are shown in Figure 69.

TABLE 44

PROGRESS OF MATURATION OF THE CLAVICULAR NOTCH
(in %)

Age	No. of Cases	Epiphysis Ununited	Epiphysis Uniting	Surface Essentially Mature
17	9	33.3	-	66.7
18	35	2.8	5.7	91.4
19	43	-	9.3	90.7
20	42	-	4.8	95.2
21	36	-	2.8	97.2
22	19	-	5.3	94.7
23	23	-	-	100.0

5. Costal I Notch

As pointed out in the introduction, the first ribs join the sternum through cartilaginous extensions (synchondroses) which are contiguous with the diarthrodial clavicular attachments. As a result of this difference in joint structure the typical costal I notch, when mature, displays a roughened and porous surface, whereas the clavicular notch has a smooth and compact surface. Occasionally, however, the surface of the costal I notch, especially in its superior part, displays a texture indistinguishable from that of the clavicular notch (Fig. 70). Presumably this altered surface represents an extension downward from the clavicular notch of the diarthrodial joint structure. In anomalous cases of this sort, maturational changes are obscured and seldom can be interpreted. Also, the porous surfaces of typical costal I notches, especially before they are fully mature, are vulnerable to weathering, with consequent loss of maturational detail. In the present series, as Table 45 shows, anomalous and weathered costal I notches are present and are the reason for eliminating a high percentage of

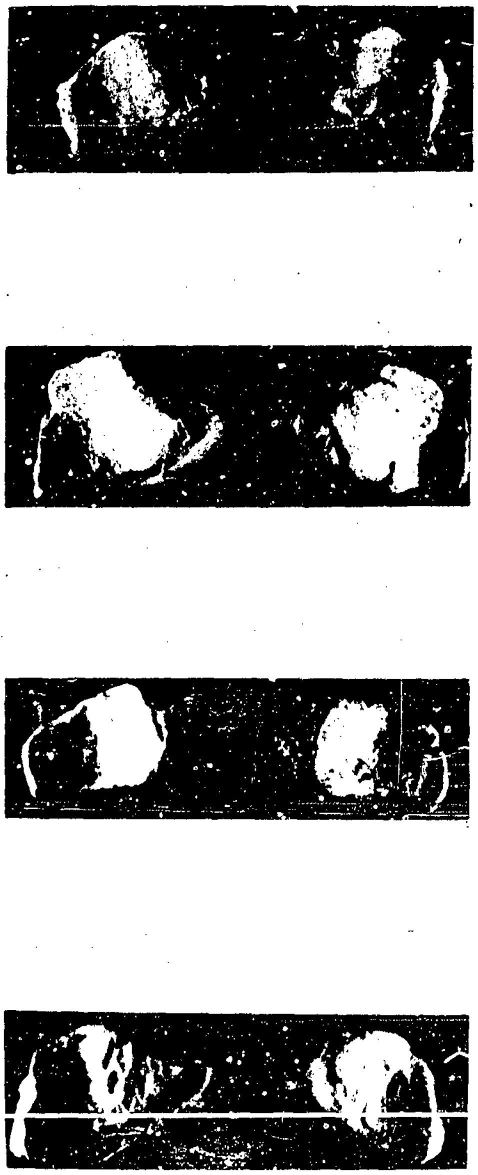


Fig. 69 Casts of the superior surface of 4 manubria showing epiphyses nearly united in the clavicular notches. (Top to bottom: No. 320, 19 years; No. 207, 21 years; No. 430, 19 years; No. 195, 18 years).

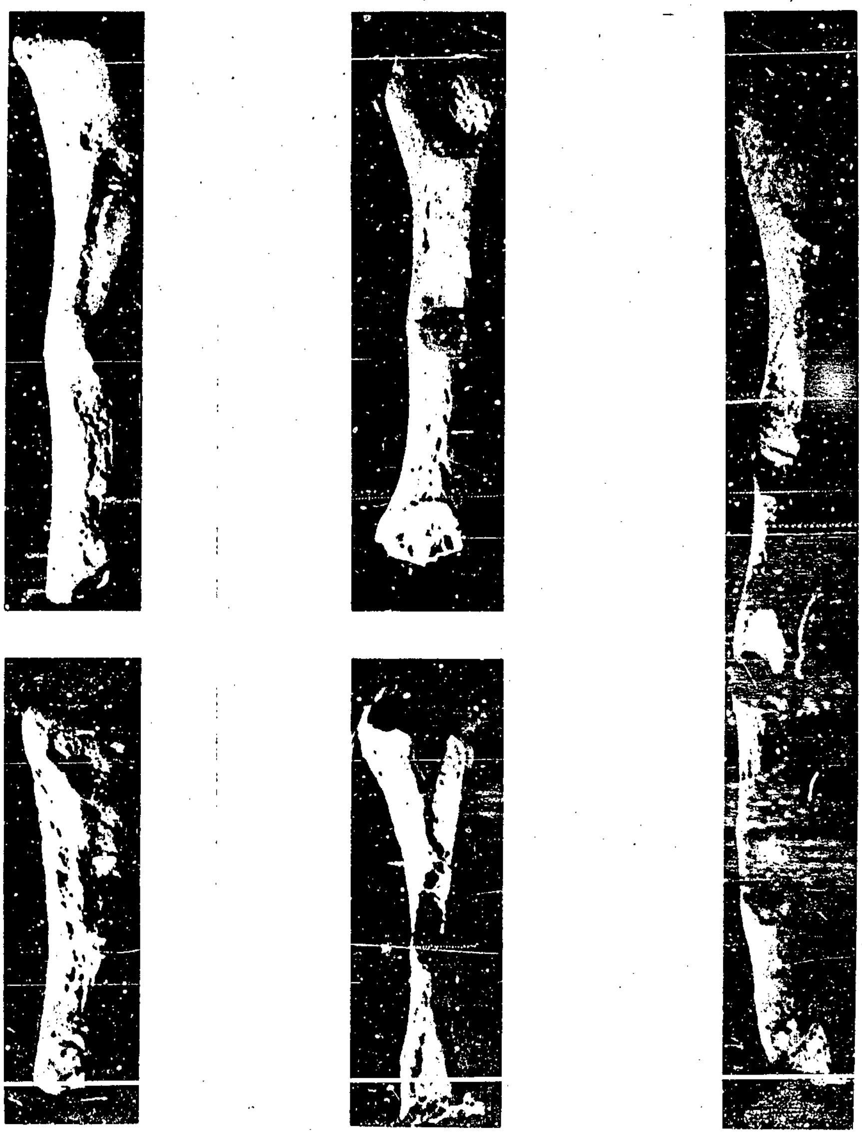


Fig. 70 Casts of the left side of 4 manubria and one manubrium fused with the corpus. The 4 separate manubria are extra long and have costal I notches resembling in texture the clavicular notches. Note the absence of joint thickening in the case where the manubrium is fused with the corpus. (Upper left: No. 22, 21 years; upper middle: No. 428, 33 years; right: No. 176, 25 years; lower left: No. 172, 20 years; lower middle: No. 332, 31 years.)

TABLE 45

DISTRIBUTION OF USABLE AND UNUSABLE COSTAL I NOTCHES BY AGE

Age	No. of Cases	Manubrium Missing	Notch Damaged	Notch Anomalous One Side	Notch Anomalous Both Sides	Usable Spec. No.	Usable Spec. %
17-18	55	10	18	4	1	26	47.3
19	53	9	14	1	2	28	52.8
20	45	4	12	3	4	25	55.5
21	39	3	9	3	3	24	61.5
22	25	6	2	-	-	17	68.0
23	27	3	7	2	2	15	55.6
24-25	28	1	2	3	7	18	64.3
26-27	25	-	2	7	1	22	88.0
28-30	29	1	2	3	1	25	86.2
31-40	43	-	-	4	4	39	90.7
41-50	6	1	-	-	1	4	60.7
Totals	375	38(10.1%)	68(18.1%)	30(8.0%)	26(6.9%)	243	64.8

specimens from analysis. In addition, the manubrium was not recovered in some cases. It is important to note, therefore, that after approximately 4 years of burial in Korea, and in spite of careful disinterment, the costal I notch is fully utilizable for age identification in only about half the cases around 17-19 years of age, and in about two-thirds of the cases between 20-25 years of age. Given different burial conditions the state of preservation might, of course, be worse or it might be much better.

As in the case of the clavicular notch, the original observations on costal I notch were judged to have been influenced by knowledge of other maturational features. Since, however, a cast had been made of one side of the manubrium in each case, new observations were made on the casts without reference to the findings on the rest of the skeleton. The following statements are based mainly on these new observation.

An essential part of the maturation and resultant differentiation of the clavicular and costal I notches is the obliteration of the anterior, or ventral, interarticular groove (Stewart, 1954, p. 525). It is clear in a number of cases that the medial portion of this groove is filled in by an extension of the epiphysis for the clavicular notch (Fig. 71). How otherwise the groove is filled in is rarely clear, but certainly most cases reach maturity without a trace of the groove. Yet in a small percentage of cases the anterior superior border of the costal I notch may appear to be defective well after the first half of the third decade. Such defects in older age groups probably do not represent a persistence of the interarticular groove, but rather an irregularity of ossification. Often the border between the two notches is the site of one or more separate ossific elements which may or may not unite with the manubrium. Union seems to be indicated when the border between the two notches is unusually prominent; nonunion is indicated when the usual sharp border is replaced by one or more facets (Fig. 72). Thus, although it seems likely that the last traces of the interarticular groove disappear by 22-23 years, it becomes necessary to base this judgment on the appearance of the costal I notch as a whole.

Fig. 71 Casts of left side of 4 manubria showing successive stages of the filling in of the interarticular groove, seen here at the upper left margin of the costal I notch (Left to right: No. 74, 21 years; No. 234, 24 years; No. 187, 26 years; and No. 78, 28 years).

While the interarticular groove is disappearing, the concavity of the costal I notch is also undergoing changes. Here the matte-like, billowed surface so typical of the immature joint tends to become smoother and yet more porous. Stewart (1954, p. 524) noted the presence at this stage of plaques of bone and judged them to be epiphyses. In the present series only the best-preserved specimens--that is, the ones listed in the last column of Table 45--could be expected to show this feature. Examination of the casts of these specimens revealed 39 with plaques between the ages of 18 and 24. The highest incidence was between 19 and 21 years. In view of the fact that these 39 cases represent only a little over 25% of the specimens examined, it is apparent that this feature by itself is of little utility for age identification.

