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SKELETAL AGE CHANGES IN YOUNG AMERICAN MALES

QUARTERMASTER RESEARCH & DEVELOPMENT CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

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10	24	Change 25 to 23
11	32,34	) Change Caucausoid to Caucasoid
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20	37	Change Montague to Montagu
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115	31	Change 22nd year to 23rd year
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154	8	Change varies to vary
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160	21	Change 23 years to 24 years
168	7	Change Table 46 to Table 51
170	5	Change Table 47 to Table 52
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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.

HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
Quartermaster Research & Development Center, U S Army
Natick, Massachusetts

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
EP-45

SKELETAL AGE CHANGES IN YOUNG AMERICAN MALES

ANALYSED FROM THE STANDPOINT OF AGE IDENTIFICATION

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Project Reference:
AE7D

May 1957

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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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 realized 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.

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

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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. Realizing 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.

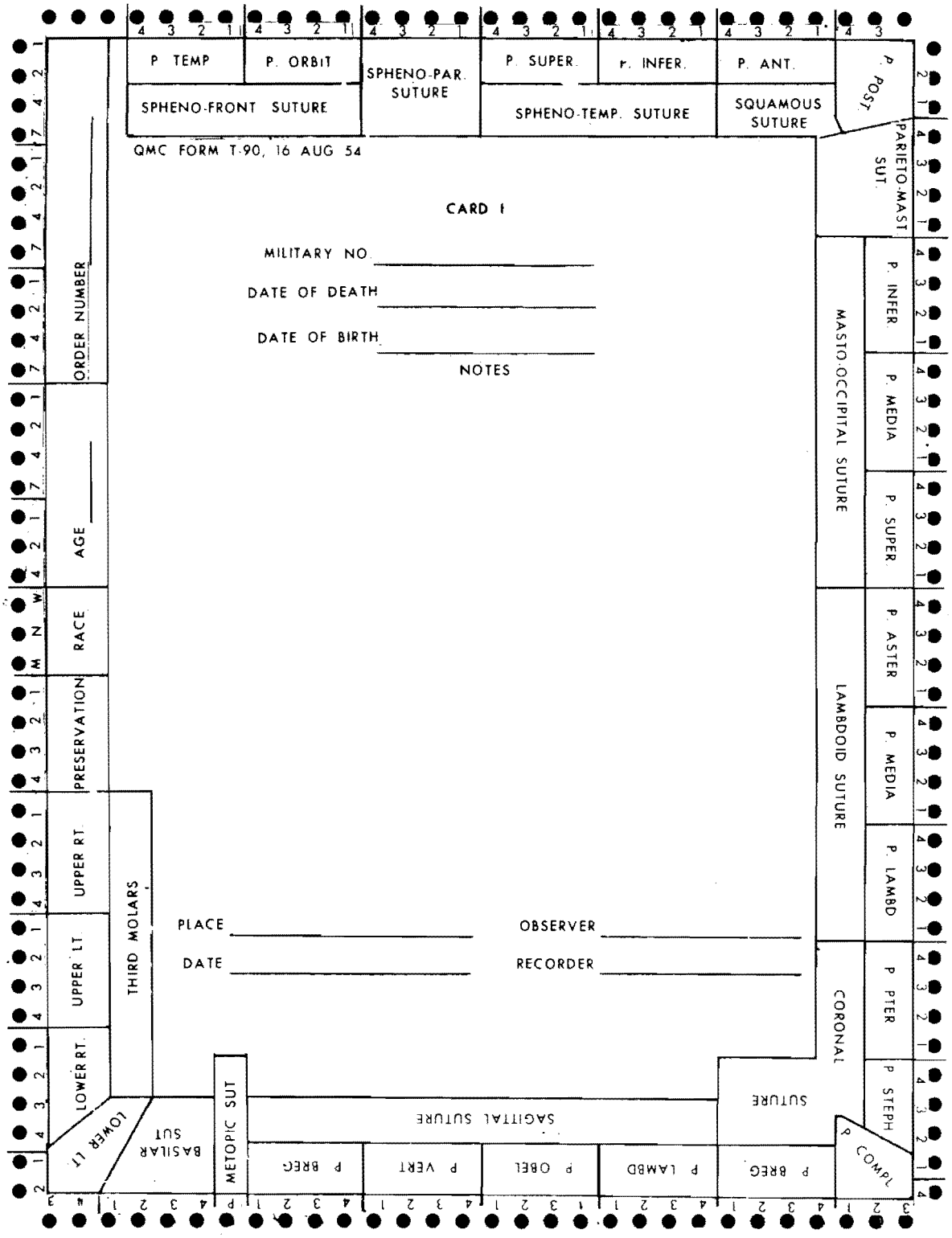


Fig.1 Keysort Card No. 1 for recording the eruption of the third molars and cranial suture closure.

