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*Communication*

# Sternal Rib Ends as a Method of Age Estimation at the CIL: A Brief Note

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**Abstract:** This communication reports the relationship between skeletal age estimates based on the sternal rib ends (using the phase method of İşcan and colleagues, later revised by Hartnett) and the chronological age at the death of 221 U.S. military casualties processed by the Scientific Analysis section of the Defense POW/MIA Accounting Agency and its predecessor laboratories from 2000 to the present. Previously published age ranges for each phase do not provide accurate estimates for a sufficient proportion of the cases for forensic use; as an example, the age ranges that accompany reference cast sets proved accurate for 55% of CIL cases. Combining the published age ranges of İşcan and Hartnett, on the other hand, proved accurate in 99% of the cases.

**Keywords:** age estimation; sternal rib ends; military casualties

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## 1. Introduction

The sternal end of the fourth rib was first identified as a useful indicator of skeletal age by İşcan and colleagues [1], who identified three separate components to quantify change with age (pit depth, pit shape, and rim and wall configuration). From this pattern of variation, they then developed a nine-phase system (0–8) for categorizing age-related variation, initially for White males [2,3]. Later studies by the same authors examined variation in the aging process in White females [4,5] and Black males and females [6]. The age ranges for each phase were later refined slightly (although no explanation for this change has been found, it appears to have been based at least partially on the 95% prediction interval for each) [7], and a set of casts was produced to standardize the application of the phases to skeletal material [8]. This method has been tested on various populations and found to be broadly accurate [9]. Subsequently, others have found that the other "standard" ribs (that is, 2–9) generally follow the same pattern and may be used as a substitute for rib 4 when the latter is not preserved [10–12]. More recently, Hartnett reassessed the system on a larger sample, providing new definitions for phases 1–7 (none of her sample fell into phases 0 or 8) that emphasized bone texture and quality over appearance, as well as new age ranges based on her data [13]. This brief study tests the applicability of prior published age ranges for rib phases [2,6–8,13] to casework from the Scientific Analysis section of the Defense POW/MIA Accounting Agency and its institutional predecessors, the Joint POW/MIA Accounting Agency—Central Identification Laboratory (JPAC-CIL) (2003–2015)—and Central Identification Laboratory—Hawai'i (CILHI) (1975–2003). There has been institutional continuity throughout these organizational changes, and the label CIL serves as a collective term for all three.

## 2. Materials and Methods

Pubic symphyses and long bone epiphyses, scored following the standards of McKern and Stewart [14], have been the primary age indicators used by the CIL throughout its history. While long bone epiphyses are only valuable for age determination up until the age that all are fully united (roughly 25 years of age), symphyses continue to develop throughout the lifespan and thus are the primary method used for aging older adults. Like pubic symphyses, sternal rib ends continue to develop throughout the lifespan and may be used to estimate the age of a skeletalized individual well past the terminus of epiphyseal development. However, they have not been as frequently used by CIL anthropologists, primarily because they are not often well preserved in archaeological cases but also because of concerns on the part of many analysts that the published age ranges may not be wholly applicable to CIL casework.

Over the past decade, an increasing proportion of the CIL's casework has come to be unknown remains exhumed from military cemeteries, which are generally better preserved than remains recovered archaeologically from aircraft crash sites or battlefield graves. As a result, CIL anthropologists have had more opportunities to score rib ends; nonetheless, many are still reluctant to rely on them for age estimation. This study compiles all available retrospective case data to determine whether their reluctance is justified. The data presented here are drawn from 154 peer-reviewed Forensic Anthropology Reports prepared by 80 different CIL anthropologists between 2000 and 2023, supplemented by 7 non-peer-reviewed preliminary analyses by 4 anthropologists and 60 additional individuals scored from 2019 to 2023 by the author. These individuals were all scored between phases 1 and 6; while phase 0 was recorded at the CIL, no individual with that score has yet been identified as a U.S. casualty. Because of the nature of the CIL's work, where cases are generally only under analysis for a brief window prior to their identification and burial, no tests of interobserver or intraobserver error were conducted. However, the scores in all peer-reviewed cases were verified by the reviewer.

