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Estimating adult age categories in commingled skeletons with Transition Analysis 3

Alyssa L. Bolster¹ | Hannah J. JeanLouis² | Lesley A. Gregoricka³ |
Jaime M. Ullinger⁴

¹Department of Anthropology, Brown University, Providence, Rhode Island, USA

²Independent Researcher, Orlando, Florida, USA

³Department of Sociology, Anthropology, & Social Work, University of South Alabama, Mobile, Alabama, USA

⁴Department of Sociology & Anthropology, Quinnipiac University, Hamden, Connecticut, USA

Correspondence

Alyssa L. Bolster, Department of Anthropology, Brown University, 128 Hope St, Providence, RI 02912, USA.
Email: alyssa_bolster@brown.edu

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Abstract

Objectives: We estimate adult age frequencies from Unar 1 and Unar 2, two late Umm an-Nar (2400–2100 BCE) tombs in the modern-day Emirate of Ras al-Khaimah, United Arab Emirates. These collective tombs each contained hundreds of skeletons in commingled, fragmented, and variably cremated states. Previous studies placed the vast majority of this mortuary community in a generalized “adult” category, as have most analyses of similar tombs from this period. We sought to test how adult age estimation methods compare in identifying young, middle, and old-age individuals in commingled assemblages.

Materials and Methods: We employed Transition Analysis 3 (TA3) and traditional age estimation methods to generate adult age frequencies for each tomb. We compared these frequencies between tomb contexts as well as by method.

Results: Unar 1 and Unar 2 had similar adult age frequencies within each method, but TA3 age frequencies included significantly more middle and older adult individuals than those generated by traditional methods.

Discussion: These results support findings of earlier iterations of transition analysis in regard to sensitivity in old adult age estimation, compared with traditional methods. Our findings indicate a potential use of TA3 in reconstructing age frequencies and mortality profiles in commingled skeletal assemblages. Increasing our understanding of everyday life in the distant past necessitates better understandings of adult age, and here, we illustrate how age estimation method choice significantly changes bioarchaeological interpretations of aging in Bronze Age Arabia.

Research Highlights

- Adult age estimation using TA3 revealed significantly more middle and older adults than traditional methods in two commingled tombs.
- Similar mean maximum likelihood point estimates by side and across skeletal elements were found between tombs.

KEYWORDS

age-at-death estimations, bioarchaeology, commingling, paleodemography, transition analysis

1 | INTRODUCTION

For bioarchaeologists, estimating community size, age and sex distributions, and disease burden in the distant past is fraught with obstacles, from concerns about the osteological paradox (Wood et al., 1992) to employing methods based on problematic reference collections, unsuitable statistical analyses, and scoring systems with descriptions that are far too subjective (Bocquet-Appel & Masset, 1982). Such issues have the potential to introduce error, not only to bioarchaeological analyses but also to subsequent interpretations as well. One could argue that room for error is only amplified when studying commingled and taphonomically damaged skeletal assemblages. Often, these collections are essentially banished to storage rooms after excavation, precluded from analysis beyond brief description and only the most basic attempts at demographic investigation (Martin & Osterholtz, 2016). Here, we argue for the utility and necessity of paleodemographic analyses of commingled skeletons by examining a case study from Bronze Age Arabia; particularly, we focus on age estimation and attempt to move beyond the region's traditional emphasis on estimating more precise ages for nonadults while identifying only a generalized "adult" age category.

1.1 | Umm an-Nar mortuary practices

In southeastern Arabia, the latter half of the Early Bronze Age is known as the Umm an-Nar, extending from 2700 to 2000 BCE. The period is characterized by increased sedentism around fortified centers supported by oasis agriculture, with communities cultivating date palm, wheat, and barley, as well as exploiting marine resources, hunting camelids, and engaging in pastoralism (Blau, 1999; Cable, 2019; Méry & Tengberg, 2009; Potts, 1990, 2001). The Umm an-Nar also saw the emergence of increasingly complex trade systems as southeastern Arabia enhanced connections with Mesopotamia, the Indus Valley, Dilmun, and Elam (Carter, 2003; Potts & Hellyer, 2012). In addition to these changes, communities in the Umm an-Nar began to produce their own ceramics using local materials (David, 1996) and to construct monumental, circular tombs near settlements (Al-Tikriti, 1989; Blau, 2001). A single tomb was used to inter the dead over hundreds of years (Potts & Hellyer, 2012).