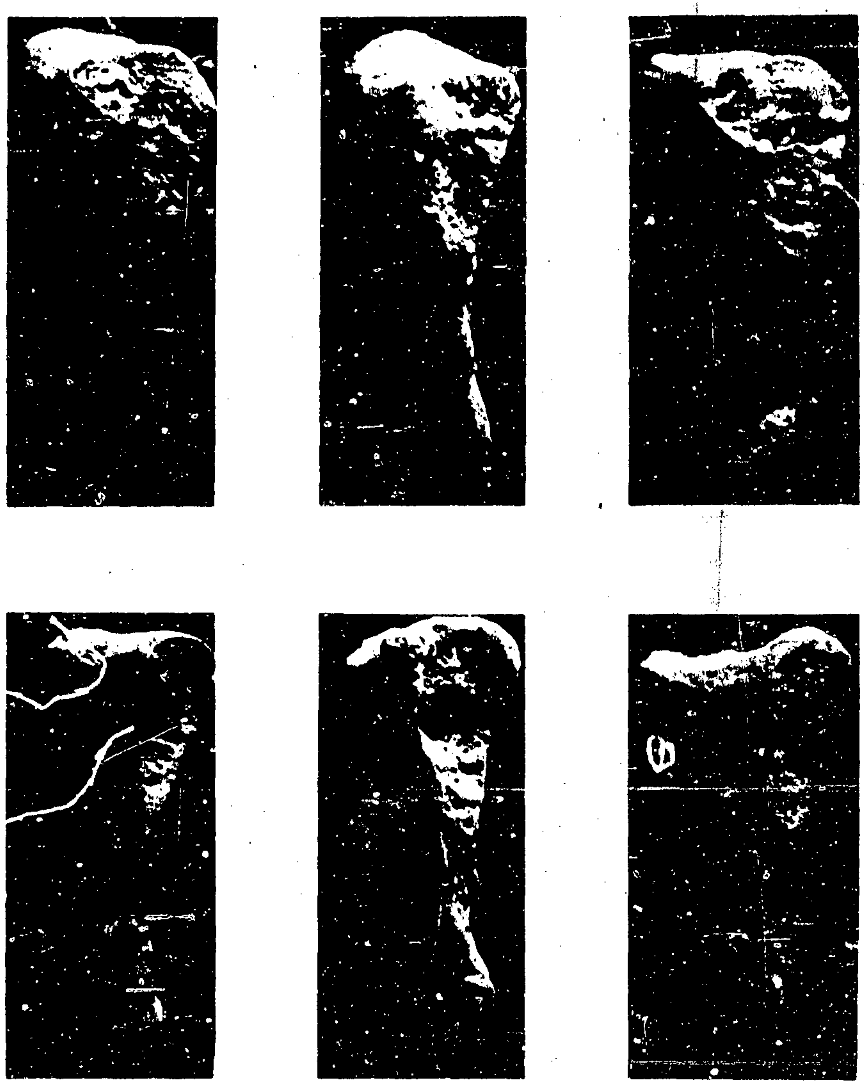


Fig. 72 Top row: Casts of 3 manubria showing costal I notches with a faceted area in the upper portion. (Left: No. 124, 18 years; middle: No. 321, 20 years; right: No. 299, 21 years).

Bottom row: Casts of 3 manubria showing ossific nodules attaching or attached to the facets. The addition of this element increases the prominence of the angle between the clavicular and costal I notches. (Left: No. 106, 22 years; middle: No. 3, 20 years; right: No. 90, 22 years).

Note the middle cast in each row is of the right side; all others are of the left side.

Returning now to the costal I notch as a whole, the signs of immaturity include remnants of the interarticular groove, a billowed and matte-like surface, the presence of plaques resembling epiphyses, and the absence of sharp margins and prominent angles. Ideally, one would like to analyze these features in somewhat the same way as we have done for the face of the pubic symphysis. However, in view of the difficulties already stated, and the fact that all of the features occupy a relatively small area, such an analysis has not seemed feasible. Instead, after arranging the casts of the manubria by age from 17 to 26 years and studying the costal I notch of each carefully, one of us (T.D.S.) undertook to separate them into three groups: 1) those obviously immature (Fig. 73, top row); 2) those with traces of immaturity (Fig. 73, middle row); and 3) those with no easily recognizable signs of immaturity (Fig. 73, bottom row). Table 46 shows the results of this sorting. Here it will be seen that obviously immature costal I notches steadily decrease from about 85% at the beginning of our series (17-18 years) and disappear after age 23, becoming scarce indeed after 21; that less obviously immature notches are already present at 17-18 (15.4%) and increase to age 20, then decrease through the next 5 years, disappearing thereafter; and also that seemingly mature notches begin to appear about age 21 and reach 100% at 26.

TABLE 46
PROGRESS IN MATURATION OF THE COSTAL I NOTCH
(BASED ON CASTS OF ONE SIDE OF THE MANUBRIUM)
(in %)

Age	Usable Cases (No.)	Obviously Immature	Suggestive of Immaturity	Not Evidently Immature
17	5	100.0	-	-
18	21	81.0	19.0	-
19	28	57.1	42.8	-
20	25	44.0	56.0	-
21	24	33.3	37.5	29.2
22	17	17.6	47.0	35.3
23	15	13.3	33.3	53.3
24	9	-	55.6	44.4
25	9	-	11.1	88.9
26	13	-	-	100.0

Since the costal I notches shown in Figure 73 were selected to demonstrate the range of variation at each age, and since the signs of immaturity in this joint surface disappear with age, the result is essentially a maturational progression from one row to the next; in other words, the last specimen in the first row is at about the same stage of maturation as

Fig. 73 Selection of manubria from ages 17 to 25 showing: (top row) obvious immaturity, (middle row) less obvious immaturity, and (bottom row) essentially complete maturity. The top and bottom rows (and the middle row in three instances) represent extremes for the ages shown. (Top row: Nos. 96, 317, 320, and 311; middle row: Nos. 11, 10, 178, and 321; bottom row: Nos. 212, 220 and 41).

Fig. 73 continued. (Top row: Nos. 203, 229, and 26; middle row: Nos. 7, 118, 85, 231 and 340; bottom row: Nos. 190, 330, 13, 37 and 111).

the first specimen in the second row, and likewise the last specimen in the second row resembles the first specimen in the third row. Besides showing the great amount of variation in the costal I notch, Figure 73 makes it clear that experience is required to interpret the signs of immaturity here.

After 25 years, when all signs of billowing are gone from the surface of the costal I notch, the main noteworthy change is the development of exotoses along the margins.* These exotoses are in addition to the attachment of ossicles at the upper extremity as already described, and as illustrated in Figure 72. Although the upper extremity of the notch is mainly involved in both processes, quite commonly a characteristic small spur develops at the inferior extremity (Fig. 74). Although these marginal exotoses are not altogether limited to the ages beyond 25, they probably represent ossification of the costal cartilage. Two extreme cases of such ossification, in which the whole external surface of the cartilage has turned to bone, are shown in Figure 75. Even in these extreme cases a joint was maintained between the first rib and the manubrium, but the position of the joint differed, being at the costal end of the cartilage in one case and at the sternal end in the other. Obviously, as the margins of the costal I notch become prominent the enclosed surface assumes a more concave appearance.

At the time the original observations were made, Dr. Stewart thought that in general the feature described in the preceding paragraph would show steady progression with age and thus might prove useful for ageing purposes. Therefore he graded subjectively all cases on the usual scale of 0-4, differentiating as far as possible the exotoses and the fused ossicles at the superior extremity. On reviewing the results, only case 216, shown at the left side of Figure 75, qualifies for grade 4 (case 360, shown in the middle of Figure 75, is not nearly as impressive without the ribs). A true grade 3 also appears to be rare (case 239, shown at the right side of Figure 75 is nearest; case 9, shown in Figure 74 also was given this rating).

Table 47 shows that the expected general trend is present, but that the progression with age is not sufficiently uniform to be of real use for ageing purposes. From the practical standpoint it appears that slight exostoses (grade 1) occur on the margins of the notch at all ages between 21 and 50, but that larger exostoses (grades 2-4) are unusual before the age of 30

*On the record card this observation was included in the category "arthritis." This categorization was more a matter of convenience than an indication of assigned significance.

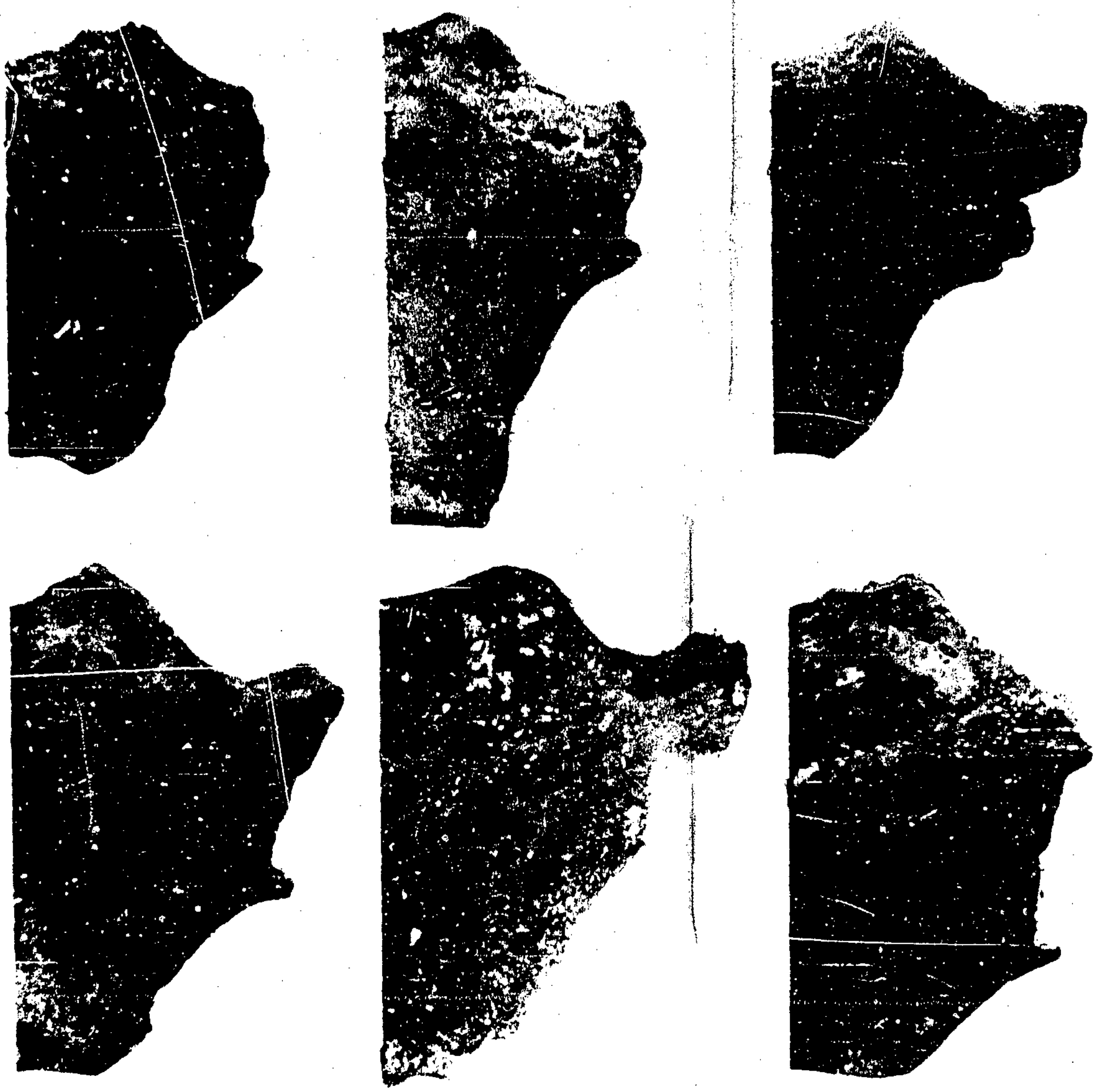


Fig. 74 Front view of the left side of a selected group of manubria between the ages of 25 and 36. Note that the outline of the costal I notch becomes distorted by extensions from the margins, particularly at the superior extremity, but also to a lesser extent at the interior extremity. These extensions are ossifications of the exterior of the costal cartilage and result in the surface of the notch becoming more and more concave. (Right to left, upper row: No. 426, 25 years; No. 450, 30 years; No. 336, 30 years. Lower row: No. 442, 31 years; No. 9, 32 years; No. 354, 36 years.)

