TECHNICAL NOTE

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Age Estimation from Sternal Ends of Ribs by Phase Analysis in South African Blacks

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ABSTRACT: The sternal ends of ribs are used in age determination of unknown adult remains. Standards for American populations have been described and tested. The method described by İşcan et al. is reviewed and compared with other age markers of the human skeleton. Three hundred and thirty-nine (265 male, 74 female) sternal ends of right fourth ribs, belonging to black individuals deceased in the Gauteng Province of South Africa, were collected during 1994, 1995, and 1996. Three South African investigators applied the existing method and found the repeatability among them acceptable, although the method was less accurate to predict age in this population. New phases with adjusted criteria and age ranges were developed specifically for the South African black population. A tendency toward delayed maturation was found, as well as a diversion of the appearance of female ribs perimenopausally. Future studies involving more individuals in the older age ranges, and females of all ages, could broaden the representativeness of these phases.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, ribs, phase analysis, sternocostal, age estimation, Negroes, South Africa, Blacks

Age estimation of unidentified human remains is a considerable problem in forensic medicine. This is especially true in the case of adult individuals, where age changes are less obvious. Several techniques have been used in the past, with varying accuracy. In South Africa there is a great need for population-specific standards, usable in the identification of unknown individuals, as the number of unidentified human bodies is very high (1).

Recently, sternal ends of ribs have been used with comparatively good results (2–7). These methods of age estimation from ribs were developed for white American individuals, and their applicability to all South African populations has not yet been ascertained. Age changes in the sternal ends of ribs vary between different populations, as is the case for most osteological standards. İşcan and Steyn (8), for example, found significant craniometric differences between North Americans and South Africans. In order to apply this method of age determination to South African populations, its accuracy needs to be determined. If it is found to be unreliable, modifications should be made to adjust it for skeletal material of South African origin.

The use of sternal ends of ribs in age determination is relatively easy to apply. No special equipment, training or laboratory are needed, the method is not time consuming, and results are rapidly obtained. Modified standards resulting from this research could thus readily be used by local forensic specialists in the identification of unknown individuals.

The existing method of using the sternal ends of ribs to determine the age at death of unknown individuals, was developed by İşcan et al. (2–6) for American populations. They deemed this method to be more accurate than other methods generally used for estimating age, e.g., cranial suture closure and changes in the symphysis pubis (9). Ribs can also be used as corroborative evidence, especially when a skeleton is incomplete. These authors later found that the morphological age changes differ among various populations (7).

Age changes may not necessarily be the same on both sides of the skeleton, and it has also been found that, with age, the first rib changes at a much faster rate than the lower ones. The fourth rib on the right-hand side has therefore been used throughout in order to reduce the possible effect of intercostal variation (2–7). The method is based on the allocation of specimens into a number of age-progressive phases, depending on the form, shape, texture, and overall quality of the sternal end of the rib. Phase characteristics differ according to population group and sex.

Results of previous studies applying the above-mentioned method to black Americans were contradictary (7,10), and the sample sizes were limited, especially where females are concerned. The aim of this study is thus to test the existing method of age determination from sternal ends of ribs on black South Africans, using a big sample. This method will be modified, if necessary, in order to render it applicable to local populations.

Materials and Methods

Specimens of sternal ends of fourth ribs of black South Africans were collected from the State Mortuary in Pretoria and the cadaver collection of the Department of Anatomy, University of Pretoria. The fourth right rib was used to minimize variability among the specimens and for easier comparison with previous studies (2–7,10). Only specimens from individuals with known age, race, and sex were included. For the purpose of this study, black South Africans were considered as a homogeneous group (11), and no distinction was made between the various groups within the South African Negroid spectrum of peoples. It should, however, be noted

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that most individuals used in this study originated from the Gauteng Province.

Three hundred and thirty-nine ribs were collected during 1994, 1995, and 1996. Two hundred and sixty-five ribs belonged to male individuals and 74 to female individuals. The ages of the individuals, as shown in Table 1, ranged between 4 and 94 years in males, and 11 and 77 years in females.

The right fourth rib was identified and removed from individuals during standard postmortem examinations at the State Mortuary. The individual ribs were then placed in glass containers bearing identification numbers. These glass containers were filled with water and the ribs were left to soak for several weeks. The specific time period depended on the rate of decomposition of the soft tissues, and was not the same for all ribs. As soon as the soft tissues could be removed with ease, the ribs were removed from the water-filled glass containers, and inserted in calico cloth pockets. These pockets were then individually marked with an indelible pen, and gently boiled in water for approximately 15 min. The ribs were finally cleaned, removing any remaining soft tissue, after which they were dried and marked by using an indelible pen and attaching aluminum labels.

Ribs from the cadaver collection from the Department of Anatomy were similarly placed into individually marked calico cloth pockets. Contrary to the ribs collected from the State Mortuary, though, these had been embalmed with a formalin mixture, necessitating several hours of boiling before soft tissue could be removed with ease. These ribs were further treated in the same way as those from the State Mortuary.