The individuals scored were all males, including 120 World War II casualties (dates of birth: 1889–1925; dates of death: 1941–1945; mean age: 24.6) and 101 Korean War casualties (dates of birth: 1909–1933; dates of death: 1950–1953; mean age: 22.0). The majority of individuals (202/221, or 91.4%) were recorded as White in their personnel files, with the remainder consisting of ten Blacks, five Mexican-Americans, and four Native Americans.

While the original age ranges published by İşcan et al. [2], and slightly emended by Loth and İşcan [7,8], offer great applicability in the 18–29 age range, in which the majority of identified U.S. casualties fall, numerous CIL anthropologists have questioned the application of a method based on such small sample sizes exhibiting tight, and largely non-overlapping, age ranges. İşcan et al. [2] included 44 males between 17 and 29 years of age, but these were distributed across 5 phases, leading to small samples for each phase. In contrast, Hartnett [13] reported on a larger sample, but it was one heavily weighted towards older individuals, which are not common in CIL casework. Table 1 illustrates the dramatically different age structures of (a) the combined White and Black male samples from İşcan et al. [2,6], (b) the male sample from Hartnett [13], and (c) the CIL sample (presented here as World War II and Korean War subsamples to illustrate the difference between their age structures). In particular, 89.3% of the CIL sample were under 30 years of age at their time of death, compared to 46.2% of İşcan et al.'s [2,6] and 14.9% of Hartnett's [13].

**Table 1.** Age composition of sternal rib end samples.

| Age | İşcan [2,6] | Hartnett [11] | CIL (WWII) | CIL (Korea) |
|---|---|---|---|---|
| <20 | 22 (12.9%) | 9 (2.2%) | 13 (10.8%) | 44 (43.6%) |
| 20–29 | 57 (33.3%) | 53 (12.8%) | 93 (77.5%) | 48 (47.5%) |
| 30–39 | 30 (17.5%) | 41 (9.9%) | 13 (10.8%) | 8 (7.9%) |
| 40–49 | 19 (11.1%) | 83 (20%) | 0 (0.0%) | 1 (1.0%) |
| 50–59 | 18 (10.5%) | 79 (19%) | 1 (0.8%) | 0 (0%) |
| 60–69 | 14 (8.2%) | 63 (15.2%) | 0 (0%) | 0 (0%) |
| 70+ | 11 (6.4%) | 87 (21%) | 0 (0%) | 0 (0%) |
| Total | 171 | 415 | 120 | 101 |

While İşcan et al. [6] reported differences between the aging process in their Black and White population samples, with morphological changes happening at a slightly younger age in Black males, neither Hartnett's sample [13] nor that from the CIL are subdivided by ancestry. Furthermore, in a test of the method, Russel et al. [8] found that their White and Black population samples exhibited an opposite pattern, with Whites developing slightly faster. As a result, it was decided to combine İşcan et al.'s White [2] and Black [6] male samples for better comparability to the CIL sample.

## 3. Results

As expected from the age structure seen in Table 1, the CIL sample contains far more individuals in phases 1–3 than the other series (Table 2). Mean ages and ranges are comparable, although they also exhibit shifts due to age structure.