Fig. 75 The most extreme cases observed of ossification of the first costal cartilages. Note that in the middle specimen (age 32) the ribs have captured the ossified cartilages, whereas in the specimen on the left (age 38) the manubrium has captured the cartilages. The specimen at the right (age 29) shows less ossification of the cartilage (stage 3 vs. stage 4). Synostosis between the corpus and the xiphoid is also present in the two specimens on the left. (Left to right. Nos.: 216, 360, 239).

TABLE 47

EXOTOSES ALONG THE MARGINS OF THE COSTAL I NOTCH, BY SIZE AND ACCORDING TO AGE (in %)

Age	No. of cases Observed 1/	No Exotoses	Exostoses Present Slight(1)	Medium(2)	Moderate(3)	Large(4)
21-23	73	94.5	5.5	-	-	-
24-25	25	80.0	20.0	-	-	-
26-27	25	68.0	28.0	4.0	-	-
28-30	26	38.5	42.3	15.4	3.8	-
31-35	28	25.0	53.6	14.3	7.1	-
36-40	15	13.3	40.0	26.7	13.3	6.7
41-50	5	-	40.0	20.0	40.0	-

1/ Cases not recorded: 18 in 21-23 age group, 3 in 24-25 age group, 3 in 28-30 age group, 1 in 41-50 age group.

6. Summary

A comparison is now in order between the present findings and the tentative findings of Stewart (1954), quoted at the beginning of this chapter, which are based on materials from archeological sources in North America.

1. Fusion of the component elements of the corpus sterni was observed to be essentially complete in most cases by 22-23 years, although rarely the uppermost segment was found still separate as late as 27 years. Signs of recent union not infrequently were observed to persist in the depths of the costal III and IV notches throughout the third decade. Stewart suggested that signs of recent union could persist to 30 years, but he was inclined to give a slightly earlier age for the main stage of segmental fusion.

2. In a considerable number of sterna the manubrium appeared to have captured the uppermost segment of the corpus. In some of these cases the related costal notches also had an anomalous character. This is a factor complicating the statistics on segmental fusion which Stewart did not take into account.

3. The epiphyseal plate for the surface of the clavicular notch, although seldom observable, was recorded as uniting between 18 and 22 years, with greatest activity at 19 years Stewart suggested that this event occurred at 19-20 years.

4. No clear end point was discovered for the obliteration of the ventral interarticular groove, on account of the variable presence of ossicles (or facets thereof) at the superior extremity of the costal I notch. Judging from the maturation of this notch as a whole, a true groove does not persist beyond 23 years (Stewart estimated between 20 and 23 years).

5. The costal I notch was found to be damaged or anomalous, and hence not usable for analysis, in a high percentage of cases (half of the cases around 17-19 years, and two-thirds of the cases between 20 and 25 years). These figures, and especially the part due to anomalies, probably could not have been anticipated.

6. Plaques (epiphyses ?) were seen in the concavity of the costal I notch in 39 cases between the ages of 18 and 24. The highest incidence was between 19 and 21 years. Stewart placed this event at 19-20 years.

7. Obviously immature costal I notches were not found after 23 years. All signs of immaturity were judged to have disappeared from this notch by 26 years. Stewart did not use this method of analysis.

8. Cases in which the costal I notch exhibited a slightly raised rim were found at all ages betweer 21 and 50 years (Stewart suggested 20-30 years), but cases with sizable spurs or exostoses were rarely seen before 30 (Stewart suggested about 35 years).

This comparison shows that Stewart came fairly close in his estimates of age for maturational events in the sternum, but that he failed to detect the extent of the variability in this bone among different racial groups.* So much variability in Whites is disappointing from the standpoint of age identification and somewhat surprising. Thus the question arises whether the sternum in modern Whites is more variable than in American Indians and Eskimos.

*Stewart used skeletal material from both American Indians and Eskimo collections for his 1954 study.

CHAPTER IX

SACRUM

1. Introduction

The sacrum is that section of the vertebral column which normally fuses into a single bone and forms part of the pelvis. Usually the sacrum consists of 5 segments, but it may have as few as 4 or as many as 6. At the age of 17 the segments are still incompletely united and the epiphyses for the top surface of S1, the lateral articular area and the lateral edge, caudad of the articular area, have just begun to unite.

The only direct observations recorded for the sacrum were the states of fusion of the joints between the centra of S1-2 and S2-3. These observations were supplemented by two photographs (the anterior surface, and lateral articular area) which were used to confirm the observations and to analyze the state of union of the marginal epiphyses.

2. Historical Remarks

The sacrum is another area of the skeleton where few studies exist that are specifically related to patterns of ossification. Stevenson (1924) does not include the sacrum in his study of epiphyseal maturation and Flecker (1942) limits his observations to the appearance of ossification centers. However, he refers to a study by Cleaves (1937) who analyzed the auricular (articular) epiphyses in repeated stereoscopic roentgenograms of 16 American boys ranging in age from 12 to 19 years. Though his sample at ages 18 and 19 consisted of only 4 and 2 cases respectively, he concluded that fusion of the auricular epiphysis takes place in the majority of boys at the age of 18.

The most generally used information on the development of the sacrum comes from those sections on ossification in anatomy textbooks. The lack of supporting research is reflected in the general disagreement among the textbook writers on the age at which the elements of the sacrum are united. For example, Cunningham's section on the ossification of the sacrum states (p. 120) that " ..the epip'yses fuse with the bodies and the bodies fuse together from below upwards between 18 and 25", whereas Grey's Anatomy claims (p. 109) that "...about the eighteenth year the lowest segments became united by bone, with the result that between the twenty-fifth and thirtieth years of life all the segments are united." On the basis of these representative statements, it would seem that the state of our knowledge concerning sacral maturation leaves much to be desired, especially as it is applied to problems of age identification.

3. Epiphyseal Union

Fig. 76 shows the earliest maturative stages of the sacrum encountered in our series. It is evident here that at this age (17 years) the segments are incompletely fused and the marginal epiphyses ununited or just beginning to unite. This being the case, it is desirable to know the date of disappearance of all such signs of immaturity. To this end we have not only analyzed the direct observations on the union of S1-2 and S2-3 but have examined all photographs. Since we had anterior and lateral views to compare, there is seldom any doubt about the status of union of any particular epiphysis. The results are summarized in Tables 48 and 49.

TABLE 48

AGE DISTRIBUTION FOR STAGES OF UNION BETWEEN THE SEGMENTS OF THE SACRUM (in %)

		S4-5					S3-4					S2-3					S1-2				
		Stages					Stages					Stages					Stages				
Age	No.	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
17-18	55	7	5	7	22	47	8	6	14	48	24			25	45	30	1	3	23	70	3
19	52		2	4	29	65		2	7	40	51			11	28	61		4	9	81	6
20	45				26	74				21	79			9	27	64		2	9	67	22
21	39				14	86			2	18	80			5	27	68		2	8	66	24
22	24				8	92				12	88				20	80			4	63	33
23	26					100					100				8	92				63	37
24	14															100				35	65
25	13																			30	70
26-27	25																			55	45
28-29	19																			56	44
30-32	27																			37	63
33+	34																				100
Total	373																				

As illustrated in Figs. 76 and 77 the lowermost sacral bodies unite from below upwards. This order of union is further demonstrated in Table 48. Here, the S4-5 and S3-4 joints show completed union at the age of

Fig. 76 Anterior and lateral surfaces of the sacrum showing earliest maturative stages encountered in our series. (No. 202, 17 years).

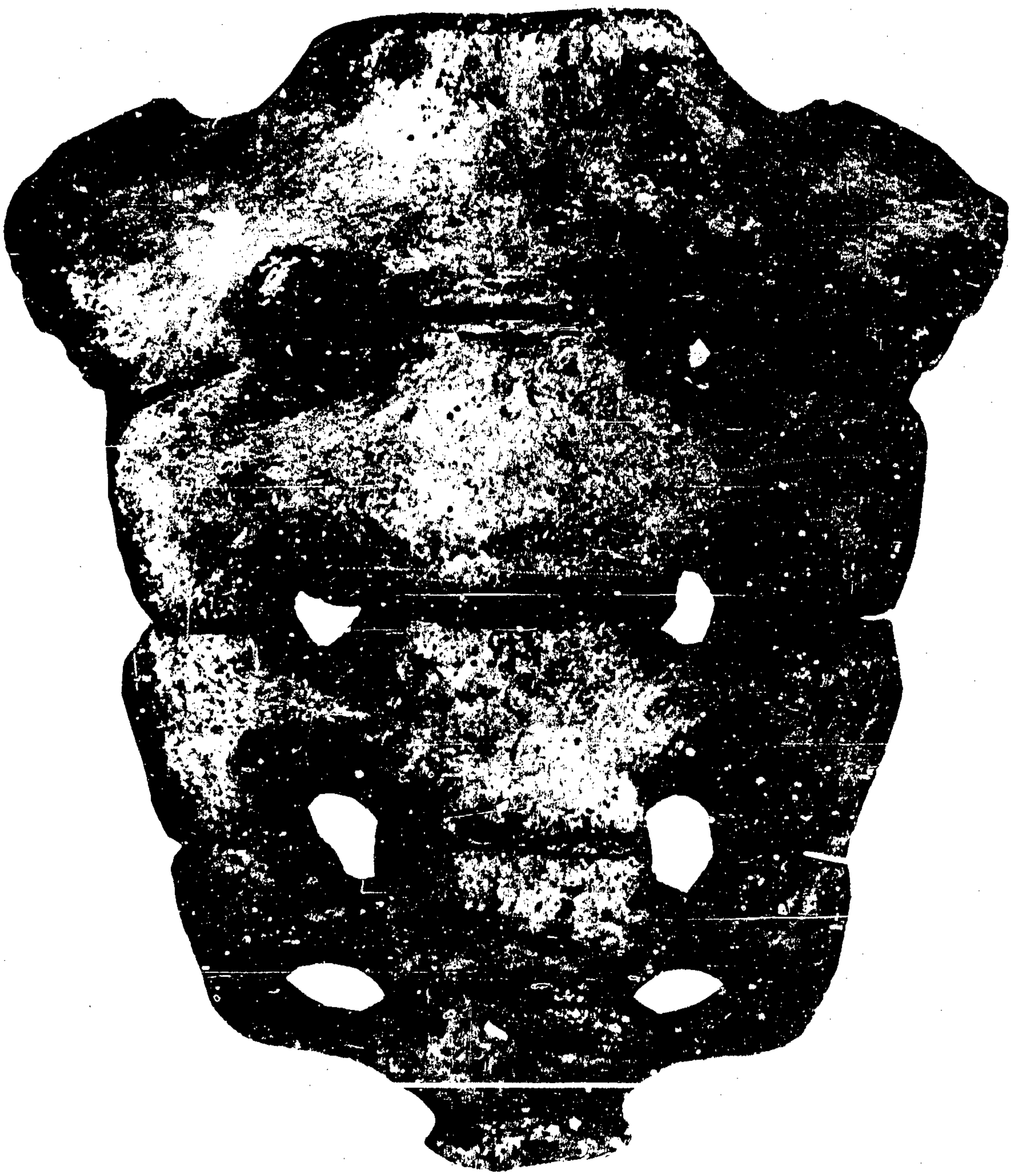


Fig. 77 Anterior surface of sacrum showing incorporation of superior and inferior rings with the intervertebral disks. (No. 30, 18 years).