Within these tombs, commingling and, sometimes, cremation resulted in disarticulated and fragmented skeletons (Blau, 2001). For example, at the Umm an-Nar tomb at Tell Abraq (2100–2000/1950 BCE), over 400 skeletons became commingled over a 150-year period, including bones from nonadults and adult males and females (Baustian, 2010; Baustian & Martin, 2010; Schrenk et al., 2016). Bioarchaeological analyses estimated that nearly 70% of the burial population at Tell Abraq was over the age of 18 (Baustian, 2010). Similarly, at Umm an-Nar Island, early Umm an-Nar tombs included the commingled skeletons of up to 50 adult males, adult females, and children, though no more specific age estimates are reported (al-Tikriti, 2012). At Hili North, Tomb A is reported to have a mortality profile indicative of high infant and young adult

mortality, with no adult living past the age of 40, though only articulated skeletons (31 out of an estimated 300 individuals) were considered (el-Najjar, 1985; McSweeney et al., 2008).

Despite a number of bioarchaeological investigations that included age-at-death in Umm an-Nar communal tombs, which support the idea that individuals of all ages were interred within them (e.g., Baustian & Martin, 2010; Blau, 2001; McSweeney et al., 2008), attention to adult age distribution has been largely overlooked beyond classification of individuals as "young adults" or generally "adults." Past analyses focused on tomb architecture and artifacts (e.g., Iacono et al., 1996; Al-Tikriti, 1985, 1989) rather than the mortuary community and, if skeletons were mentioned, it was usually done in reference to their poor preservation, disturbance in antiquity, and fragmentation or degree of burning. These foci seem to imply the supposed lack of analytical potential that these commingled assemblages hold.

1.2 | Tombs of the Shimal Necropolis

The Shimal Necropolis is located in the modern-day Emirate of Ras al-Khaimah in what is now the United Arab Emirates. The surrounding landscape features oases that would have supported agriculture and pastoralism, while hundreds of single and collective Wadi Suq (2000–1600 BCE) tombs indicate a large second millennium population (de Cardi, 1989). However, two Umm an-Nar tombs, Unar 1 and Unar 2, were discovered embedded into this mortuary landscape as well (Blau, 1998). Tomb Unar 1 (2400–2200 BCE) was excavated in the late 1980s, and while initial analyses suggested the tomb contained a minimum number of 438 individuals based on the left petrous part of the temporal bone (Schutkowski, 1989), more recent investigations of the same feature put tomb membership closer to 200 individuals (Ullinger et al., 2020). Later work in the 1990s revealed tomb Unar 2 (2300–2100 BCE); a minimum number of 431 individuals was estimated by Blau (2001) using an unreported element, which was largely confirmed by Ullinger et al. (2020)'s count of left petrous parts of the temporal bone.

1.3 | Age estimation and commingled assemblages

Numerous techniques are available to bioarchaeologists for estimating age-at-death. Estimating age in nonadults is generally more accurate than in adults, as it relies on specifically timed developmental stages of the young skeleton (Buikstra & Ubelaker, 1994). Popular methods for nonadult age estimation include epiphyseal union and fusion of primary ossification centers and the development and eruption of dentition. In commingled assemblages, methods, such as nonadult long bone measurement overcome some issues of taphonomy, using better-preserved elements, such as the femur and tibia (Anderson et al., 1964; Gindhart, 1973; Jeanty, 1983; Scheuer et al., 1980). Conversely, adult aging techniques generally utilize age-progressive, degenerative changes that vary more broadly in onset and severity between individuals and even among different age indicators and

elements within the same skeleton, subsequently producing wider age intervals (DeWitte, 2018). Traditional macroscopic observations to estimate age in the adult skeleton include the pubic symphysis (Brooks & Suchey, 1990; Hartnett, 2010; Todd, 1920), auricular surface (Lovejoy et al., 1985), and cranial sutures (Meindl & Lovejoy, 1985), while newer methods include examinations of tooth root translucency (Prince & Ubelaker, 2002). Despite the development of numerous methods, the accuracy of age estimation in adults is much less than that of nonadults, resulting in broad, generalized age ranges, and particularly, a lack of age estimation for older adults beyond categorizing individuals as “50+” years of age.