Female and male ribs were separated and arranged according to identification numbers, without revealing the ages of the individuals. Three anthropologists, familiar with the existing method developed by İşcan et al. (2–4), estimated age phases on the above-mentioned ribs. These three judges were the authors and M. Loots (from the Department of Anatomy, University of Pretoria).

The standards for white individuals were used, since their age-related features had been grouped into phases and a method had been devised for age estimation that had been tested by various judges on various study groups. It had also been used by several researchers as a gold standard to test age-related changes in other population groups (e.g., 10). The selected method involves allocating specimens to phases, according to age-related changes noted in the form, shape, texture, and overall quality of the sternal rib. After the age phase estimations had been done by each investigator, a consensus was reached regarding each rib.

TABLE 1—*Age distribution of males and females.*

Age (years)	Males (*n*)	Females (*n*)
0–9	2	0
10–19	15	8
20–29	72	18
30–39	71	17
40–49	46	16
50–59	22	7
60–69	21	6
70–79	13	2
80–89	2	0
90–99	1	0
Total	**265**	**74**

The second part of the study entailed comparing the actual age phase with the consensus estimated age phase. The comparison between the real and the estimated phases was done in tabulated form. The McNemar test for symmetry was applied to detect bias in any direction. This could mean general under- or overestimation of ages or, on the other hand, either lack of association with real phases or near accuracy. The results of both males and females were also tested, by means of the McNemar test, in order to determine whether or not the actual and the estimated ages occurred with equal probability (12).

The existing method was considered not to be effective for estimating age on this sample, and new phases were developed. The ribs were therefore seriated according to morphological features reflecting age changes. Specimens were grouped according to similar morphological features, in progressive age phases. These morphological features included those described above, as well as others seen in black Americans (7). Features only found in ribs of blacks are, for example, more squared off and pointy scallops, and bony projections are found in early phases, accompanied by good bone quality.

Phases with median ages and age ranges were developed accordingly, as the third part of this study. The phases were analyzed with the help of the Statistical Package for the Social Sciences (SPSS), subroutines crosstabs, breakdown, and one-way analysis of variance. The 95% confidence intervals of each phase were used to derive the age range of each phase. The main morphological features of each of these phases were described and a rib age phase method developed for black South Africans. The first appearance and the last presence of a certain feature were noted in that particular phase. Overlapping age ranges were accepted between subsequent age phases, but if an age was omitted by the 95% confidence interval between subsequent age phases, a value midway between the two 95% confidence intervals was calculated. This was done to include all ages within one of the phases.

Results

The first phase of this study was to estimate the age phase of each particular rib according to the set criteria (2–4). Estimations of the three judges agreed in approximately 80% of the cases. The judges exhibited a certain tendency regarding estimations in the males, e.g., investigator 2 tended to make individuals older, but the estimations for the females differed in a more random fashion, and the agreement percentages were also lower. The established method seemed to be less repeatable among the judges as far as the female ribs were concerned.

A comparison was made between the actual age phases and the consensus phases, by means of the McNemar test. The McNemar test showed a significant asymmetry, with a p value of 0.0153 (where $p < 0.05$ is significant) for males. The consensus values tended to age ribs in a younger phase, in general, as compared to the phase that is expected (actual phase). The older age groups, though, seemed to be judged older than what is expected. The agreement was 36%. If one phase difference is considered acceptable, the agreement was 78.86% (Fig. 1). The McNemar test showed an insignificant (random) asymmetry, with a p value of 0.9972 (where $p < 0.05$ is significant) in females. The consensus values showed no specific tendency to age ribs in a younger or in an older phase, as compared to the actual phase. The agreement was 35.14%. If one phase difference is considered acceptable, the agreement was 71.62% (Fig. 2).

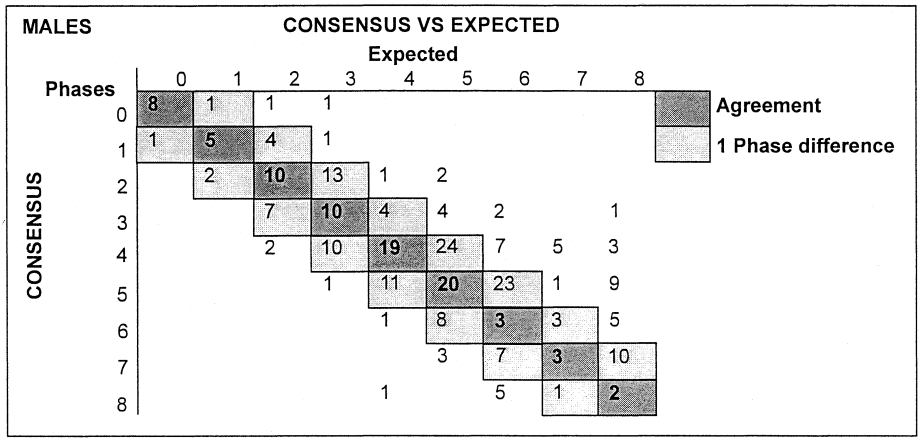

FIG. 1—*McNemar test for asymmetry in males. The consensus phase estimations arrived at by the three investigators are compared with the actual or expected age phases according to the described method. For example, the three investigators phased 11 ribs as phase O, while only nine ribs were expected to be placed there.*