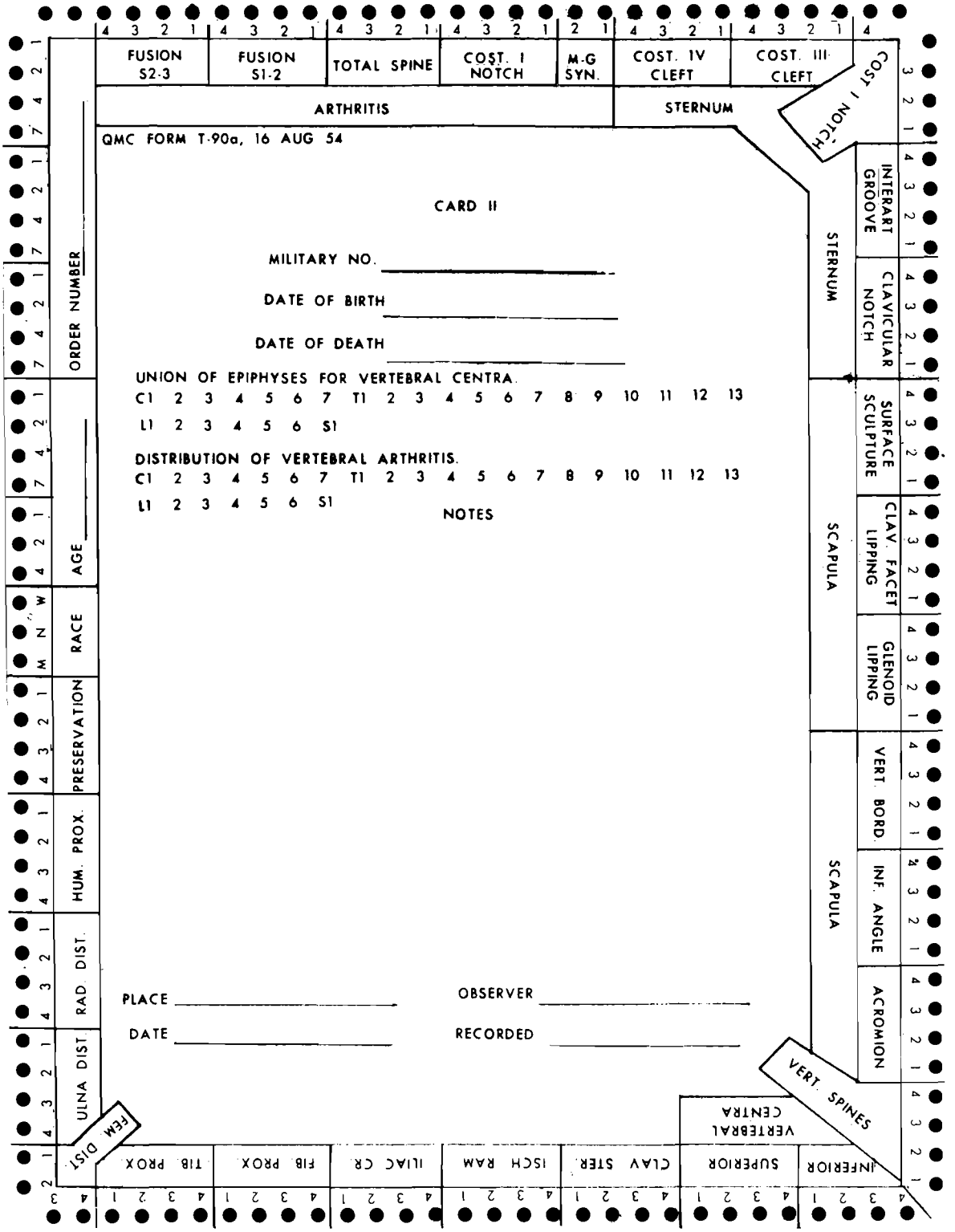


Fig. 2 Keysort Card No. 2 for recording the union of certain epiphyses and joint changes.