Reconstructing community demography aids in our understanding of life in the past, including parameters of care, survival, and social expectations (Tung, 2016). However, commingled skeletal collections pose several unique challenges to bioarchaeologists interested in demographic analyses, such as age estimation (Osterholtz, 2016; Osterholtz et al., 2014). Typically, multiple age indicators from traits across an individual's skeleton are used to produce more accurate age ranges in articulated assemblages, even when elements are fragmented or damaged (Konigsberg et al., 2008; Wittwer-Backofen et al., 2008). Commingled skeletal collections, on the other hand, preclude observation of related skeletal elements due to a lack of discrete individuals, resulting in age distributions or frequencies that are typically generated from only one bone or landmark. Therefore, we have a dearth of evidence about past lifeways from regions and time periods that practiced communal mortuary rituals where large numbers of people were interred together, and a significant obstacle in the form of available methods to adequately approach these themes. The need for methodological approaches when studying commingled assemblages has been recognized, and newer methods may be the key to overcoming obstacles in adult age estimation within these assemblages (Osterholtz et al., 2014).

1.4 | Transition analysis in bioarchaeology

Transition analysis (TA), generally, is a statistical approach used by bioarchaeologists to assess age-at-death by estimating the most likely age of an individual as a skeletal feature transitions from one stage to the next. This statistical framework can utilize a variety of skeletal landmarks (e.g., pubic symphysis, auricular surface, femoral head and neck) characterized by ordinal stages, regardless of a phase- or component-based system (e.g., Brooks & Suchey, 1990; Konigsberg et al., 2008). Transition analysis, through the application of Bayes' theorem, generates a probability distribution for a given feature correlated with aging and informed by a selection of priors (Hoppa & Vaupel, 2002). This distribution indicates the likelihood that a feature would develop or change across an individual's lifetime, generating a maximum likelihood point estimate and age interval for the feature when seen on a skeleton (Getz, 2020).

Using this Bayesian framework with a component-based scoring system, Boldsen et al. (2002) proposed a new method known as Transition Analysis 1 (TA1), denoted with the use of capital letters. This

method relies on a specific set of traits from across the skeleton and utilizes a “prior” (reference distribution) originally developed from the Terry Collection. TA1 was followed by TA2, which employs more approachable user interface software (ADBOU; currently version 2.1.046 (2016), available at <https://www.statmachine.net/software/ADBOU2/>) and allows users to select a prior that more closely corresponds to one's own sample (e.g., archeological, forensic, or unknown), yet still focuses on relatively standard skeletal landmarks used previously in age estimation: pubic symphyses, iliac auricular surfaces, and cranial sutures. When using TA2 software, analysis of an individual skeleton is ideally done with as many of the 19 scorable features present as possible, though it has been tested using features available on single elements, even when working with taphonomically damaged collections (Brickley et al., 2016).

Studies have shown that this more recent form of TA potentially overcomes many concerns about traditional age estimation techniques, including the problem of age mimicry, or the systematic bias of data toward the original reference sample (Boldsen et al., 2002; DeWitte & Yau, 2020). Further, TA focuses on adult individuals, estimating age by assuming natural degradation of the skeleton over an individual's lifespan with minimal influence from external factors, and has produced different, more accurate age distributions compared with traditional methods in the same human groups (Bullock et al., 2013; Clark et al., 2020).

The latest, yet unpublished iteration of this method, Transition Analysis 3 (TA3), is reported to incorporate updated statistical analyses and mathematical modeling into the age estimation framework by using a random generalized linear model, which is trained on an increase in the number of reference collections from two (one archeological and one modern) to six (adding four diverse, modern collections, and updating the previous two) (Getz, 2018, 2021). TA3 does not require user selection of a specific prior or for analysis to be sex-specific. Moreover, TA3 appears to be useful in all descent groups, estimates conglomerate scores when entire individuals or multiple elements are available, and is not as sensitive to interobserver error (Getz, 2020). This is achieved by the increased number of “sectors” or observation points on the skeleton as compared with previous iterations (Getz, 2020). These observation points incorporate elements not traditionally seen in adult age estimation methods (Galimany & Getz, 2023), signaling the potential utility of TA3 for estimating adult age of disarticulated skeletons, such as those found in commingled and taphonomically damaged groups where traditional age estimation methods—and TA2—might fall short.

Methodological variation in adult age estimation has important implications for bioarchaeological interpretations, particularly regarding our ability to accurately and meaningfully discuss longevity, survivorship, onset of pathological conditions, and activity load (Boldsen et al., 2022; Bullock et al., 2013; Clark et al., 2020). Subsequently, in this study, we estimate adult age in commingled, fragmentary, cremated, and taphonomically deteriorated skeletal assemblages from the Umm an-Nar communal tombs of Unar 1 and Unar 2 by comparing TA3 results (maximum likelihood point estimates) with mean age-at-death estimates generated by traditional techniques using the

pubic symphysis (Brooks & Suchey, 1990; Harnett, 2010). We hypothesize that TA3 will yield more fine-grained adult age estimates that differentiate between young, middle, and old adult individuals as compared with traditional methods, thus assigning more individuals within the same sample to an older-age interval, supporting the idea that Umm an-Nar tombs were occupied by people of all ages (including older-aged adults).