**Table 2.** Descriptive statistics for sternal rib end phases 1–6.

| Phase | Sample | *n* | Mean Age | SD | Age Range * |
|---|---|---|---|---|---|
| 1 | İşcan (White males) [2] | 4 | 17.3 | 0.50 | 17–18 |
| | İşcan (Black males) [6] | 2 | 18.0 | 4.24 | 15–21 |
| | İşcan (all males) [2,6] | 6 | 17.5 | 1.97 | 15–21 |
| | İşcan (male cast set) [7,8] | - | - | - | 17–19 |
| | Hartnett [13] | 20 | 20.0 | 1.45 | 18–22 |
| | CIL | 71 | 19.81 | 1.23 | 17.7–23.8 |
| 2 | İşcan (White males) [2] | 15 | 21.9 | 2.13 | 18–25 |
| | İşcan (Black males) [6] | 8 | 22.0 | 2.93 | 17–26 |
| | İşcan (all males) [2,6] | 23 | 21.9 | 2.37 | 17–26 |
| | İşcan (male cast set) [7,8] | - | - | - | 20–23 |
| | Hartnett [13] | 27 | 24.6 | 2.00 | 21–28 |
| | CIL | 67 | 21.88 | 2.26 | 18.0–27.2 |
| 3 | İşcan (White males) [2] | 17 | 25.9 | 3.50 | 19–33 |
| | İşcan (Black males) [6] | 7 | 24.9 | 3.24 | 20–30 |
| | İşcan (all males) [2,6] | 24 | 25.6 | 3.39 | 19–33 |
| | İşcan (male cast set) [7,8] | - | - | - | 24–28 |
| | Hartnett [13] | 27 | 32.4 | 3.69 | 27–37 |
| | CIL | 48 | 24.59 | 2.78 | 20.8–31.8 |
| 4 | İşcan (White males) [2] | 12 | 28.2 | 3.83 | 22–35 |
| | İşcan (Black males) [6] | 6 | 28.5 | 3.83 | 23–32 |
| | İşcan (all males) [2,6] | 18 | 28.3 | 3.72 | 22–35 |
| | İşcan (male cast set) [7,8] | - | - | - | 26–32 |
| | Hartnett [13] | 47 | 42.4 | 2.98 | 36–48 |
| | CIL | 27 | 30.92 | 5.18 | 22.6–42.2 |
| 5 | İşcan (White males) [2] | 14 | 38.8 | 7.00 | 28–52 |
| | İşcan (Black males) [6] | 14 | 38.9 | 7.72 | 26–51 |
| | İşcan (all males) [2,6] | 28 | 38.9 | 7.23 | 26–52 |
| | İşcan (male cast set) [7,8] | - | - | - | 33–42 |
| | Hartnett [13] | 76 | 52.1 | 3.50 | 45–59 |
| | CIL | 6 | 35.62 | 8.63 | 28.8–52.0 |
| 6 | İşcan (White males) [2] | 17 | 50.0 | 11.17 | 32–71 |
| | İşcan (Black males) [6] | 4 | 43.5 | 15.93 | 27–62 |
| | İşcan (all males) [2,6] | 21 | 48.8 | 12.03 | 27–71 |
| | İşcan (male cast set) [7,8] | - | - | - | 43–55 |
| | Hartnett [13] | 61 | 63.1 | 3.53 | 57–70 |
| | CIL | 2 | 35.49 | 0.37 | 35.2–35.8 |

* Note that this is the range of ages observed in each study, with the exception of those first published by Loth and İşcan [7] and later issued with the casts provided by İşcan and Loth [8], which are modified from the previously published ranges.

In Forensic Anthropology Reports at the CIL, the two most common ways of obtaining an estimated age range from a particular skeletal indicator (in this case, sternal rib phase) are (a) reporting the age range within which that indicator was observed in the reference sample or (b) reporting a range of two standard deviations around the mean age at which that indicator was observed. With a large enough sample size, the former generally provides a more conservative estimate, while the latter approximates the range within which one might expect 95% of individuals to fall. The age ranges provided with the reference cast set for sternal rib ends [8], however, are neither of these. Instead, they are rounded-off versions of the 95% Confidence Interval of the mean age for each phase, which are, in fact, smaller than the observed age ranges for all phases other than 1. As an example, for Phase 3 (as shown in Table 2), İşcan et al. [2] originally reported an age range of 19–33 and a mean of 25.9, with 95% confidence that the mean was between 24.1 and 27.7; with the cast set [8], they provided a range of 24–28, which is dramatically smaller than both the observed range and the range plus or minus two standard deviations (18.9–32.9). To assess the accuracy of different estimates, each CIL case was compared to (1) the cast set prescriptive range for that phase [8], (2) the observed range from İşcan et al. [2], as well as the ranges within one and two standard deviations of the mean, (3) the same three ranges from the combined İşcan et al. sample [2,6], (4) the same three ranges from Hartnett [13], and (5) the age range observed by İşcan et al. [2,6] and Hartnett [13] combined, since that should logically cover the broadest range of variation available (Table 3).