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).

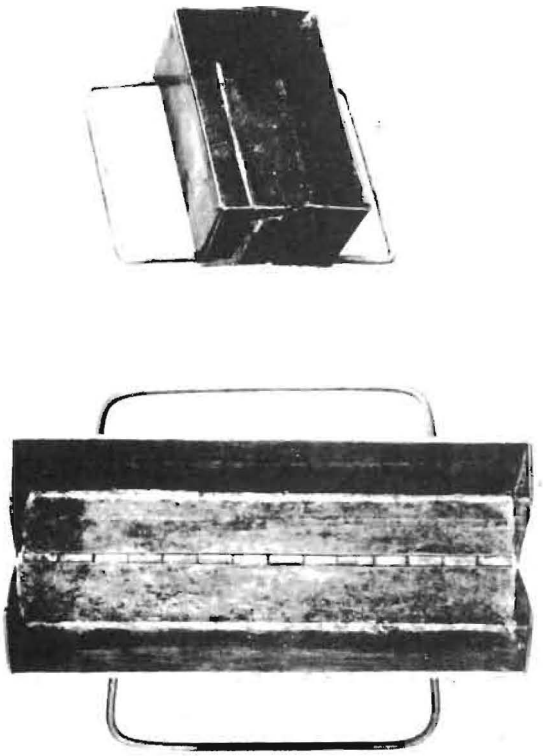


Fig.3 Molding trays used in making the casts. The tray below is partially open to show hinge in base as well as the construction of the interlocking sides.

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

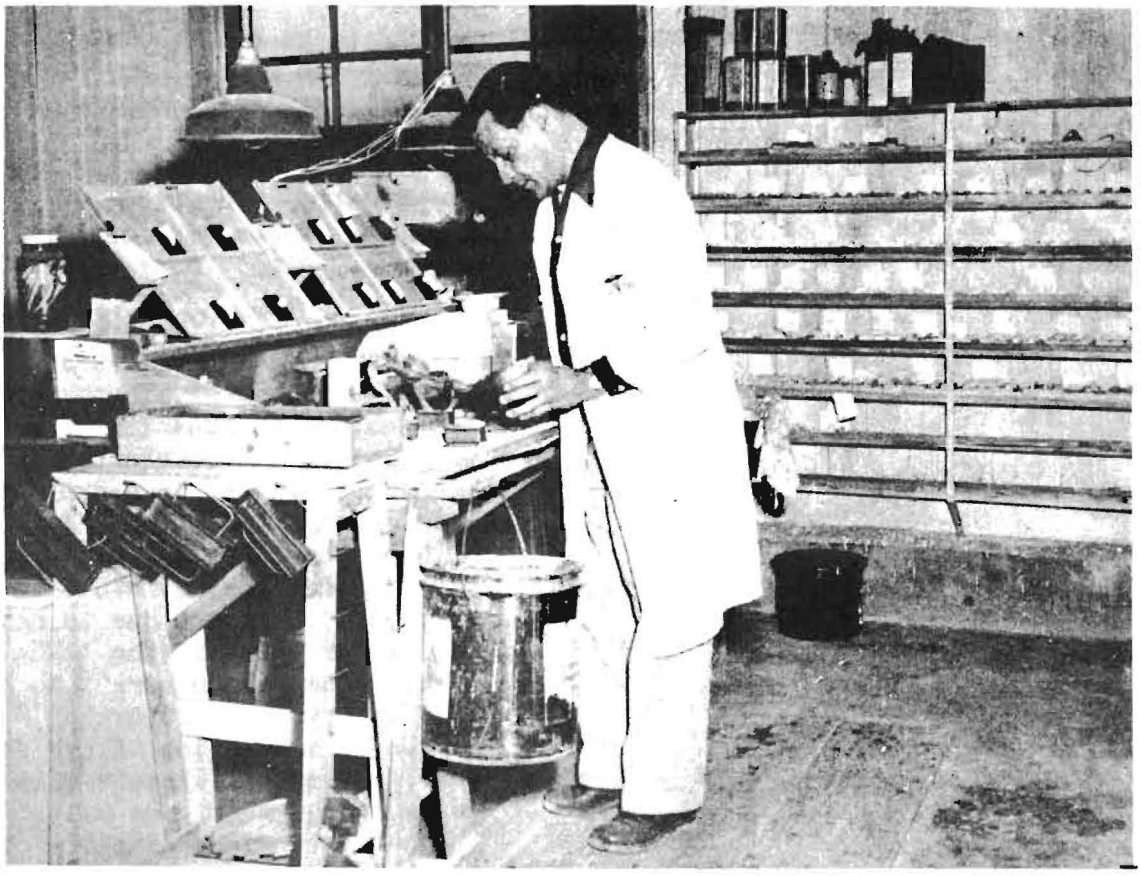


Fig. 4 Preparation of casts of pubic symphyses showing arrangement of equipment (Mr. Doram).