2 | MATERIALS AND METHODS

We observed skeletal age indicators using pubic symphyses, proximal femora, proximal humeri, and distal humeri recovered from Umm an-Nar-period tombs Unar 1 and Unar 2, which are currently housed at the University of South Alabama. Earlier research estimated age using only dental eruption and wear and thus generated broad age groupings, placing the majority of individuals (Unar 1: 97.72%; Unar 2: 91.0%) into a generalized “adult” category (Blau, 1998). To better understand adult age frequencies within Unar 1 and Unar 2, and in particular, whether older-age categories might be identified, we compared TA3 (Getz, 2020) with a traditional age estimation method developed by Brooks and Suchey (1990) and modified by Harnett (2010).

2.1 | Transition Analysis 3

We employed the maximum likelihood point estimates generated in TA3 for analysis of adult age frequencies within both assemblages. We selected four anatomical sites in the skeleton analyzed in the TA3 software: pubic symphysis ($n = 49$), proximal femur ($n = 93$), proximal humerus ($n = 18$), and distal humerus ($n = 67$). Only fragments with

at least one observable feature and those able to be assigned a side were included. Within the TA3 program, we treated each skeletal area (e.g., distal humerus) as though it represented an independent individual, acknowledging the likelihood of overlap once we began analyzing other elements. In other words, for the same individual, we potentially estimated age more than once using age indicators on different skeletal elements, but did so under the assumption that we were looking at a representative sample of adults found in the tombs. Features and associated scores used are identified in Table 1, as outlined in the TA3 Trait Manual (https://www.statemachine.net/software/TA3/docs/TA3_Trait_Scoring_Manual_1.0.pdf). All observable elements were scored initially by authors AB and HJ together, then rescored independently without knowing the original results to confirm accuracy and validity of trait scores. Any disagreements were discussed, and blind tests were rerun until concordance (Jacobi & Danforth, 2002) between the two observers reached 100%, to avoid any bias in individual scoring.

2.2 | Traditional age estimation

We employed standard demographic techniques (Buikstra & Ubelaker, 1994) using the same pubic symphyses selected for TA to estimate mean age-at-death. Right and left pubic symphyses were scored using the Suchey–Brooks six-phase system (Brooks & Suchey, 1990), following former comparisons of TA to traditional methods (e.g., Hurst, 2010), though with an additional seventh phase added that reflects advanced deterioration in older-age individuals (70+ years), based on Harnett's (2010) revisions of the original method. All observable elements were scored by authors AB and HJ together, then rescored independently and discussed until we reached concordance, as done for TA3 scoring. We then assigned the mean

TABLE 1 Elements and features from tombs Unar 1 and Unar 2 scored using transition analysis 3 software (L = left, R = right).

Element/fragment	<i>n</i>	L	R	Possible features present	Scoring options
Pubic symphysis	49	19	30	Symphyseal collar	Absent/present
				Symphyseal relief	Billowed/residual/flat
				Superior apex	Serrated/knob-like/flat
				Ventral margin	Serrated or beveled/rampart-like/rim-like/broken down
				Dorsal margin	Serrated/flat/rim-like/broken down
Proximal femur	93	45	48	Fovea capitis margin lipping	≥10 mm lipping absent/present
				Head surface bony growth	Small/≥5 mm/≥10 mm
				Greater trochanter lateral surface roughening	Absent/rough triangular/rough rectangular/overhang
				Trochanteric fossa exostoses	Absent/present
				Trochanteric fossa medial surface exostoses	Absent/present
Proximal humerus	18	5	13	Lesser tubercle anterior surface bumps	≥1/3 surface absent/present
				Lesser tubercle margin	Round/raised/lipped
				Greater tubercle pits	Absent/present
Distal humerus	67	32	35	Medial epicondyle	Smooth/rough
				Lateral epicondyle	Smooth/rough

age-at-death corresponding to the phase given to the element. We occasionally used “combined” scores (e.g., 4/5), or estimates of two Suchey–Brooks phases, as taphonomic alteration reduced the ability to confidently identify a single phase for the pubic symphyseal face. When assigning a combined score, we expanded the estimated age range accordingly, starting and ending with the lowest and highest possible ages of the two phases; we then took the average of the mean age-at-death for the two phases.