**Table 3.** Accuracy of different age brackets when applied to the CIL sample.

| Phase | N | 1 | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 71 | 62% | 25% | 3% | 8% | 96% | 45% | 89% | 89% | 77% | 97% | 97% |
| 2 | 67 | 64% | 93% | 64% | 96% | 97% | 73% | 97% | 61% | 30% | 63% | 99% |
| 3 | 48 | 35% | 100% | 71% | 100% | 100% | 75% | 100% | 21% | 10% | 38% | 100% |
| 4 | 27 | 56% | 81% | 44% | 81% | 81% | 44% | 81% | 19% | 7% | 19% | 100% |
| 5 | 6 | 50% | 100% | 50% | 100% | 100% | 50% | 100% | 17% | 17% | 17% | 100% |
| 6 | 2 | 0% | 100% | 0% | 100% | 100% | 0% | 100% | 0% | 0% | 0% | 100% |

Age brackets: 1. Loth and İşcan [7,8], predicted range. 2. İşcan et al. [2], (a) observed range, (b) within one standard deviation of mean, and (c) within two standard deviations of mean. 3. Combined İşcan et al. [2,6], (a) observed range, (b) within one standard deviation of mean, and (c) within two standard deviations of mean. 4. Hartnett [13], (a) observed range, (b) within one standard deviation of mean, and (c) within two standard deviations of mean. 5. Combined İşcan et al. [2,6] and Hartnett [13], observed range.

It is immediately apparent from this comparison that the age ranges that are most often used for each phase (that is, the ones that come with the reference casts) [8] are too inaccurate for forensic use. Of the CIL cases in phases 1 and 2, fewer than two in three fell within the prescribed age range of 17–19. In subsequent phases, even fewer fell within the cast age ranges, while most fell within those observed by İşcan et al. [2].

It is also clear that the combined ranges observed by İşcan et al. [2,6] capture almost all of the variation within the CIL sample. The addition of the Black male sample is particularly important for phase 1, where it increases the range from 17–18 to 15–21.

Hartnett's ranges [13] are substantially less accurate when applied to the CIL sample. This should be expected, given the dramatically different age composition of the two samples.

When Hartnett's and İşcan et al.'s ranges are combined, only 3/221 individuals in the CIL sample are misclassified. One of them is an individual scored in phase 2 who was 17 days shy of his eighteenth birthday when he was killed, and thus is only a minimal outlier. The other two are individuals scored in phase 1, whose ages were 23.5 and 23.7. Given that the next youngest individual in phase 1 was 21.8, these two are clearly outliers (perhaps, but not necessarily, due to mis-scoring).

## 4. Discussion and Conclusions

At the CIL, age estimation is most commonly used as an exclusionary tool to narrow the pool of possible individuals that a particular set of remains might belong to. Age ranges therefore need to be conservative in order to not falsely exclude potential candidates for identification. Based on this review, no single published set of age ranges is accurate enough for routine use at the CIL. The cast ranges [8] are not accurate enough at any phase; İşcan et al.'s original published ranges [2] are particularly bad at phase 1, the phase most often observed at the CIL; and Hartnett's ranges [13], while better than İşcan et al.'s at phase 1, are not sufficiently accurate at any other phase. While adding İşcan et al.'s Black sample [6] to their White sample [2] improves the ranges' accuracy, particularly for phase 1, the most reliable estimates are provided by the combined ranges of İşcan et al. [2,6] and Hartnett [13].

The discrepancies between the different published ranges are a logical result of their small sample sizes and different age structures (see Tables 1 and 2). Combining the reference data sets helps ameliorate these issues, which is why the combined ranges are so much more accurate. For future analyses of skeletal remains drawn from an unknown population, analysts may wish to use these combined ranges. For work on military casualties specifically, and particularly for casework analyses conducted at the CIL, the CIL-derived ranges published here are recommended for individuals in phases 1–4; for the few CIL cases in later phases, use of the combined ranges is preferred. In the future, the use of this method on a larger number of CIL cases may somewhat improve the sample sizes for the later phases, but by its nature, a sample of military casualties will always have a distinct age bias.

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