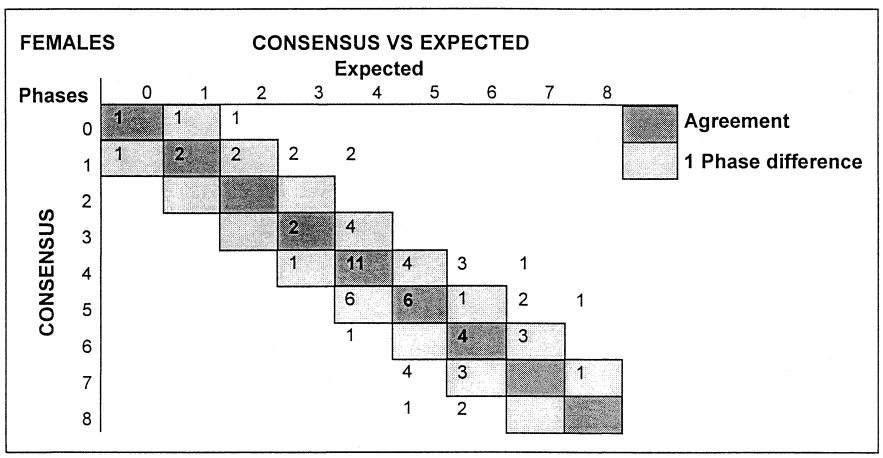

FIG. 2—*McNemar test for asymetry in females.*

The existing method, when used by the three judges, did not seem to estimate the ages of this population accurately. Estimations on the female ribs were worse than for the males, the judges were less certain of their findings and consensus was more difficult to reach.

Judging from the relatively poor results when using the established method, it became necessary to develop a new method specifically for this group. Specimens were allocated to phases according to age-related changes noted (2). The morphological features for males are as follows, with the new age ranges for each phase, as derived from the 95% confidence interval, given in parentheses.

Male Rib Phase Description (Fig. 3)

Phase O (Prephase Seen in Children)—The articular surface is flat or billowy with a regular rim and rounded edges. The bone itself is smooth, firm, and very solid, with an epiphyseal ring.

Phase 1 (18 to 21 Years)—An amorphous indentation in the articular surface is beginning. Parts of the pit can show more advanced features than the rest. The rim is rounded and regular. In some cases scallops may start to appear at the edges.

Phase 2 (22 to 24 Years)—The pit is deeper and has a V-shaped appearance formed by the anterior and posterior walls. The walls are thick and smooth and can exhibit a scalloped or slightly wavy rim with rounded edges. The scalloping features may be pointed, squared off, or flattened, or may be regular and receding.

Phase 3 (25 to 29 Years)—The deepening pit has taken on a narrow to moderately U-shape. Walls are still fairly thick with rounded edges. The rim may be unscalloped, smooth, and regular, or may manifest some scalloping which are becoming more irregular. Bony projections from the rim and, occasionally, a plaque-like deposit from the interior of the pit may already be seen.

Phase 4 (30 to 37 Years)—Pit depth is increasing. The walls are thinner, but the edges remain rounded. The rim is more irregular with no uniform scalloping pattern remaining. There is some decrease in the weight and firmness of the bone; however, the overall quality of the bone is still good.

Phase 5 (38 to 46 Years)—The pit is predominantly a moderately wide U-shape. Walls show further thinning and the edges are becoming sharp. The scalloping pattern disappears and the rim is