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

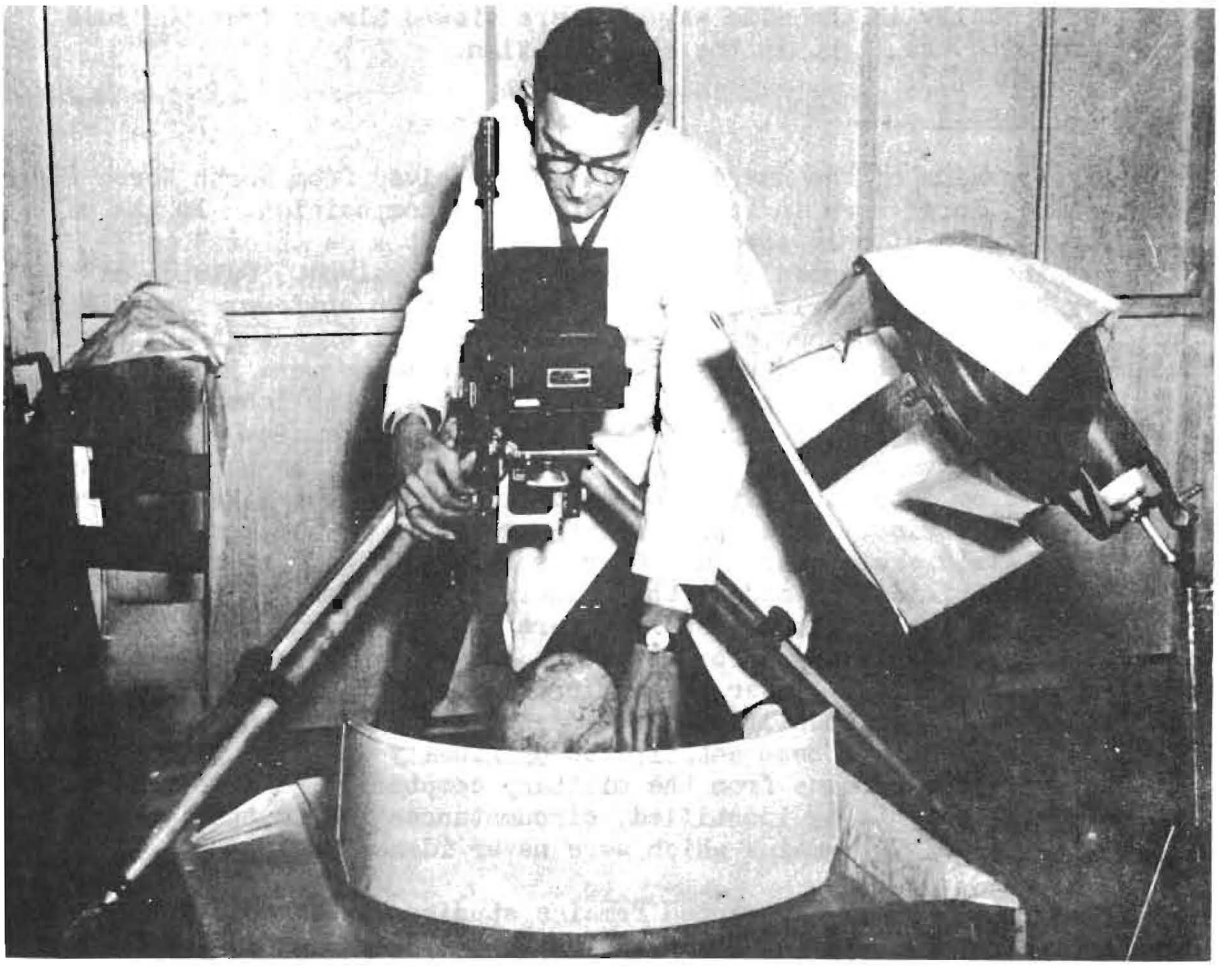


Fig. 5 Arrangement of photographic equipment (Pfc. Bloomenheim photographing skull).