2.3 | Comparing age estimation techniques

In order to compare the results from TA3 (maximum likelihood point estimate) and Suchey–Brooks/Hartnett (mean age-at-death), we assigned age estimates from each method to the following categories: young adult (YA, 18–34 years), middle adult (MA, 35–49 years), and old adult (OA, 50+ years). Following Getz and Galimany (2022), who examined accuracy for individuals under and over 40, we then further divided our MA category into two intervals: MA1, or 35–39 years, and MA2, or 40–49 years. We evaluated the congruency in age classification in these subgroups among different age indicators, methods, and tombs by applying Pearson Chi-square (χ^2), Fisher's exact (FE) tests, and Fisher's exact tests with the Freeman–Halton extension (FEFH), where appropriate. We also calculated the greatest difference between the oldest and youngest age estimate for a single individual, which we define as the maximum Δ age estimate, and produced Kaplan–Meier survivorship curves using these individual age estimates to compare methods.

Given the commingled and fragmentary nature of both assemblages, we selected whichever side was better represented for each element in each tomb to have the most robust sample size for statistical analyses. We tested for and observed no significant differences in age category frequency between sides within either tomb ($p > 0.05$), indicating that either side could have been used for subsequent analyses. For the humerus and pubic symphysis, the left side was used for Unar 1, and the right side from Unar 2. For the femur, the right side from Unar 1 was used for TA3 age estimation, while the left side was more numerous in Unar 2. All statistical analyses were conducted using SPSS (Version 28.0.1.0 [142]), except for Fisher's exact tests with the Freeman–Halton extension, which were run on the online platform VassarStats (<http://vassarstats.net>).

2.4 | Human remains statement

Human skeletons from tombs Unar 1 and Unar 2 were loaned to the University of South Alabama in January 2017 by His Highness Sheikh Saud bin Saqr al-Qasimi, Ruler of Ras al-Khaimah, in conjunction with the Department of Antiquities and Museums, Emirate of Ras al-Khaimah. These collections are housed at the Bioanthropology Laboratory in the Center for Archaeological Studies at the University of South Alabama. Bioarchaeological research results have been disseminated through conference presentations, public lectures, blog posts (<https://reubioarchaeology.home.blog>), digital stories (short videos with both

English and Arabic subtitles) published to the NSF-REU website (<https://reubioarchaeology.home.blog/digital-stories/>) and YouTube channel (<https://www.youtube.com/channel/UCj-82KGPSbETlcWuXzQzbsw>), and forthcoming publications.

3 | RESULTS

3.1 | Transition Analysis 3

Due to varying levels of taphonomic degradation, skeletal elements and their features were not equally scorable. Some features present in the TA3 system preserved better than others, and some elements as a whole varied in preservation likelihood. Nonetheless, we observed similar mean maximum likelihood point estimates by side and across each skeletal element analyzed in TA3 (Table 2). Maximum likelihood point estimates and upper and lower bounds are available in Tables S1–S4. Using TA3, we report age frequencies using adult pubic symphyses, proximal femora, and proximal and distal humeri from individuals in Unar 1 and Unar 2 independently and combined (Table 3).

3.2 | Traditional age estimation

Using the Brooks and Suchey (1990) and Hartnett (2010) models, we report age frequencies for adult pubic symphyses (Table 4). Sex could not be reliably estimated in enough individuals of either side, so we estimated a mean age-at-death as if the entire sample was male (30.757 years) or female (32.022 years). Individual age estimates and ranges are available in Table S1.

3.3 | Statistical comparisons

Using TA3, there were no statistically significant differences in age frequencies (YA, MA, and OA) between tombs for the pubic symphysis ($n = 30$; FE, $p = 0.17$, comparing YA and MA + OA), the proximal femur ($n = 50$; FE, $p = 0.55$, comparing MA and OA), the proximal humerus ($n = 13$; FE, $p = 0.42$, comparing MA and OA), or the distal humerus ($n = 35$; FE, $p = 1.00$, comparing MA and OA) (Figure 1). Similarly, there was no statistically significant difference between tombs in the number of individuals assigned to each of the age categories when using the Brooks and Suchey (1990) and Hartnett (2010) method ($n = 30$; FE, $p = 0.66$, comparing YA and MA + OA).