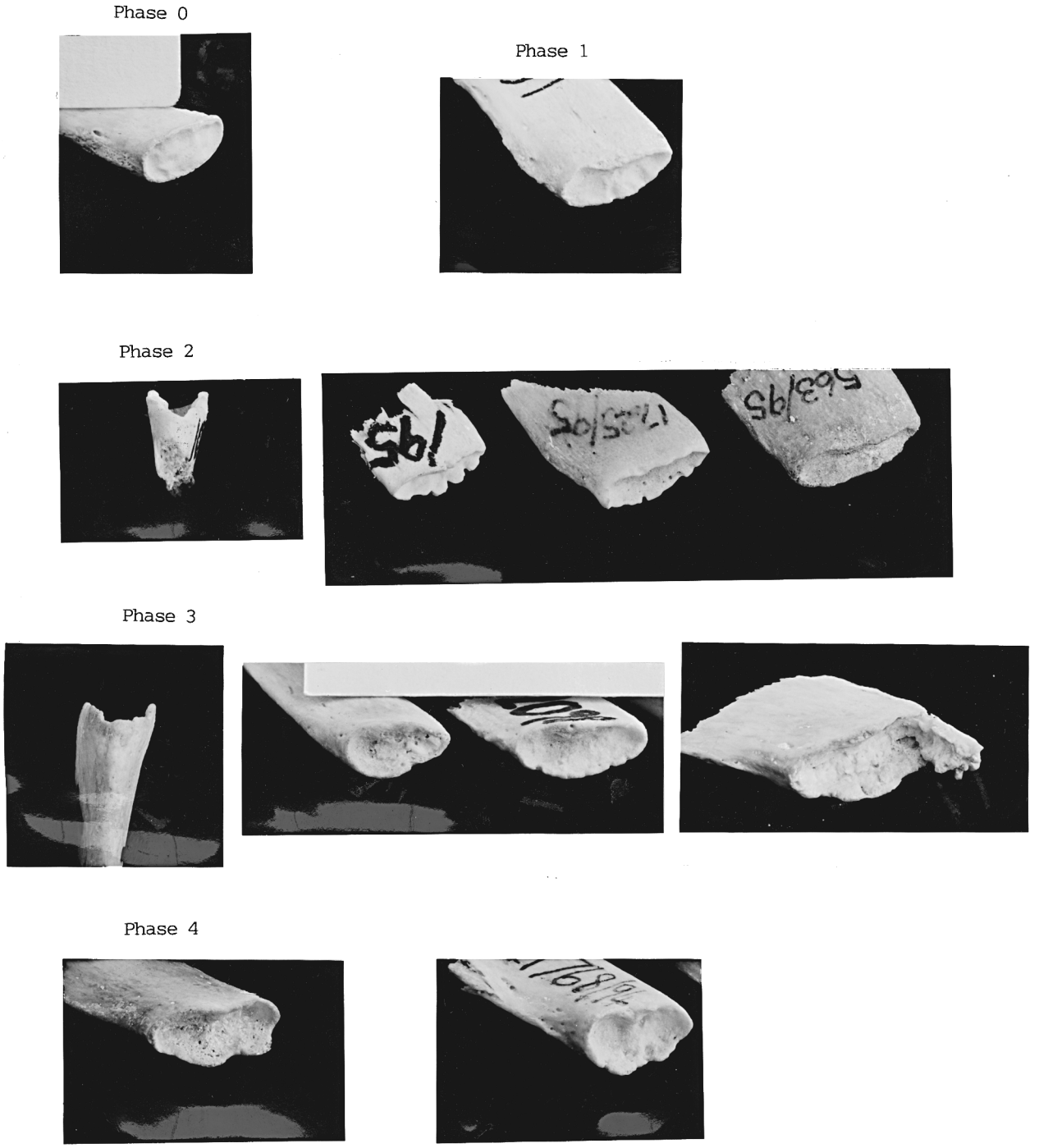

FIG. 3—*Morphological features of sternal ends of ribs in males. Phase 0—The articular surface is flat or billowy with a regular rim. Phase 1—There is an amorphous indentation of the articular surface and in some cases scallops at the edges. Phase 2—Note the shallow young-looking, Vshaped pit. The typical scalloping pattern of the rim can be seen on the left, the atypical pointy and flattened-off appearance in the center, and the smooth rim on the right. Note the shallow young-looking, V-shaped pit. Phase 3—The rim can be scalloped or smooth. Note the narrow to moderately wide U-shaped pit. Bony projections and a plaque-like deposit can be seen from the interior of the pit. Phase 4—Note the pointed anterior and posterior rims.*