TABLE 49

AGE DISTRIBUTION OF STAGES OF UNION FOR
THE MARGINAL EPIPHYSES OF THE SACRUM.
(in %)

		S1: Sup. Epiphyseal Ring					Lateral Joints					Auricular Epiphysis				
		Stages					Stages					Stages				
Age	No.	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
17	10	30	10	20	30	10	-	20	30	50	-	20	50	20	10	-
18	45	2	6	14	45	33			14	54	32	2	16	42	28	12
19	52	2	2	7	22	67			10	37	53	2	7	10	44	36
20	45				8	92				29	71			2	41	57
21	39				6	92				13	85			2	13	85
22	24					100					100					100
Total	215															

23 years with the former slightly in advance. By contrast, the S2-3 and S1-2 joints at this age are still in active stages of union; they complete their maturation at 24 and 33 years respectively. However, the progress of union for the S1-2 joint exhibits irregularity between the ages of 26 and 30, or just before the joint becomes completely fused. The explanation for this irregularity probably lies in the drawn-out process of terminal ossification and the consequent difficulty in determining when maturation is complete. Sometimes when examining these cases of delayed union it was tempting to regard them as comparable to the so-called "lapsed union" found in sutures (Todd and Lyon, 1924, p. 337). It was also observed that the gaps are probably related to the varying distances that separate the segments. Where the space between the sacral elements is small, ossification is more likely to be complete early (Fig. 78), whereas widely separated segments will often exhibit incomplete ossification in the form of medial gaps (Fig. 79). Thus, a persistent gap at the S1-2 level requires careful evaluation.

As will be recalled, we have followed the progress of union of the superior and inferior rings of the presacral centra. In the sacrum, most of these rings are incorporated with the intervertebral disks in the process of ossification (Fig. 77) and only the one on the superior surface of the first segment fuses in the same manner as its presacral counterparts. Referring to Table 49, the first column shows the maturative progress of

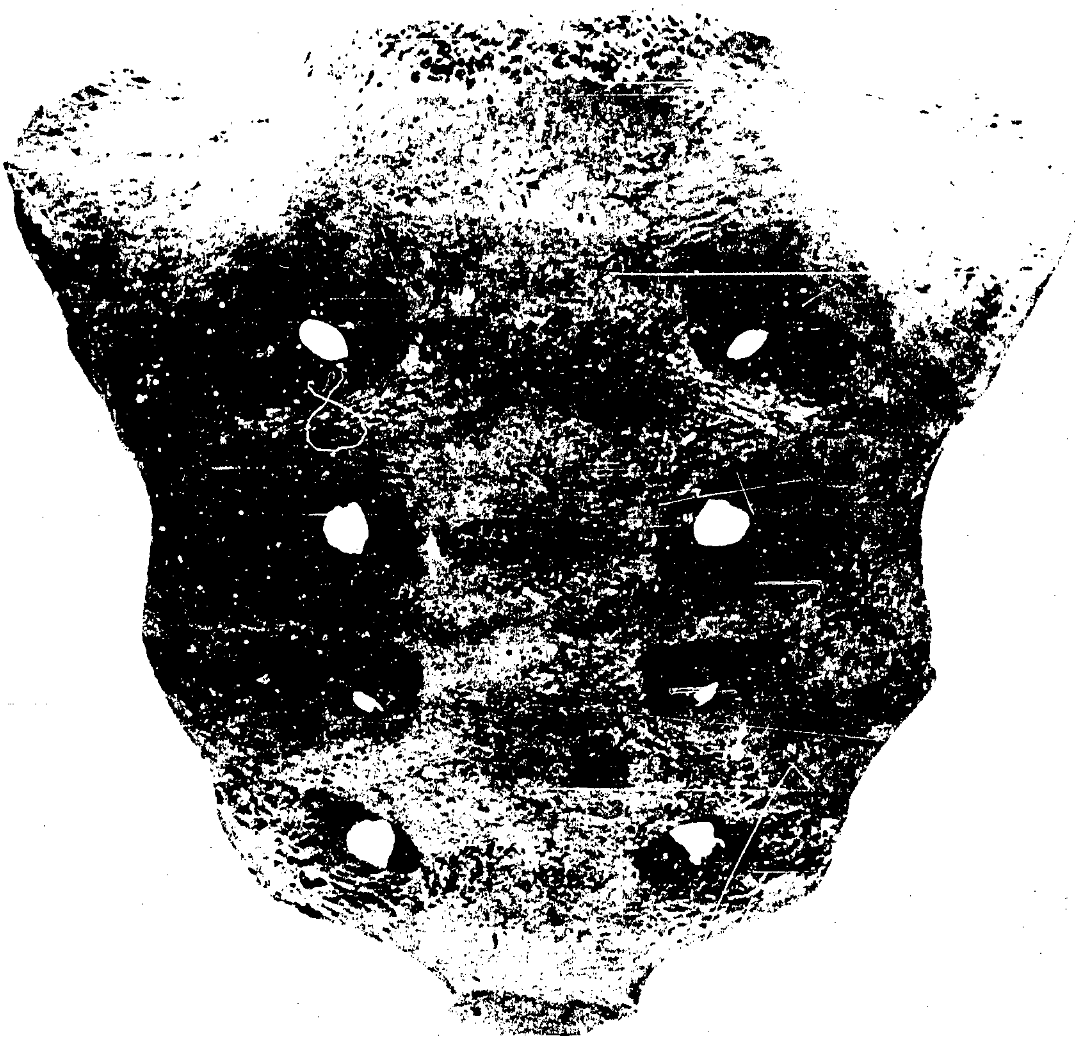


Fig. 78 Anterior surface of sacrum showing completely united segments. (No. 216, 38 years).

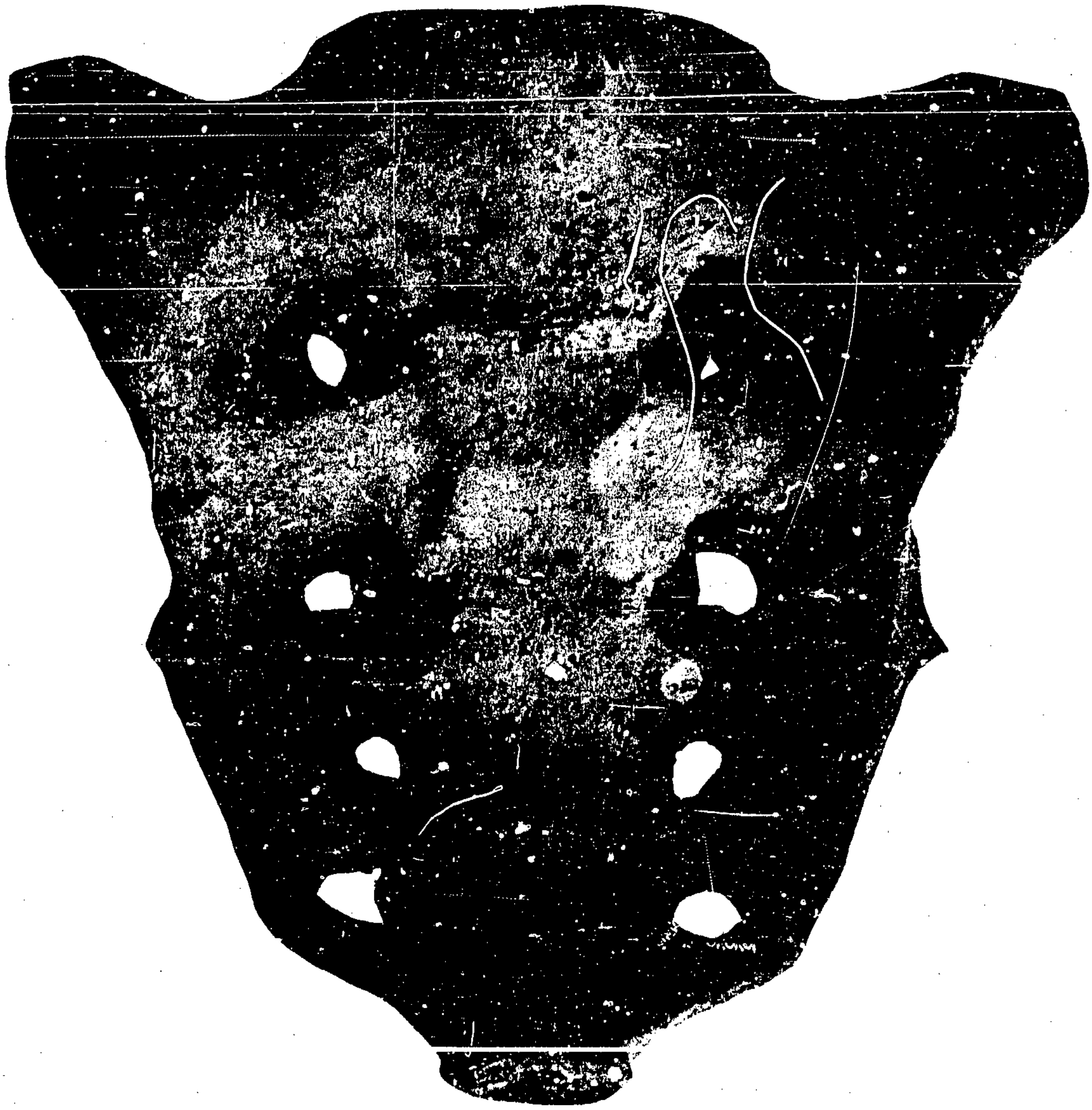


Fig. 79 Anterior surface of united sacrum showing medial gap between segments 1 and 2. (No. 16, 22 years).

this ring and demonstrates its complete fusion by 22 years of age.