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 23. 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: Caucasoid, Negroid, and Mongoloid. Table 5 shows the distribution by age of these racial elements in the identified series. The Caucasoid 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.

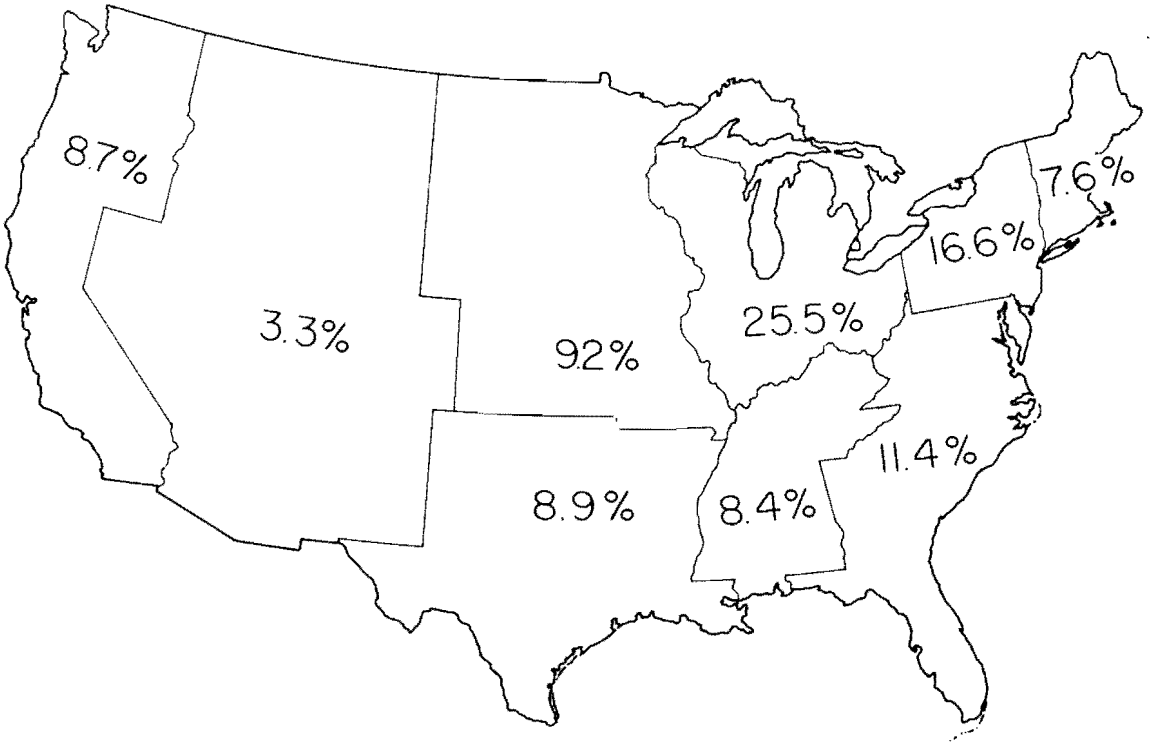


Fig. 6 Sectional distribution of the Army series.

Judging from the names of identified (Caucasoids) — 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

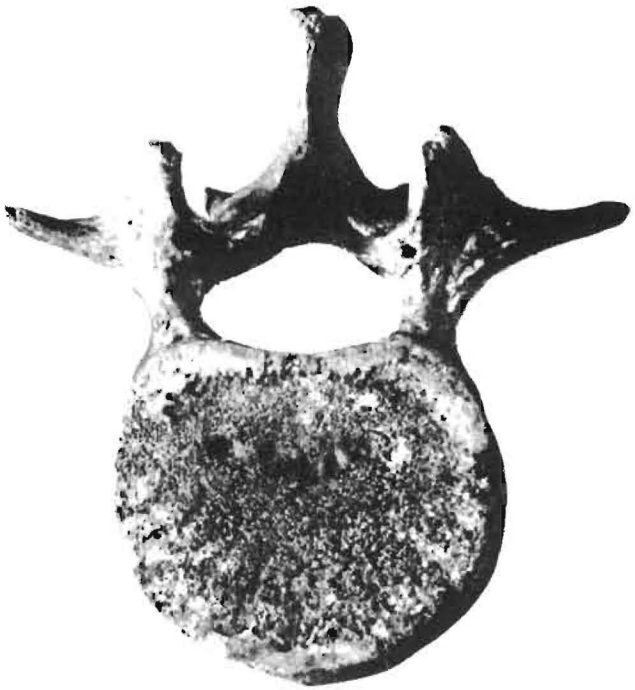
Age	No.	%	Intervals of captivity (months) 0 - 3 (No.)	0 - 3 (%)	3 - 6 (No.)	3 - 6 (%)	6 - 9 (No.)	6 - 9 (%)	9 - 13 (No.)	9 - 13 (%)	13 + (No.)	13 + (%)
17 - 18	3		2	66	1	34		-		-		-
19	6		3	50	3	50		-		-		-
20	8			-	3	38	3	38	2	24	-	-
21	10	36.1%	3	30	4	40		-	3	30		-
22	8			-	6	76	2	24		-		-
23	13		4	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.)