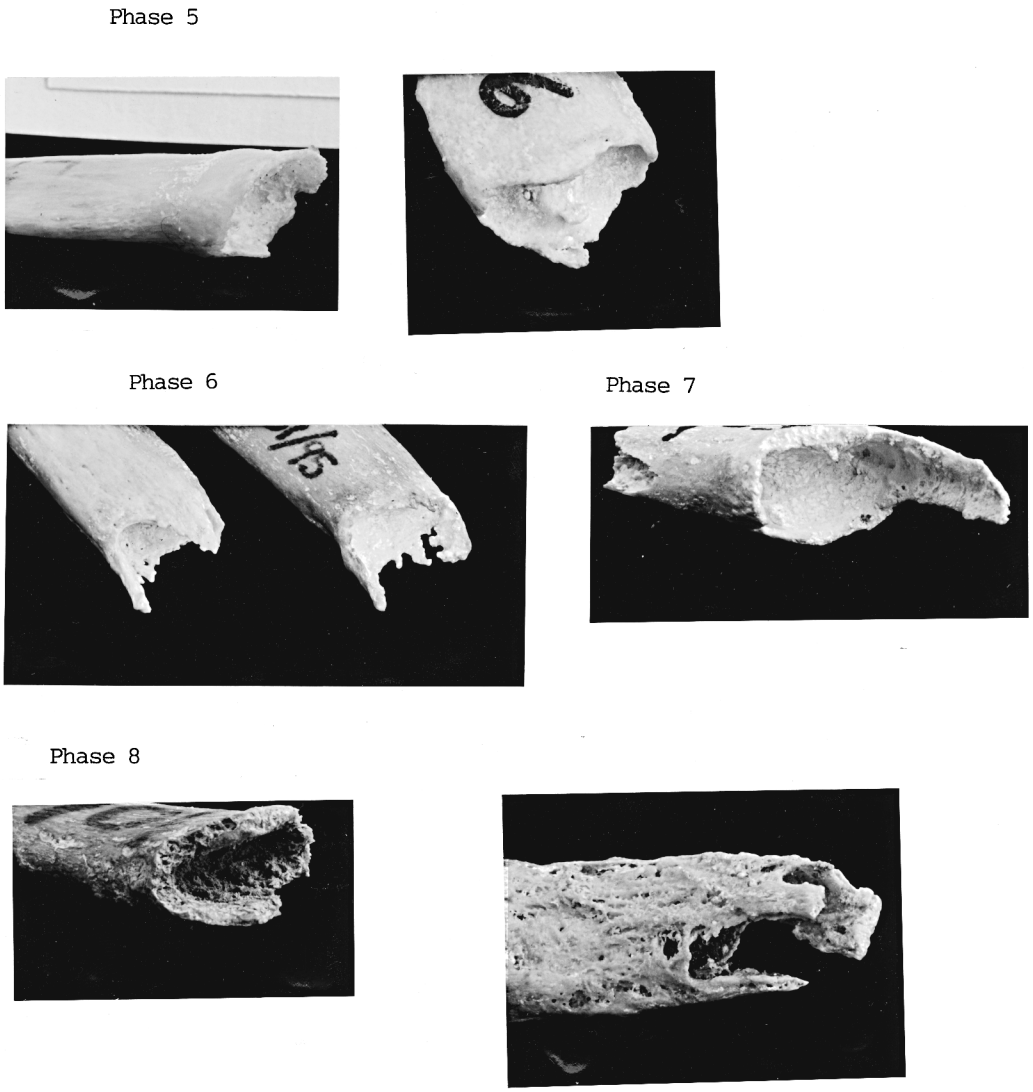

FIG. 3—*(Continued) Phase 5—The walls are irregular and thin, with sharp edges and bony projections from the rim and interior of the pit. Phase 6—The wide U-shaped pit has thin walls, sharp edges, and irregular bony projections. Phase 7—The U-shaped pit is deep and wide to very wide. Phase 8—Note the very deep pit and the thin fragile bone with "window" formation.*

irregular with bony projections, or has a flattened and pointy appearance. The condition of the bone is fairly good, although there are some signs of deterioration with evidence of porosity and loss of density. Small bony growths from the pit interior are sometimes present.

Phase 6 (47 to 55 Years)—The pit is noticeably deep with a wide U-shape. The walls are thin with sharp edges. The rim is irregular and exhibits some rather long bony projections that are frequently more pronounced at the superior and inferior borders. The bone is noticeably lighter in weight, thinner, and more porous, especially inside the pit.

Phase 7 (52 to 69 Years)—The pit is deep with a wide to very wide U-shape. The walls are thin and fragile with sharp, irregular edges and bony projections. The bone is light in weight and brittle with significant deterioration in quality and obvious porosity.

Phase 8 (63 to 77 Years)—The pit is very deep and widely U-shaped. In some cases the pit is absent or filled with bony projections. The walls are extremely thin, fragile, and brittle with sharp, highly irregular edges and bony projections. The bone is very lightweight, thin, brittle, friable, and porous. "Window" formation is sometimes seen in the walls.

Female Rib Phase Description (Fig. 4)

Phase 0 (Prephase Seen in Children)—The articular surface is nearly flat with ridges or billowing. The outer surface of the sternal extremity of the rib is bordered by what appears to be an overlay of bone, the epiphyseal growth plate. The rim is regular with rounded edges, and the bone itself is firm, smooth, and very solid.

Phase 1 (12 to 17 Years)—An amorphous indentation is beginning in the articular surface. Ridges or billowing may still be present. The rim is rounded and regular with a little waviness in some cases. An epiphyseal growth plate or ring could still be noticed.

Phase 2 (16 to 26 Years)—The amorphous indentation becomes deeper at more than one point, and then continues to form a V-