The sacrum fuses through the lateral processes as well as through the centra. According to Table 49, the lateral joints are fully united by the 22nd year, that is, just ahead of the lowermost centra. Note too that last remnants of union occur as shallow grooves, usually at the level of the 2nd and 3rd segments (Fig. 80).

The epiphyses for the articular surface of the sacrum and for the lateral edges, caudad to the articular area, varies in length according to the number of segments involved. We have disregarded the subdivisions and considered them as a single epiphysis. As seen in Table 49, the articular epiphysis reaches complete union by the age of 22 years.

Beyond this age, we can only point out the general distinction between the appearance of the articular surfaces in young and old. Fig. 81, left, shows this surface in a 20 year old individual. Note the smooth and rounded relief. On the other hand, Fig. 81, right, shows the same surface in a 33 year old individual. By this age the surface has become rough and erroded with a sharp and irregular anterior margin. These changes are not orderly enough to be useful in ageing.

4. Summary

The several elements comprising the sacrum begin to fuse from below upwards and along the sides. By 23 years ossification is complete except often between the S1-2 centra, where a gap may persist until the 32nd year. This gap seems to represent a sort of "lapsed union" which may be related to an extra wide intersegmental space.

The lateral joint surfaces of the sacrum also undergo gradual changes but these are not very useful for ageing purposes.

Fig. 80 Anterior and lateral surfaces of the sacrum showing late stages of union for the lateral joints. (No. 174, 20 years.) Note shallow fissures at level of 2nd and 3rd segments.

Fig. 81 Left lateral views of sacra showing auricular surface of young (left, No. 153, 20 years) and older (right, No. 418, 33 years) individuals.

CHAPTER X

RIBS

1. Introduction

Usually there are 12 pair of ribs which articulate posteriorly with the thoracic vertebrae. Epiphyses are located at the points of articulation: namely, 1) on the head (single), and 2) on the tubercle (often double) (Fig. 82).

No provision was made on the data sheet for recording stages of epiphyseal union for the ribs but it was decided to make notes on the epiphyses of the heads. The epiphyses for the tubercles were not recorded because of the difficulty of interpreting their status of union; they are among the smallest in the skeleton and their appearance is much the same before and after union.

Fig. 82 The 6th (left) and 11th (right) right ribs showing location of the epiphyses (head and tubercle). Note that the head epiphysis of the 11th rib is in stage 1 of union as is the epiphysis of the tubercle for the 6th rib. (No. 2, 19 years).

In each case the ribs were arranged in anatomical order so that the serial number of each could be easily identified (Fig. 83). Also, each head epiphysis, on both right and left sides, was recorded simply as united or ununited.

2. Historical Remarks.

Most anatomy textbooks state simply that the epiphyses for the ribs unite around 23 years of age. Stevenson (1924) records, in general and not individually, observations on the union of the rib epiphyses. He concludes (p. 73) that, "they are found to be united in all cases after the twenty-second year." X-ray studies have contributed little if anything to this subject. For example, Flecker (1942) limits his discussion of the ribs to two short paragraphs on the number of ribs present in fetuses. No mention of the ribs is found in his final chronological summary.

Since studies of epiphyseal union have treated the ribs as a unit and more or less ignored the progress of union in the individual ribs, we feel there is a real need for further details on rib maturation.

3. Epiphyses of the Rib Heads.

Table 50 shows the percentages of cases with complete union for each age group. Although both right and left sides were observed, no significant difference in the progress of union for either side was found.

TABLE 50

RIB HEAD EPIPHYSES: AGE DISTRIBUTION OF THE PERCENTAGE OF COMPLETE UNION
(Ribs)

Age	No.	1	2	3	4	5	6	7	8	9	10	11	12
17	10	-	-	-	-	-	-	-	-	-	-	-	-
18	45	40	24	17	15	15	11	13	15	20	22	22	38
19	52	41	30	25	19	17	17	11	13	15	21	30	36
20	45	64	55	52	46	46	31	28	28	31	38	53	60
21	37	78	73	70	64	67	64	54	51	62	67	73	78
22	25	96	92	86	80	84	84	72	72	80	86	92	92
23	27	96	96	96	92	92	92	92	92	92	96	96	96
24	14	100	100	100	100	100	100	100	100	100	100	100	100
Total	255												

Fig. 83 Left ribs in anatomical order. Note that the head epiphyses of the middle ribs are in stage 1 of union. (No. 390, 18 years).

It is worthy of note that complete union has not occurred in any of the 10 cases constituting the 17 year age group. However, since the next age group shows percentages of union of as much as 40 percent, it is likely that a larger 17 year sample would reveal some instances of complete union.

It is interesting also that the ribs at both ends of the sequence mature more rapidly than those in the middle (also seen in Fig. 83). The epiphyses on the heads of the 4th to 9th ribs are particularly slow to unite. As has been shown in Chapter VI, a similar pattern of maturation characterizes the vertebrae. The ribs complete their maturation in the 23rd year.

The utility of any ageing criterion depends on the parts of the skeleton available. Though Stevenson questions the value of rib epiphyses as age indicators, they can be helpful in cases where age identification must rely on the ribs alone. However, since all rib epiphyses do not unite at the same time, but in a demonstrated sequence, age estimates must be qualified according to the particular ribs upon which the estimations are based.

4. Summary

The present data point to a probable age of 17 years for first appearance of complete union of the head epiphyses and a definite age of 23 years for the stage when all ribs are mature in all cases. However, ossification begins in the upper and lower ribs and slowly progresses toward the middle. Thus, the last ribs to become fully united are ribs 4 to 9.

CHAPTER XI

TOTAL PATTERN OF SKELETAL MATURATION

In the foregoing chapters we have concentrated on individual events in skeletal maturation without considering their interrelationship. It has been generally believed, however, that an estimation of age should be based on the maturational status of as many events as possible. Therefore, we need now to consider the total pattern of ossification as a possible tool for purposes of age identification.

With this in mind, we have attempted to formulate a mathematical expression of the major events in skeletal maturation that could, for any individual skeleton, be translated into a probable mean age.

The data were treated much the same as outlined in the section on the total pattern of suture closure, so that the maturational stage for each individual is represented by the sum of the scores for the over-all epiphyseal activity. Again, the standard scale of 0-4 was changed to 1-5. Also, since the total skeleton is not always available for epiphyseal scoring, we have computed regression equations for three skeletal segments as follows:

Segment I. Sutures:

Spheno-frontal	Lambdoid
Spheno-parietal	Coronal
Spheno-temporal	Sagittal
Squamous	Metopic
Masto-occipital	Basilar

Postcranial epiphyses

Humerus, proximal	Tibia, proximal
Humerus, distal	Tibia, distal
Humerus, medial epicondyle	Fibula, proximal
Radius, proximal	Fibula, distal
Radius, distal	Innominate, primary elements
Ulna, proximal	Iliac crest
Femur, head	Ischial ramus
Femur, gtr. trochanter	Clavicle, medial
Femur, lsr. trochanter	Vertebral centra
Femur, distal	Scapula, acromion

Postcranial epiphyses: (cont'd)

Scapula, inferior angle	Sacrum, S1 ring (sup.)
Sacrum, S1-2 joint	Sacrum, lat. joints
Sacrum, S2-3 joint	Sacrum, auricular epiphyses
Sacrum, S3-4 joint	Ribs, 1-4 and 9-12
Sacrum, S4-5 joint	Ribs, 5-8

Segment II. Includes all postcranial epiphyses listed for Segment I.

Segment III. Postcranial epiphyses:

Humerus, proximal	Femur, distal
Humerus, medial epicondyle	Iliac crest
Radius, distal	Clavicle, medial
Femur, head	Sacrum, 3-4 joint
Sacrum, lateral joints	

Scatter diagrams, in which age is plotted against total maturation scores for the three segments, are represented in Figures 84, 85 and 86. As can be seen, the distribution indicates a curvilinear relationship but for simplicity, two straight line regressions were derived to fit the discrete segments of the curve. The age range and predicted age for the total scores in all three segments are shown in Table 51. The use of the two straight line regressions leads to minor differences in the predicted age columns for Segments II and III where the regressions are overlapped. However, the overlap is slight (not more than .19 of a year), and no significance should be attributed to these differences in age prediction.

Table 51 has not been carried beyond the 25th year because, with the exception of the metamorphosis of the pubic symphysis, ossification is essentially complete by that year. Those epiphyses that still show degrees of non-union at 25 linger on for several years and terminate erratically. There is further consideration that our samples for age groups above 25 years are too small to be representative. Thus, for information in the older ages, we can do no more than refer the reader to the foregoing chapters on individual maturational events (for example, Table 30 in Chapter V shows that the medial epiphyses of the clavicle are united in all cases by the 31st year).

To apply Table 51 to specific cases of age identification, we have constructed a scoring form (Figure 87) in which the maturational events are arranged in the order of their appearance in chapters 1-10. When the age of an unidentified skeleton is to be estimated, the observed status of