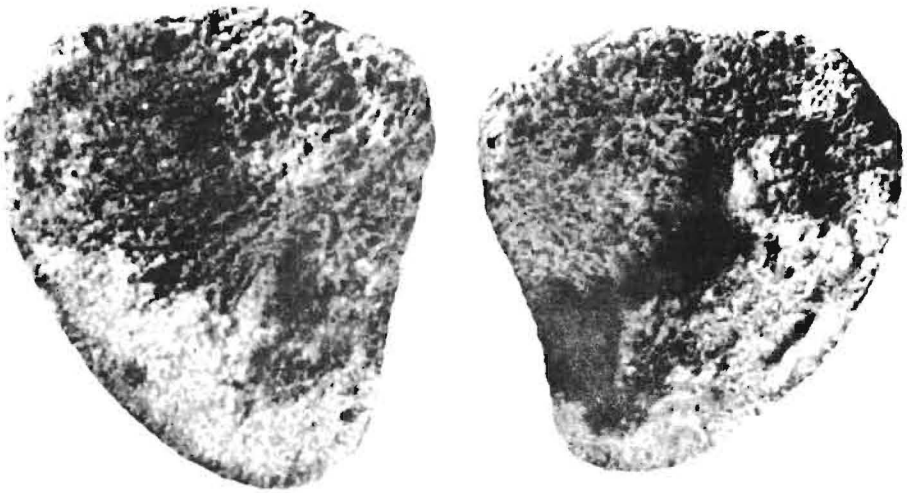


Fig. 9 Top: Superior surface of the 1st lumbar vertebra showing the porous nature of the cortical bone. (No. 86, 18 years.)
Bottom: Medial surfaces of left and right clavicles showing the porous nature of cortical bone. (No. 73, 20 years.)

porous in such cases. So far as the vertebrae 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 daysc/	-	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 Montagu (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.

Suture	Endocranial						Ectocranial					
	Male white			Male negro			Male white			Male negro		
	C†	T†	Remarks	C	T	Remarks	C	T	Remarks	C	T	Remarks
1. Sagittal	22	35	Slows at 31 at 3.9. Slow to 26	22	31	Slow to 26 complete	20	29	3.9 in obelica 2.4 alone 2.9 in gen. Slow to 26	20	32	Slowly to 24–2.9–3.6 in gen., 4.0 in obelica alone
2. Spheno-frontal orbital	22	64	Slows at 30 at 3.0. Final burst of act.	20	44	Slow to 26 complete	28	46	2.3 at 31, 3.8 at 46	21	35	3.5 at 35, may reach 4.0 at 43
3. Spheno-frontal temporal	22	65	Same	23	44	Slow to 26 complete	28	38	2.1 at 38, may reach 4.0 in old age	25	46	1.9 at 35
4. Coronal 1 and 2	24	38	Slows at 29 at 3.4	24	38	Slows at 32 at 3.6	26	29	Bregmatica at 2.3, complicata at 0.9	23	32	Breg. at 2.4, compt. a 1.7
5. Coronal 3	26	41	Slows at 29 at 2.1 rapid to ca. 30	25	44	Slows at 31 at 2.3	28	50	50 at 3.8, spurious rise at 21	25	35	35 at 2.8, spur rise at 21
6. Lambdoid 1 and 2	26	42	Slows at 31 at 3.4	23	46	Slows at 30 at 2.5. Slow to 46	26	30	Spurious rise at 21. Lambdica 2.3, media 1.9	23	31	Lamb 2.4, media 2.0
7. Lambdoid 3	26	47	Slows at 30 at 2.2	27	46	Slows at 31 at 2.7	26	?30	Not more than 1.0	22	?31	Not more than 1.0
8. Masto-occipital 3	26	72	32–48 at 3.2. Slow progress thereafter	17	30	30 at 3.3. No further progress thereafter	26	33	1.4 at 33, may read 4.0 in old age	26	31	Spurious rise at 21 sec. Act. at 50
9. Spheno-parietal	29	65	29–46 at 3.0	23	49	Slows at 30 at 2.7	28	38	2.0 at 38, 5 at 31, continues to old age	28	46	1.4 at 31
10. Spheno-temporal 2	30	67	Slow at once, 67 at 3.9, grad. progress	40	51	51 at 3.3. Oscillations thereafter	36	?65	Prob. never closes	50?	0	Prob. never closes
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.	37	?65	Prob. never closes	50?	0	Prob. never closes
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.	28	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	37	81	Almost inact. till 50, slow thereafter	33	51	51 at 3.6, then oscil.	39	?64	Prob. never closes	50?	0	Prob. never closes
14. Squamous posterior	37	81	Bursts at 63 & 79, almost inact. till 62	40	49	49 at 1.7, then oscil.	38	?65	Prob. never closes	50?	0	Prob. never closes
15. Squamous anterior	37	81	Same	40	49	Same	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." (Gray'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.