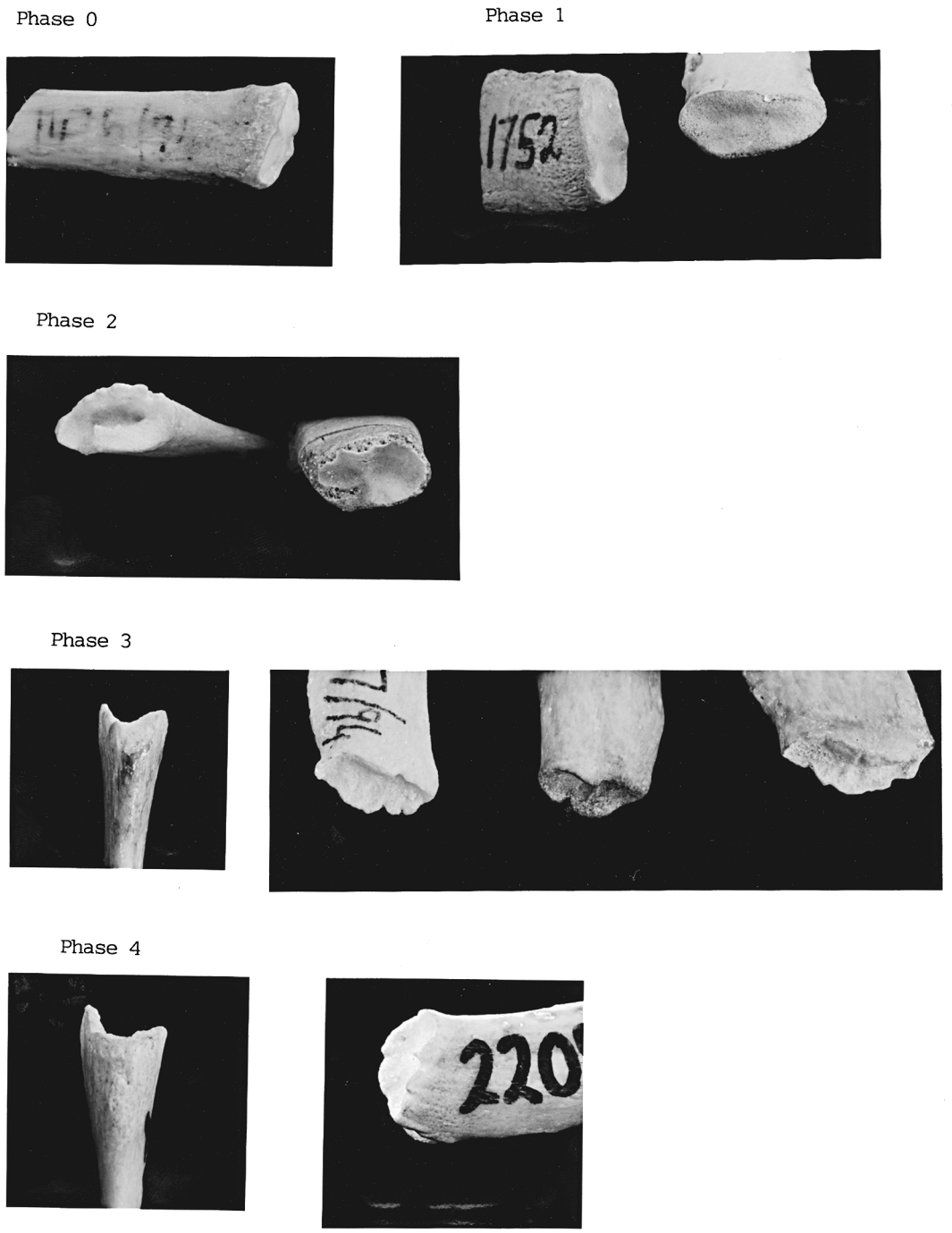

FIG. 4—*Morphological features of sternal ends of ribs in females. Phase 0—The articular surface is nearly flat. Phase 1—There is an amorphous indentation, with a rounded rim and epiphyseal growth plate. Phase 2—On the right, the indentation becomes deeper at two points and then (on the left), continuous to form a V-shaped pit. Phase 3—The V-shaped pit becomes wider. Note the different rim configurations: on the left, a regular scalloping pattern and, in the center, an irregular scalloping pattern with a pointy appearance. The specimen on the right demonstrates a central semicircular arc of bone. Phase 4—The pit is now a narrow U-shape. Some scallops remain as well as a plaque-like deposit lining the pit. The rim may demonstrate a pointy appearance.*