Given an overall lack of difference in age frequency between the two tombs (seen in Tables 2 and 3), we combined Unar 1 and 2 to compare the Suchey–Brooks/Hartnett ($n = 30$) method with the four applications of TA3. Using the traditional age interval classifications (YA, MA, and OA), we observed significantly different frequencies of individuals in adult age categories for all bones, with TA3 estimating higher frequencies of middle and older adult individuals relative to Suchey–Brooks: pubic symphysis ($n = 30$; FEFH, $p = 0.03$), proximal femur ($n = 51$; $\chi^2 = 44.40$, $df = 2$, $p < 0.001$), proximal humerus

Element/fragment	Tomb	Side	n	Mean TA3 maximum likelihood point estimate (years)
Pubic symphysis	U1	L	7	32.443
	U1	R	6	43.267
	U2	L	13	43.269
	U2	R	23	42.083
	U1L + U2R		30	39.833
Proximal femur	U1	L	6	56.950
	U1	R	13	46.408
	U2	L	38	48.578
	U2	R	35	48.051
	U1R + U2L		51	48.025
Proximal humerus	U1	L	3	46.767
	U1	R	3	35.200
	U2	L	2	52.550
	U2	R	10	41.820
	U1L + U2R		13	42.962
Distal humerus	U1	L	7	47.000
	U1	R	7	44.300
	U2	L	25	47.008
	U2	R	28	49.639
	U1L + U2R		35	49.111

TABLE 2 Mean maximum likelihood point estimates by element using transition analysis 3 (TA3) for tombs Unar 1 and Unar 2 combined.

Element/fragment	Tomb	Side	n	YA		MA		OA	
				n	%	n	%	n	%
Pubic symphysis	Unar 1	L	7	6	85.7%	0	0.0%	1	14.3%
	Unar 2	R	23	13	56.5%	1	4.3%	9	39.1%
	Combined		30	19	63.3%	1	3.3%	10	30.0%
Proximal femur	Unar 1	R	13	0	0	7	53.8%	6	46.2%
	Unar 2	L	38	1	2.6%	21	55.3%	16	42.1%
	Combined		51	1	2.0%	28	54.9%	22	43.1%
Proximal humerus	Unar 1	L	3	0	0	2	66.7%	1	33.3%
	Unar 2	R	10	0	0	9	90.0%	1	10.0%
	Combined		13	0	0	11	84.6%	2	15.4%
Distal humerus	Unar 1	L	7	0	0	6	85.7%	1	14.3%
	Unar 2	R	28	0	0	21	75.0%	7	25.0%
	Combined		35	0	0	27	77.1%	8	22.9%

TABLE 3 Age frequencies of individuals interred within tombs Unar 1 and Unar 2 by element using transition analysis 3.

Note: The side (L or R) that possessed the largest sample size in each tomb was selected prior to statistical analyses. Young adult (YA) = 18–34 years; middle adult (MA) = 35–49 years; and old adult (OA) = 50+ years.

($n = 13$; FEFH, $p < 0.001$), and distal humerus ($n = 35$; $\chi^2 = 36.47$, $df = 2$, $p < 0.001$). These frequencies are modeled in Figure 2.

Using further divided age categories (YA, MA1, MA2, and OA), we again found statistically significant differences in age frequency for all elements when comparing Suchey–Brooks and TA3 for the pubic symphysis ($n = 30$; FEFH, $p = 0.004$), femur ($n = 51$; $\chi^2 = 49.50$, $df = 2$, $p < 0.001$), proximal humerus ($n = 13$; FEFH, $p < 0.001$), and distal humerus (omitting the MA1 category) ($n = 35$; $\chi^2 = 36.47$, $df = 2$, $p < 0.001$).

4 | DISCUSSION

4.1 | Comparing tombs Unar 1 and 2

Whether using TA3 or traditional age estimation methods, there is a relatively comparable categorical frequency of adults interred in tombs Unar 1 and Unar 2. The lack of significant difference may be related to small sample sizes given the assemblages' fragmentary nature, but working with the information available, it appears that the

TABLE 4 Age frequencies of individuals interred within tombs Unar 1 and Unar 2 using Brooks and Suchey (1990) and Hartnett (2010), with comparative transition analysis 3 (TA3) data.

Method	Tomb	Side	n	YA		MA		OA	
				n	%	n	%	n	%
Suchey–Brooks/Hartnett	Unar 1	L	7	5	71.4%	2	28.6%	0	0%
	Unar 2	R	23	15	65.2%	5	21.7%	3	13.0%
	Combined		30	20	66.7%	7	23.3%	3	10.0%
TA3	Unar 1	L	7	6	85.7%	0	0.0%	1	14.3%
	Unar 2	R	23	13	56.5%	1	4.3%	9	39.1%
	Combined		30	19	63.3%	1	3.3%	10	30.0%

Note: The side (L or R) that possessed the largest sample size in each tomb was selected prior to statistical analyses. Young adult (YA) = 18–34 years; middle adult (MA) = 35–49 years; and old adult (OA) = 50+ years.