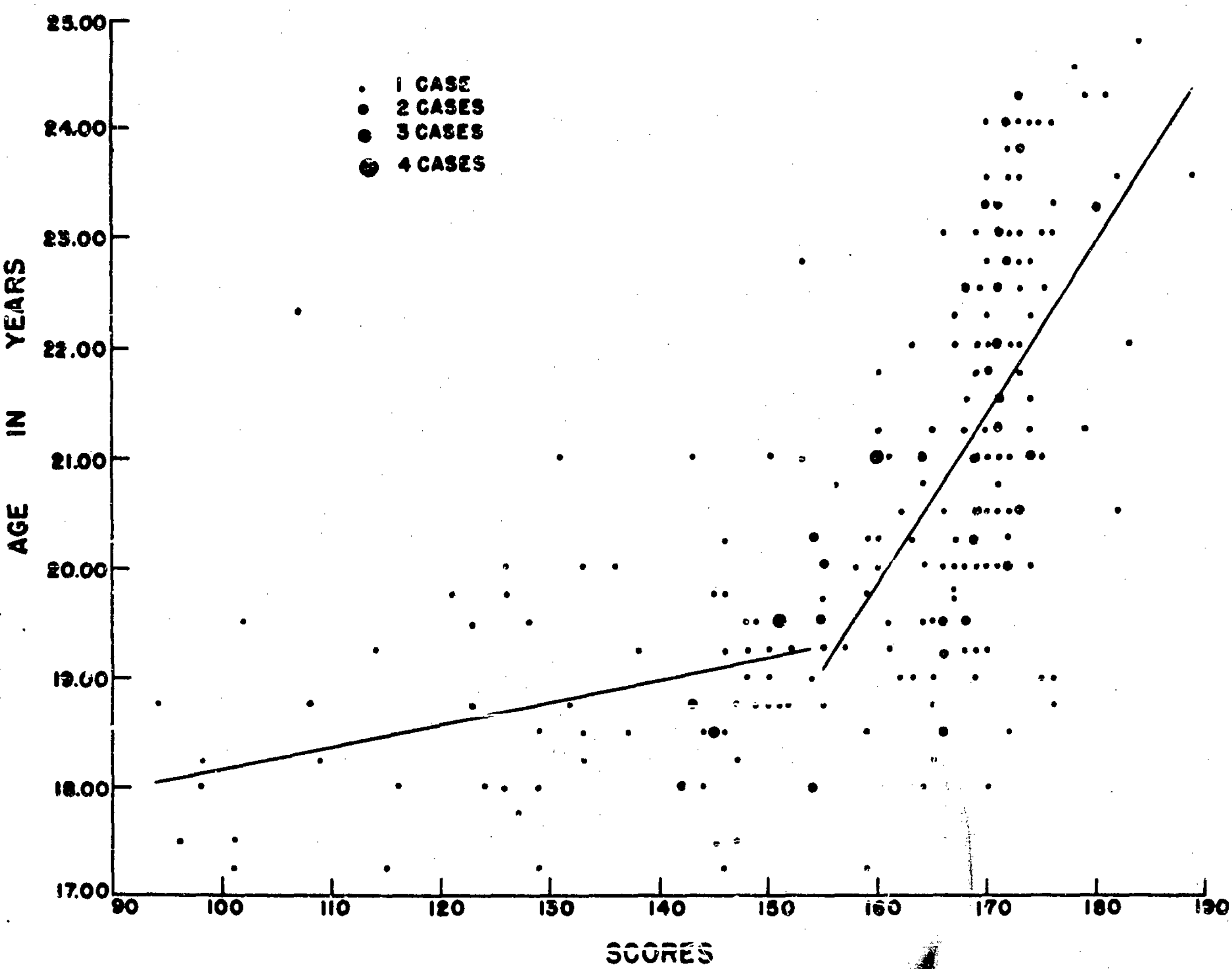


Fig. 84 Scatter diagram with regression lines showing relationship between Segment I scores and age.

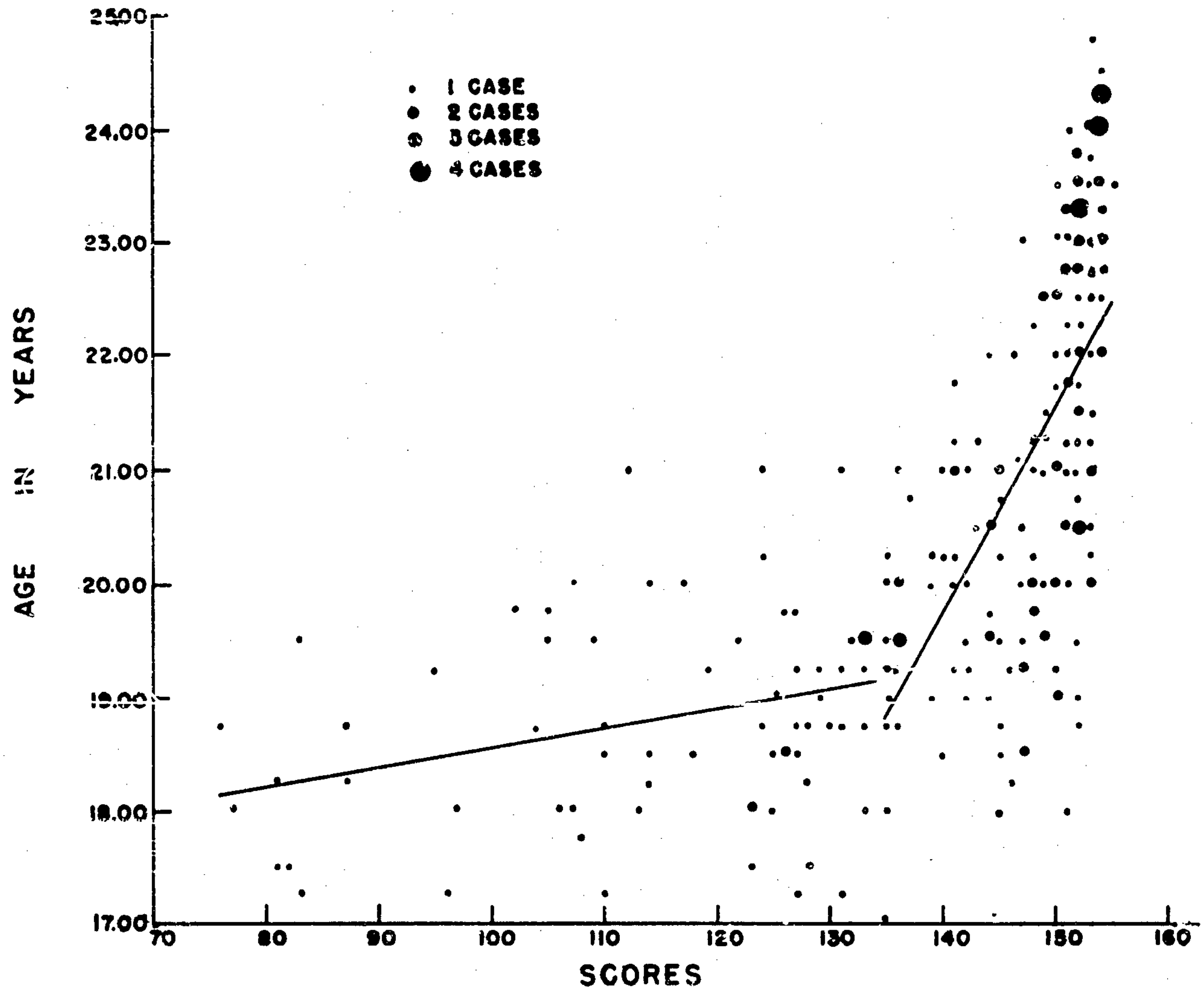


Fig. 85 Scatter diagram with regression lines showing relationship between Segment II scores and age.

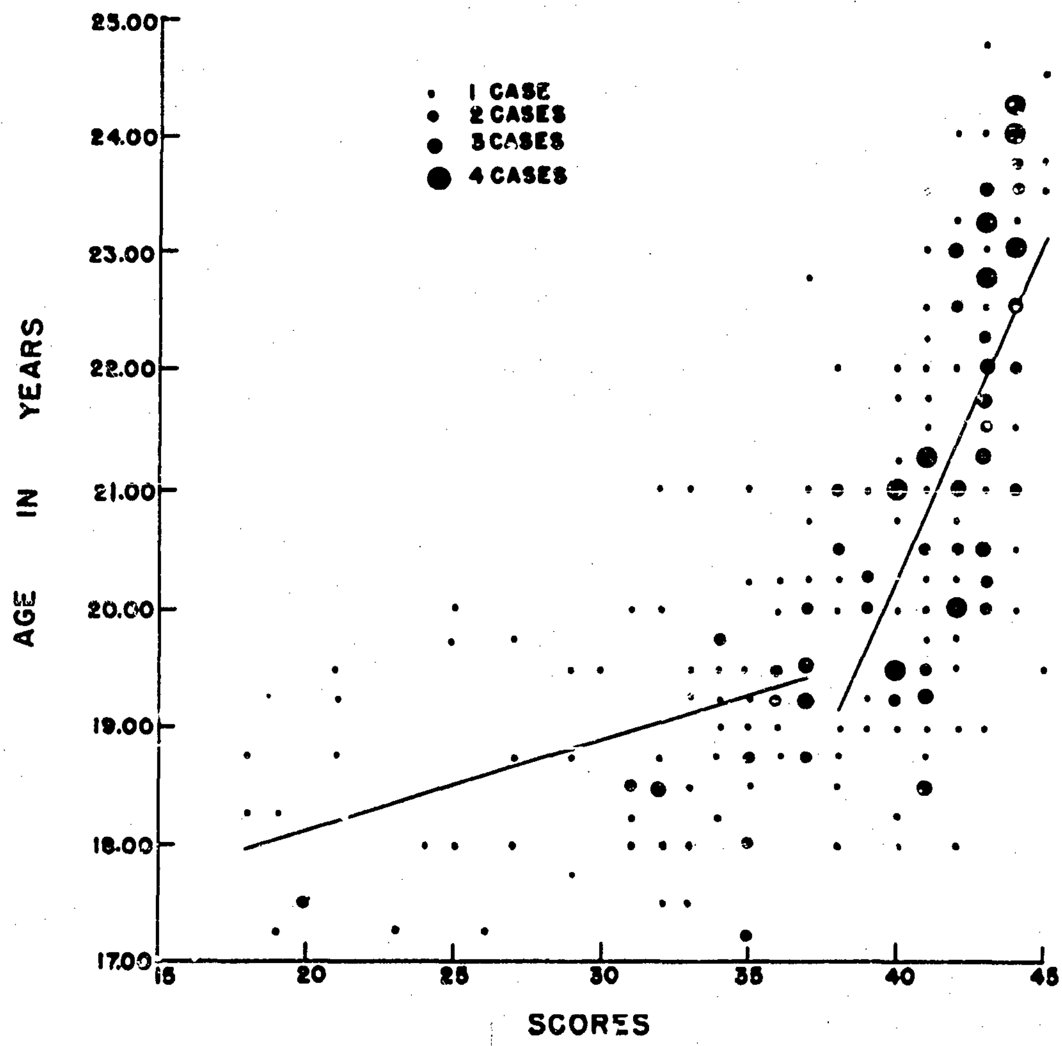


Fig. 86 Scatter diagram with regression lines showing relationship between Segment III scores and age.

TABLE 51

TOTAL MATURATIONAL SCORE FOR SKELETAL SEGMENTS I, II, AND III SHOWING AGE RANGE AND PREDICTED AGE BASED ON THE REGRESSION OF SEGMENTAL SCORES AND AGE.*

SEGMENT I

Score	**Observed Age Range	Predicted Age
90	17-19	17.96
95	17-19	18.07
100	17-20	18.17
105	17-20	18.27
110	17-20	18.38
115	17-19	18.48
120	17-20	18.58
125	17-21	18.69
130	18-22	18.79
135	18-22	18.89
140	18-22	19.00
145	18-21	19.10
150	18-23	19.21
155	18-21	19.09
160	18-23	19.86
165	18-24	20.63
170	18-25	21.40
175	18-25	22.17
180	20-25	22.93
185	20-25	23.70
190	21-25	24.47

SEGMENT II

Score	Observed Age Range	Predicted Age
75	17-19	18.13
80	17-20	18.21
85	17-20	18.30
90	17-20	18.39
95	17-20	18.48
100	17-20	18.56
105	17-21	18.65
110	17-22	18.74
115	17-21	18.83
120	17-22	18.91
125	17-21	19.00
130	17-23	19.09
135	18-22	18.81
140	18-23	19.73
145	18-24	20.65
150	18-24	21.57
155	19-25	22.49

SEGMENT III

Score	Observed Age Range	Predicted Age
18	17-18	17.98
20	17-20	18.13
22	17-20	18.28
24	17-21	18.43
26	17-20	18.59
28	17-20	18.74
30	17-21	18.89
32	17-22	19.04
34	17-22	19.19
36	17-22	19.34
38	18-23	19.15
40	18-24	20.27
42	18-25	21.39
44	19-25	22.52
46	19-25	23.64

*Age prediction equations:

SEGMENT I

(Scores 90-150) Age = .0207 Score + 16.1003

(Scores 155-190) Age = .1537 Score + 4.7311

SEGMENT II

(Scores 75-130) Age = .0175 Score + 16.8140

(Scores 135-155) Age = .1842 Score + 6.0598

SEGMENT III

(Scores 18-36) Age = .0758 Score + 16.6146

(Scores 38-46) Age = .5617 Score + 2.1995

**Score intervals for Segments I, II, and III are in units 5, 5, and 2 respectively. To calculate for scores between intervals, the appropriate prediction equations are provided.