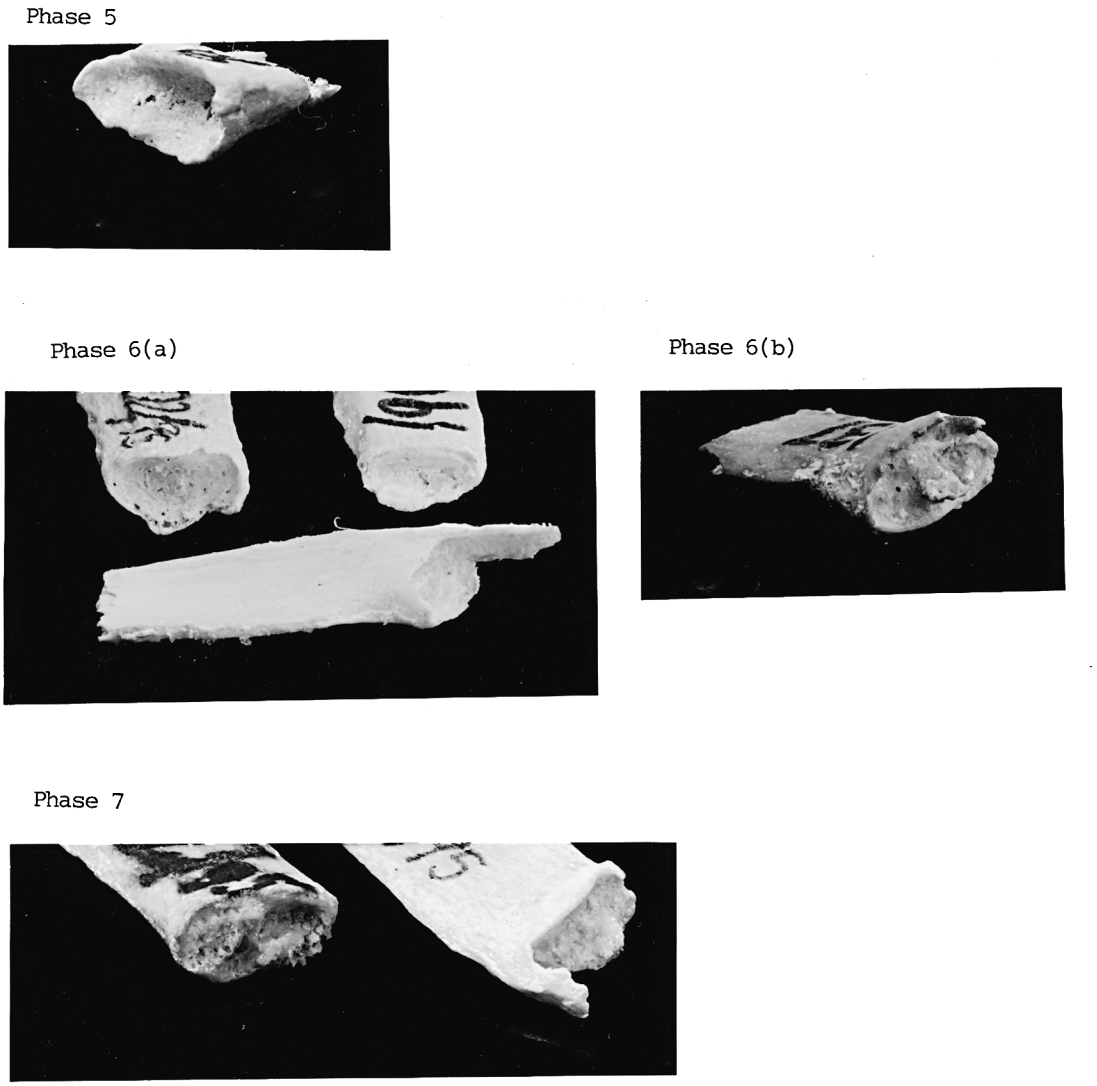

FIG. 4—*(Continued) Phase 5—The U-shaped pit is wider with an irregular rim and brittle bone texture. Phase 6 (Group a)—Note the wide U-shaped pit with the thin walls, sharp edges and irregular rim. Below a bony projection can be seen. (Group b)—Note the irregular rim and bony growths from pit interior. Phase 7—The floor of the pit is shallow and eroded.*

shaped pit between the thick, smooth anterior and posterior walls. Some ridges or billowing may still remain inside the pit. The rim is wavy with some scallops beginning to form at the rounded edge.

Phase 3 (23 to 27 Years)—There is only slight or no increase in pit depth, but the V-shape is wider, sometimes approaching a narrow U as the walls become a bit thinner. The rounded edges now show a pronounced, regular, scalloping pattern, or the rim may exhibit an irregular scalloping pattern, which gives it a pointy appearance.

Phase 4 (28 to 32 Years)—The pit now has a narrow U-shape with at times, flared edges. The pit interior may contain plaque-like deposits. The walls are thinner and the rim remains rounded, but may also be flat and pointed. Some scalloping is still present, but this is not as well defined and the edges look somewhat worn down. There is some decrease in density and firmness of the bone.

Phase 5 (33 to 43 Years)—The pit depth increases, and the thinning walls are flaring into a wider U-shape. A smooth, hard, plaque-like deposit lines at least part of the pit in some ribs. No regular scalloping pattern remains and the edge is beginning to sharpen. The rim is becoming more irregular. The bone is noticeably lighter in weight, density, and firmness. The texture is somewhat brittle.

Phase 6 (44 to 59 Years)—(Group a)—An increase in pit depth is again noted, and its U-shape has widened again because of pronounced flaring at the end. The plaque-like deposits may still appear but are rougher and more porous. The walls are quite thin with

sharp edges and an irregular rim. In many cases, sharp points or bony projections project from the rim of the sternal extremity. The bone itself is fairly thin and brittle with some signs of deterioration.

(Group b)—The pit depth, although not increasing, does not decrease. Obvious bony growths from the pit interior can be seen. No central arc of bone is present. Pointed projections, often at the superior and inferior borders, or anywhere around the rim, are found. The very thin walls have irregular rims and sharp edges.

Phase 7 (56 to 79 Years)—The floor of the U-shaped pit in this final phase is relatively shallow, badly deteriorated, or completely eroded. Sometimes it is filled with bony growths. The central arc is barely recognizable. The extremely thin, fragile walls have highly irregular rims with very sharp edges. The bone itself is in a poor condition—extremely thin, light in weight, brittle, and fragile.

Discussion

This study presents the results of age estimation on 339 ribs which were collected during 1994, 1995, and 1996. Two hundred and sixty-five of these ribs belonged to male individuals and 74 to female individuals. Their age distribution ranged between 4 and 94 years in males, and 11 and 77 years in females. Although the initial studies on whites by İşcan et al. (2–4) included a high number of individuals, follow-up studies on blacks had insufficient numbers (7). This study was more extensive, across all age ranges. More individuals in the older age ranges would have been desirable, especially where females were concerned. As compared to previous study groups, though, this sample had more representative numbers.