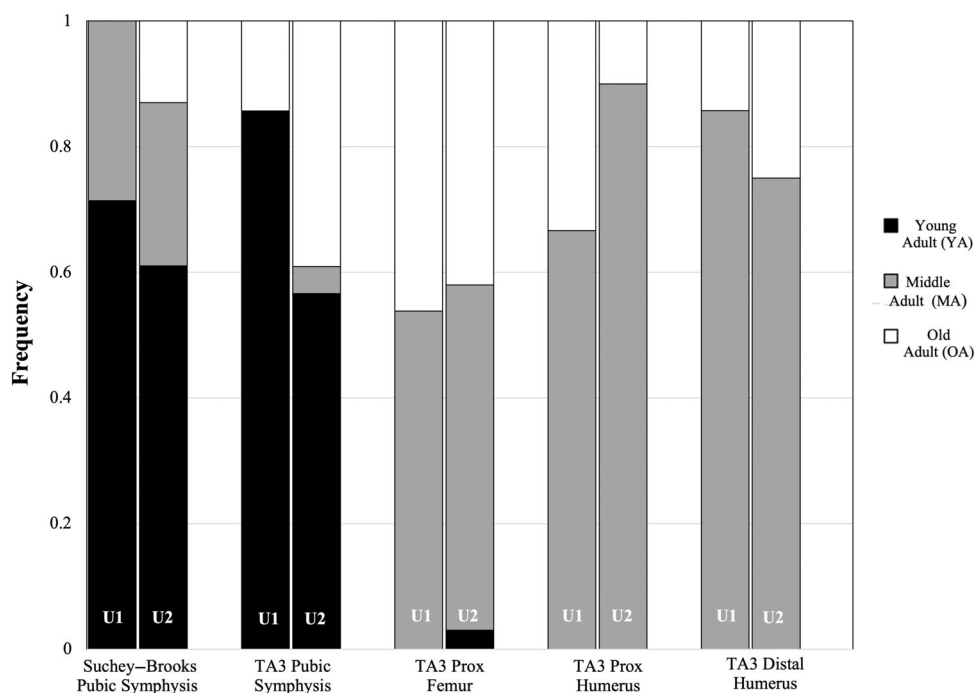


FIGURE 1 Age frequency by method for tombs Unar 1 (U1) and Unar 2 (U2). The side (L or R) that possessed the largest sample size in each tomb was selected prior to statistical analyses. Young adult (YA) = 18–34 years; middle adult (MA) = 35–49 years; and old adult (OA) = 50+ years.

two tombs were similar in age inclusivity. Given the temporal overlap in use between the tombs, this may be evidence of adult age inclusivity in Umm an-Nar collective burials despite potential intracommunity differences. If, for example, the tombs were in use by different subgroups within a larger Umm an-Nar settlement, such as extended families, heterarchical groups of occupational specialists, or even different hierarchical social factions, then similar age frequencies would indicate similar life expectancies and age-at-death within the community, regardless of kinship, occupation, and/or social status.

These age frequencies also provide important contextual information for understanding everyday activity in the Shimal community. For instance, a study of patellae found significantly more osteoarthritis in Unar 2, but no significant difference in enthesal changes between the tombs (Cabañas et al., 2023). One might interpret the difference in occurrence of osteoarthritis as the presence of more old adults in the Unar 2 burial community, but our finding of similar age

frequencies between the two assemblages disputes this; with adult age data, one can more meaningfully investigate daily activity patterns that might have caused a higher prevalence of osteoarthritis in Unar 2, such as the possibility of different occupational groups within this community who interred their dead in different tombs. Thus, more specific adult age frequencies make for more robust studies of daily activity and other lifeways.

4.2 | Comparing methods

Examining Unar 1 and Unar 2 together reveals significantly higher proportions of middle and old adults in the assemblage generated by TA3 when compared with Suchey–Brooks/Hartnett. Similar results have been seen with the application of earlier TA iterations alongside traditional methods (Bullock et al., 2013; Clark et al., 2020), and might