	Observed Score	Remarks
Sutures:*		
Spheno-frontal		
Spheno-parietal		
Spheno-temporal		
Squamous		
Masto-occipital		
Lambdoid		
Coronal		
Sagittal		
Metopic		
Basilar		
Postcranial Epiphyses:		
Humerus, prox.		
Humerus, dist.		
Humerus, med. epicondyle		
Radius, prox.		
Radius, dist.		
Ulna, prox.		
Ulna, dist.		
Femur, head		
Femur, gtr. troch.		
Femur, lsr. troch.		
Femur, dist.		
Tibia, prox.		
Tibia, dist.		
Fibula, prox.		
Fibula, dist.		
Innominate, prim. el.		
Iliac crest		
Ischial ramus		
Clavicle, medial		
Vertebral centra		
Scapula, acromion		
Scapula, inf. angle		
Sacrum, 1-2 joint		
Sacrum, 2-3 joint		
Sacrum, 3-4 joint		
Sacrum, 4-5 joint		
Sacrum, lat. joints		
Sacrum, auricular		
Ribs, 1-4 and 9-12		
Ribs, 5-8		
Total Score		Estimated Age
Pubic Symphysis:		
Component I		
Component II		
Component III		
Total Score		Estimated Age

All events scored on scale of 1-5: 1 = no closure; 2 = one quarter closed; 3 = one half closed; 4 = three quarters closed; 5 = complete closure.

*Sutures treated as complete units.

Fig. 87 Score sheet for the age identification of unknown remains.

each maturational event is entered on the form in the space provided. When the form is completed, the scores are then added, and their sum can be translated into 2 predicted ages by referring to the regressed values in Table 51. Thus, if an individual score was found to be 120 for Segment I, the individual case could be anywhere from 17-20 years, but has the high probability of having the predicted age of 18.58 years. The age prediction equations for each segment are footnoted to Table 46. Also, a separate space has been provided on the scoring form for the purpose of entering clarifying or additional information for individual events. In interpreting such data, it may be necessary to refer to the more detailed analyses in the preceding chapters before completing the analysis.

Obviously the three segments we have outlined do not cover all the possible combinations of maturational events. Thus, to aid in the estimation of age from skeletal remains that are too deficient in maturation areas to fulfill the required number of events for any of the three segments, we have arranged the complicated data of epiphyseal activity in a more subjective manner (Table 52). This has amounted to emphasizing the cases showing minimum and maximum maturation at all age levels. In other words, we have subjectively selected a few cases in each age group representing the least and most mature individuals.

In Table 52, the selected extreme cases are arranged chronologically and in the order of completion of the component maturational events. The table thus clearly shows not only the order of maturational progression from 17 to 25 years, but also the extreme variability of skeletal maturation for each age group. Inspection of the different age groups shows individuals who are older, chronologically, but least mature, osteologically. The reverse is also true. This chronological over-lap further emphasizes the fact that the full range of variability for current populations must be known before reliable methods for estimating skeletal age can be formulated.

The first column in Table 52 includes 50 epiphyses and 1 suture (basilar) beginning with the first area to show complete union for all cases (distal end of humerus) and ending with the last epiphysis to unite in all cases (sacrum, S1-2 joint).* As one follows an event across the chart from left to right, the age at which maturation is reached is indicated by the occurrence of stage 4 for all cases and the discontinuance of scores from that age on.

*Since the basilar suture has proved itself a most reliable ageing criterion, we have included it with the epiphyseal data in Table 52.

TABLE 52

EXAMPLES OF LEAST AND MOST MATURE INDIVIDUALS FOR EACH AGE GROUP SHOWING THE INDIVIDUAL MATURATIONAL SCORES LISTED IN CHRONOLOGICAL ORDER.

Age group	17 years		18 years		19 years		20 years	
Size of sample from which cases were selected	10		45		52		45	
Serial number	425 96 210	50 381 99	44 72 30	51 10 298	2 289 264	165 [illegible] 292	93 73 233	41 65 83
Individual age (years, months & days)	17-6-21 17-8-2 17-9-9	17-7-3 17-9-0 17-10-10	18-0-18 18-5-24 18-11-18	18-9-17 18-9-27 18-11-23	19-5-4 19-7-23 19-11-19	19-1-1 [illegible] 19-10-1	20-0-28 20-0-14 20-6-22	20-6-10 20-7-26 20-10-25
	least mature	most mature	least mature	most mature	least mature	most mature	least mature	most mature
Humerus, distal end	4 / 4	4 4 4	4 4 4	4 4 4				
Innominate, primary elements	3 3 3	4 4 4	4 4 4	4 4 4				
Ulna, proximal end	4 4 4	4 4 4	4 4 3	4 4 4	4 4 4	4 4 4		
Radius, proximal end	3 3 3	4 4 4	4 4 3	4 4 4	4 4 4	4 4 4		
Tibia, distal end	4 4 3	4 4 4	2 0 2	4 4 4	4 2 4	4 4 4	4 4 4	4 4 4
Humerus, medial epicondyle	3 1 3	4 4 4	2 0 2	4 4 4	4 3 4	4 4 4	4 4 4	4 4 4
Fibula, distal end	3 4 0	3 4 4	1 3 0	4 4 4	2 2 4	4 4 4	4 4 4	4 4 4
Femur, head	3 2 3	4 4 4	1 3 2	4 4 4	3 3 4	4 4 4	4 4 4	4 4 4
Femur, gtr. trochanter	3 2 2	4 4 4	1 2 2	4 4 4	4 2 4	4 4 4	4 4 4	4 4 4
Femur, lsr. trochanter	3 2 0	4 4 4	0 2 2	4 4 4	4 2 4	4 4 4	4 4 4	4 4 4
Basilar suture	3 0 4	4 3 3	2 3 3	4 4 4	4 4 4	4 4 4	4 3 4	4 4 4
Femur, distal end	0 0 0	4 4 4	0 0 0	4 4 4	4 0 3	4 4 4	3 3 3	4 4 4
Fibula, proximal end	0 0 0	4 4 3	0 0 0	4 4 4	4 0 2	4 4 4	4 2 4	4 4 4
Sacrum, epiphyseal ring, S1	0 0 0	3 3 3	/ 0 0	3 4 4	0 0 1	4 4 4	3 2 3	4 4 4
Sacrum, lateral joints	2 1 3	3 4 4	/ 3 2	3 4 4	2 3 3	4 4 4	3 3 3	4 4 4
Sacrum, auricular epiphysis	0 0 0	3 3 3	/ 0 0	4 4 4	0 2 2	4 4 4	3 2 3	4 4 4
Tibia, proximal end	2 0 1	4 4 4	0 0 0	4 4 4	2 0 3	4 4 4	4 3 4	4 4 4
Iliac crest	0 0 0	3 3 3	0 0 0	4 4 4	0 0 0	4 3 4	1 1 1	4 4 4
Ulna, distal end	0 0 0	3 4 4	0 0 0	4 4 4	0 0 2	4 4 4	1 0 0	4 4 4
Radius, distal end	0 0 0	3 3 3	0 0 0	4 4 4	0 0 2	4 4 4	2 0 0	4 4 4
Scapula, acromion	0 0 0	4 4 4	0 0 0	4 4 4	2 0 3	4 4 4	0 2 0	4 4 4
Scapula, inferior angle	0 0 0	4 4 4	0 0 0	4 4 4	0 0 0	3 4 4	0 0 0	4 4 4
Scapula, medial border	0 0 0	4 4 4	0 0 0	4 4 4	0 0 0	/ 4 /	0 0 0	4 4 4
Spines, vertebral	0 0 0	4 4 4	/ 0 /	4 4 4	0 0 1	4 4 4	0 0 1	4 4 4
Sacrum, S4-5 joint	3 / 3	3 3 3	/ 3 3	/ 4 4	3 3 /	4 4 4	3 3 3	4 4 4
Sacrum, S3-4 joint	2 0 3	3 3 3	/ 2 2	3 4 4	2 2 3	4 4 4	3 3 3	4 4 4
Ischial tuberosity	1 0 1	3 2 3	1 / 0	4 4 4	4 1 3	4 4 4	3 4 3	4 4 4
Sternum, clavicular notch	2 2 2	3 3 3	3 3 1	4 3 /	2 / 2	4 / 4	3 2 2	4 4 4
Humerus, proximal end	0 0 1	3 3 3	0 0 0	4 4 4	0 0 2	4 3 4	2 0 1	4 4 4
Ribs, 1-4 and 9-12	0 0 0	2 2 3	0 0 0	[illegible] 4 4	0 0 0	4 4 /	0 / 0	4 / 4
Ribs, 5-8	0 0 0	2 2 2	0 0 0	4 4 4	0 0 0	4 4 /	0 / 0	4 / 4
Vertebral column, superior epiphyseal rings (thoracic)	1 0 0	2 3 3	/ 0 /	4 4 4	1 1 0	4 4 4	2 2 2	4 4 3
Sacrum, S2-3 joint	2 2 3	3 3 3	2 2 2	3 3 4	2 2 3	4 4 4	3 3 2	4 4 4
Ischial ramus	0 0 0	3 2 3	0 0 0	4 4 4	1 0 0	4 4 4	0 1 0	4 4 4
Sternum, costal I notch	1 1 1	2 2 3	1 1 0	/ 2 /	1 / 1	1 / /	/ / 1	4 4 /
Clavicle, medial epiphysis	0 0 0	0 0 0	0 0 0	1 0 2	0 0 0	1 2 3	0 0 0	2 1 1
Sacrum, S1-2 joint	3 0 3	3 3 3	1 2 2	3 3 3	2 1 3	4 3 3	2 2 2	4 4 4