The different progressive age changes of the phases can often be seen as a continuum, rather than being clearly demarcated between the phases. Another factor causing different interpretations could be the fact that a specimen could exhibit advanced age in certain aspects, but younger features in other aspects. These shortcomings are inherent to any method of age estimation, and no clear solution is available. It is recommended that investigators repeatedly avail themselves of the details of the criteria of each phase, and check their estimates to ensure that they are consistent throughout.

In males the consensus values tended to age ribs in a younger phase, in general, as compared with the expected phase. The older phases (6, 7 and 8), though, seemed to be placed in an older group than expected. This could mean that black South African males take longer to show certain age-related features, but also show changes of old age sooner. Projections from the rim as well as from the pit appeared in a younger age group in our study population and in black American males (7), in comparison with white males (3). "Window" formation was also seen in a relatively young specimen. In black South Africans, projections and window formation did not necessarily indicate advanced age. Plaque-like formation in the interior of the pit seemed to be more universally present. Small outgrowths in the pit interior could be seen in phases 5 and 6.

Other investigators (13,14) who studied costochondral calcification found some racial variations which they ascribed to dietary differences among populations. One of the factors responsible for the delay in maturation seen in our younger specimens may be insufficient nutrition. Malnutrition is relatively common in developing countries, and it is a well-known fact that it may lead to a late catch-up growth phase and delayed maturation (15).

Other factors that may contribute to the observed variations include disease, physical activity, and genetic differences. Historically, a large proportion of black South Africans were manual laborers, often not having access to good health care. It may be speculated that this could have contributed to the early appearance of degenerative age changes seen in older individuals.

İşcan et al. (7), found that black American ribs had nearly identical mean ages per phase (as compared with white ribs) in phases 1 through 4, but were consistently overaged by 3 to 10 years after age 30, or phases 5 through 7. They attributed this to genetic influences since unique changes, such as different scalloping patterns, were consistently found. Environmental factors such as cultural, socioeconomic, and nutritional disparity, and differences in physical activity, though, might also have been involved. Russell et al. (10), in contrast to the above, found that Americans of African descent showed a nonsignificant trend for the rib changes to be delayed compared with Americans of European descent. Their results corresponded more closely to those seen in black South Africans.

An insignificant (random) deflection was found between the consensus and the actual age phases in females. In females the consensus values showed no specific tendency to age ribs in a younger or older phase, in general, as compared with the expected age phases. This means the method was less effective at predicting age phase in the female study group.

Sanders (15) postulated that hormonal differences may be implicated as etiological factors in male-female patterns, as the typical female pattern changed to a typical male pattern after oophorectomy or hysterectomy in some individuals. The typical female pattern is a solid tongue of calcification extending from the rib into the adjacent cartilage. The typical male pattern, on the other hand, presents as calcifications extending directly in continuity from the ends of the bony ribs. Hypoestrogenic states can be caused by surgical interventions, but also by long-standing hormonal therapy, such as depot medroxyprogesterone (16,17). This hypoestrogenic state may lead to early osteoporosis and lower bone density, resulting in premature fractures. Depot medroxyprogesterone, injected three-monthly, is commonly used in South Africa as a contraceptive method. This may account for the variation seen in the middle age groups. Some of the individuals in this group showed the typical male pattern (projections from the edges), while others had the typical female pattern (a projection from the center). Unfortunately, no information on antemortem hormonal status of the individuals is available.

In black South African females, "window" formation and bony projections from the rim were not good age markers. Phases 6 and 7 in females have overlapping age ranges. One of the criteria of phase 7 is the obvious irregular bony growths extruding from the pit interior (4). In this study, this specific feature led to the allocation of relatively young individuals to this age phase. Those individuals without the central projection, but with deepening of the pit, were allocated to phase 6. As previously described, those in phase 6 could be considered as exhibiting the male pattern and those in phase 7 the female pattern. These two phases have similar age ranges, and were thus, in this study, pooled into one phase. The differences in the morphological features of this new phase are not necessarily age related, but are characteristic of certain individuals and may be ascribed to differences in hormonal status, as discussed previously.

Although an extensive number of individuals were used, across all age ranges, the inclusion of more individuals in the older age ranges could add to the representatives of these phases in both sexes. More female ribs are necessary in all age ranges, and could clarify the overlapping age ranges. The two distinct patterns seen in phase 6 could be verified by increasing the sample size in the perimenopausal age group.

Further possibilities include investigating the occupation, as well as the medical and drug history, of each individual studied. A relationship between these factors and the morphological features of the sternal end of the rib may be found. Such factors may provide more information regarding unidentified individuals, e.g., nutritional status or physical activity.

The sample used in this study was assumed to be representative of the black South African population as a whole. This, of course, may not necessarily be the case. Other black South African groups may show different patterns of aging; therefore, the results now need to be tested or expanded by other researchers.

Acknowledgments

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