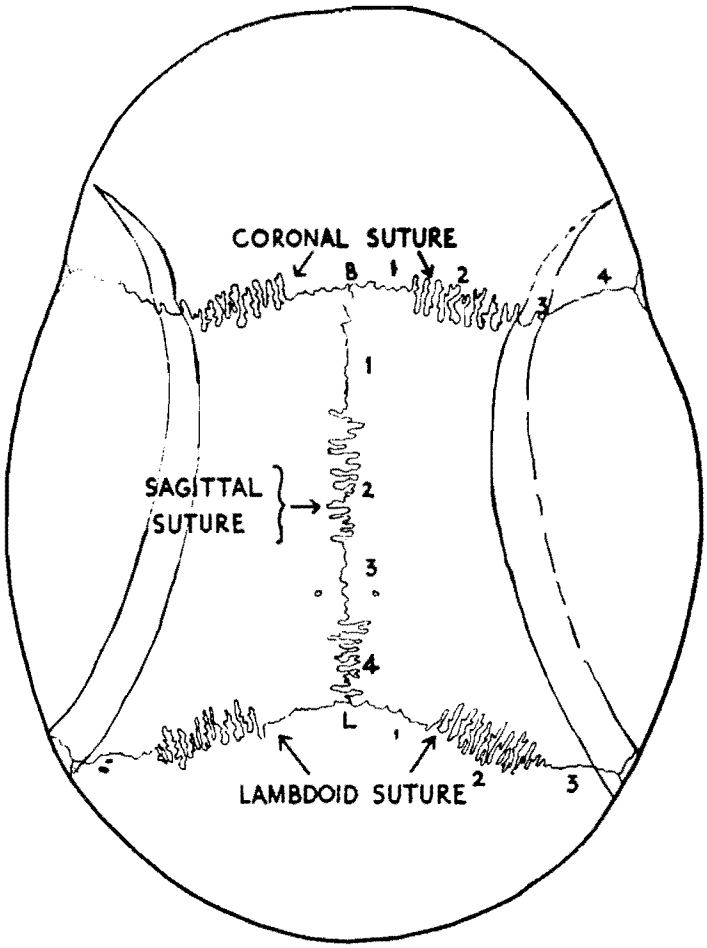
Since suture closure proceeds at varying rates it is usually recorded on a scale of 0 - 4. In other words:

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 Closures*				Lambdoid Closures*				Coronal 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	23	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	16	-	-	33	-	-	33	-	-	-
Total	369											

TABLE 11

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

		Spheno-temporal				Parieto-mastoid				Masto-occipital				Squamous Suture			
		Closures*				Closures*				Closures*				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 Closures*				Spheno-parietal 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	38	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 Closures*				Maxillomalar 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 %)

		Closure*				
Age	No.	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 21 years. It has been known that this suture closes rapidly and completely but no evidence has been presented heretofore on the terminal date.