Age group	21 years		22 years		23 years		24 years		25 years	
Size of sample from which cases were selected	37		24		26		14		13	
Serial number	305 151 152	252 190 144	213 432 229	330 80 271	245 29 85	167 279 145	21 225 231	234 276 37	380 111 176	170 140 196
Individual age (years, months & days)	21-0-? 21-0-24 21-1-0	21-4-8 21-9-17 21-10-19	22-0-10 22-7-12 22-11-10	22-1-5 22-2-26 22-5-0	23-1-10 23-1-18 23-3-6	23-2-9 23-3-2 23-3-8	24-0-8 24-2-23 24-3-0	24-6-3 24-9-16 24-11-5	25-5-25 25-7-25 25-10-9	25-2-29 25-6-18 25-11-3
	least mature	most mature	least mature	most mature	least mature	most mature	least mature	most mature	least mature	most mature
Humerus, distal end										
Innominate, primary elements										
Ulna, proximal end										
Radius, proximal end										
Tibia, distal end										
Humerus, medial epicondyle										
Fibula, distal end										
Femur, head										
Femur, gtr. trochanter										
Femur, lsr. trochanter										
Basilar suture	4 4 4	4 4 4								
Femur, distal end	3 3 3	4 4 4	4 4 4	4 4 4						
Fibula, proximal end	4 3 3	4 4 4	4 4 4	4 4 4						
Sacrum, epiphyseal ring, S1	3 2 1	4 4 4	4 4 4	4 4 4						
Sacrum, lateral joints	3 3 3	4 4 4	4 4 4	4 4 4						
Sacrum, auricular epiphysis	3 3 2	4 4 4	4 4 4	4 4 4						
Tibia, proximal end	4 3 3	4 4 4	4 3 4	4 4 4	4 4 4	4 4 4				
Iliac crest	1 1 3	4 4 4	3 4 4	4 4 4	4 4 4	4 4 4				
Ulna, distal end	3 3 3	4 4 4	3 3 3	4 4 4	4 4 4	4 4 4				
Radius, distal end	2 3 3	4 4 4	3 3 3	4 4 4	4 4 4	4 4 4				
Scapula, acromion	4 3 3	4 4 4	4 4 0	4 4 4	4 4 4	4 4 4				
Scapula, inferior angle	0 3 0	4 4 4	4 4 2	4 4 4	4 4 4	4 4 4				
Scapula, medial border	/ / 1	4 4 4	2 4 1	4 4 4	4 4 4	4 4 4				
Spines, vertebral	3 / 2	4 4 4	3 4 1	4 4 4	4 4 4	4 4 4				
Sacrum, S4-5 joint	3 3 3	4 4 4	/ 4 3	4 4 4	4 4 4	4 4 4				
Sacrum, S3-4 joint	3 3 3	4 4 4	/ 4 3	4 4 4	4 4 4	4 4 4				
Ischial tuberosity	3 4 3	4 4 4	3 4 4	4 4 4	4 4 4	4 4 4				
Sternum, clavicular notch	3 4 4	4 4 4	/ 4 2	4 4 /	4 4 4	4 4 4				
Humerus, proximal end	2 3 3	4 4 4	3 3 3	4 4 4	3 4 4	4 4 4	4 4 4	4 4 4		
Ribs, 1-4 and 9-12	1 1 1	4 4 4	4 4 2	4 4 4	4 2 3	4 4 4	4 4 4	4 4 4		
Ribs, 5-8	0 0 0	4 4 4	1 3 0	4 4 4	4 2 3	4 4 4	4 4 4	4 4 4		
Vertebral column, superior epiphyseal rings (thoracic)	2 1 2	4 4 3	3 4 3	4 4 4	3 4 3	4 4 4	4 4 4	4 4 4		
Sacrum, S2-3 joint	4 3 2	4 4 4	/ 3 3	4 4 3	3 4 4	4 4 4	4 4 4	4 4 4		
Ischial ramus	0 4 0	4 4 4	3 4 0	4 4 4	4 2 3	4 4 4	4 4 4	4 4 4		
Sternum, costal I notch	/ / 1	4 4 4	/ 4 1	4 / /	4 4 2	4 4 4	3 / 2	4 4 3	4 4 4	4 4 4
Clavicle, medial epiphysis	0 1 0	2 3 2	0 1 0	3 2 2	0 1 1	3 / 3	2 3 1	3 4 2	2 4 2	3 4 4
Sacrum, S1-2 joint	4 2 2	4 4 4	3 3 3	4 3 3	3 3 4	4 3 4	4 4 3	4 3 4	3 3 3	4 4 4

When the age of fragmentary remains is to be estimated, the observed status (by the standard scoring method of 0-4) of as many maturational events as possible should be listed in an order similar to that shown in Table 52. When these observations have been completed they may be compared directly to the chronological list in Table 47 and, by moving the prepared column of observed scores from one age to another, it can be related to the most applicable column of sample scores. Of course, the reliability of this system depends largely on the number of observed events that can be used. Ageing estimates based on single events may best be analyzed by referring to the chapter of this paper which is concerned with that particular event.

Inspection of the age ranges for the total score groups in Table 51 and for the selected extreme cases in Table 52 clearly shows the high variability of skeletal maturation. For several years, around the end of the second decade of life, many maturational events are occurring simultaneously in the individual. Also, in each age group, we are dealing with cases of retarded maturation on the one hand and with cases of accelerated maturation on the other. However, nothing has been said so far about the causes of this variable rate of maturation. Todd (1935) and others have emphasized the effect on the growing individual of cultural factors centering mainly in the fields of health and nutrition. They claim that retarded growth is more common among the less-favored economic groups and accelerated growth is characteristic of the well-to-do classes. Our records do not include data on social status, except as it may be reflected in race.

As we pointed out on page 20, the present sample includes 35 American Negroes. Of the 20 most retarded and 20 most accelerated cases in age groups 17-25, the retarded cases comprise 15 Caucasoids and 5 Negroids, whereas the accelerated cases comprise 19 Caucasoids and 1 Negroid. The retarded Negroids are distributed as follows: 2 at 17-18, 1 at 20 and 2 at 25 years. Although 5 is not a large number, in this instance it represents 14.3 percent of the total Negroids in our series. By contrast, the 15 retarded Caucasoids represent only 2.9 percent of the total Caucasoids in our sample. On the other hand, the 1 accelerated Negroid and 19 accelerated Caucasoids represent 2.8 and 5.6 percent of their respective samples. From this meager evidence it would seem that cultural factors may have affected the present sample, or that genetic differences may cause retardation.

At the time our sample was assembled, all cases selected were unknowns. Even though the presence of retarded individuals was suspected, due to various factors, we made no effort to eliminate them. We feel that this procedure was justified, because in the actual work of age identification there is no way of knowing the sociological status of unknowns and hence any method used to derive age estimates must include all possibilities.

As a result of the experience gained in constructing Tables 51 and 52, we are now able to distinguish certain critical areas, or those areas that, if possible, should be observed first as the best indicators of skeletal age. By giving first attention to these critical areas, the observer can make a rapid appraisal of the age status of the skeleton in question and thus learn his subsequent course for final age analysis. Actually, Segment III (refer to tabulation, beginning of this chapter) is comprised of 9 of the most critical epiphyses.

We suggest that the innominate bone is the most critical ageing area of the skeleton. The combination of pubic symphysis, iliac crest, ischial tuberosity and ramus will immediately place the skeleton in its proper age group. If the pubic symphysis, which is a good age indicator over much of the life span, is damaged or missing, the remaining age areas of the innominate will give the observer a clue as to his next most reliable source of age information. For example, if the iliac crest suggests an adolescent age, then the basilar suture and the epiphyses of the elbow can be turned to for both clarification and supportive evidence. On the other hand, if the iliac crest exhibits the pattern of a young adult, the epiphyses of the shoulder, wrist and knee joints as well as the medial end of the clavicle will help to establish an exact age estimate.

CONCLUDING STATEMENT

One of the principal conclusions emerging from the foregoing study is that individual maturational features or events are highly variable in the chronological sense. An epiphysis, for instance, which is completely closed in 100% of the population only after the 24th year, can have reached this stage for the majority of individuals several years earlier. It is incorrect and misleading, therefore, to state categorically, as has been done all too often in the past, that this epiphysis closes, let us say, at 21 years, or even at 20.5-21.5 years. We feel that the present documentation of full variability and the emphasis we have placed thereon is a step forward in identification procedure.

We also point out that, although variability in individual maturational features leads to variability in the total pattern of maturation, it is usually less, again in the chronological sense. Viewing an unknown individual as a total skeleton, rather than bone by bone, it is possible thus to estimate the age at death within narrower limits. We have seen that the anthropologists who first examined the material on which this study is based, and who judged the skeleton as a whole, succeeded in giving remarkably good estimates of age. Their errors, it is now clear, were due to reliance on existing standards which do not allow for variability.

There is no denying the fact that a remarkable orderliness exists in the progress of maturation; that in the case of the epiphyses, closure takes place in a surprisingly uniform sequence, and especially when age is disregarded. We have laid very little stress on this fact since it is already well established and is of secondary importance in age identification. Nevertheless, the establishment of this principle was an important advance in our knowledge of ageing.

The skeletons used in previous studies on ageing were derived mostly from dissecting rooms, which are the repositories of the unclaimed dead of our large cities. In many cases the individuals had died in hospitals of lingering illnesses. But the fact that they were not claimed by families carries implications of irregular living and low social status. Under the circumstances it is understandable that the scientists studying age changes in these skeletons were prone to be suspicious of the normality of individual cases. Not infrequently, as we have pointed out, they eliminated cases that varied widely from their concepts of normal maturation. However it should be remembered that the goal of these investigators was the establishment of broad principles of maturation, not the collection of data for application to problems of age identification. In retrospect we can see clearly that variability is present in the skeletons which they studied, but almost wholly disregarded in the principles they enunciated.

By contrast with the doubtful physical status of the dissecting-room population which provided existing ageing standards, the military population used in the present study can only be considered more typical and normal. Soldiers are selected for physical fitness and trained for endurance; they are well cared for, medically and nutritionally. Never before has there been an opportunity to study ageing on such fine physical specimens. Here, then, the elimination of cases on account of variability in maturation would amount to scientific dishonesty. One might even expect that the variability encountered in the military sample is less than in the unselected, less evenly healthy, general population.

No case has been eliminated from the present series on the basis of supposed abnormality. Moreover, we have included POW's who were subjected to malnutrition for many months. In some of these POW's, undoubtedly, the malnutrition was accentuated by dysentery and other debilitating conditions. Yet we feel that any resulting maturational disturbances are within the limits of the general population. Certainly their inclusion does not appreciably detract from the validity of the results obtained.

Our concern with the problem of variability in maturation stems, of course, from the very nature of human identification. As a rule the identification specialist has no way of knowing what was the racial, sociological or health status of the individual he is dealing with. Any or all of these factors could have affected (accelerated or retarded) the unknown's rate of growth. All that the specialist can predict with safety is the age range in which the observed complex of maturational features are known to occur. If he attempts to place the individual in a particular spot in the age range, he is only guessing. The present evidence of variability should make the specialist more cautious.

Finally, we would point out that our insistence on chronological variability in maturation is derived ultimately from the impressive sample we were privileged to study. Where, in one of the few comparable studies, Stevenson (1924) had only 10 individuals (3 of them females) at the critical age of 18, we have 45; where he had only 6 at the age of 21, we have 39; and so on. Although it is distressing to consider the extent of the loss of American youth implied in these figures, we are consoled in part by being able to perpetuate them in the form of knowledge. At the same time, we hope that our efforts will not discourage others from continuing in this area of investigation. Certainly there is an immediate need for additional research in the younger and older age groups.

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