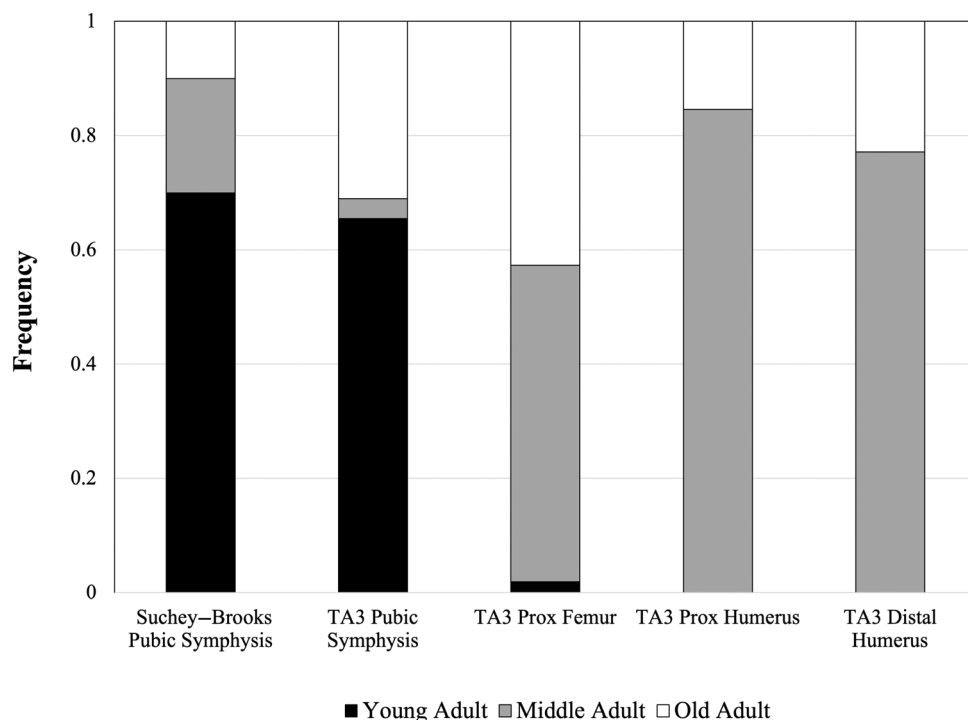


FIGURE 2 Age frequency by method with tombs Unar 1 and Unar 2 combined. The side (L or R) that possessed the largest sample size in each tomb was selected prior to statistical analyses. Young adult (YA) = 18–34 years; middle adult (MA) = 35–49 years; and old adult (OA) = 50+ years.

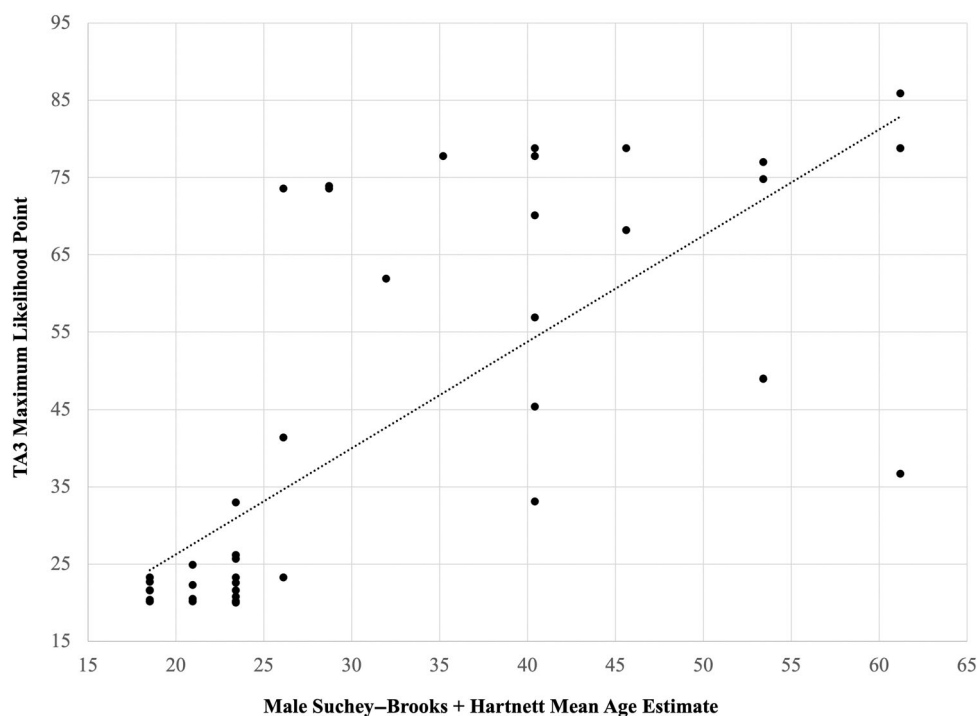
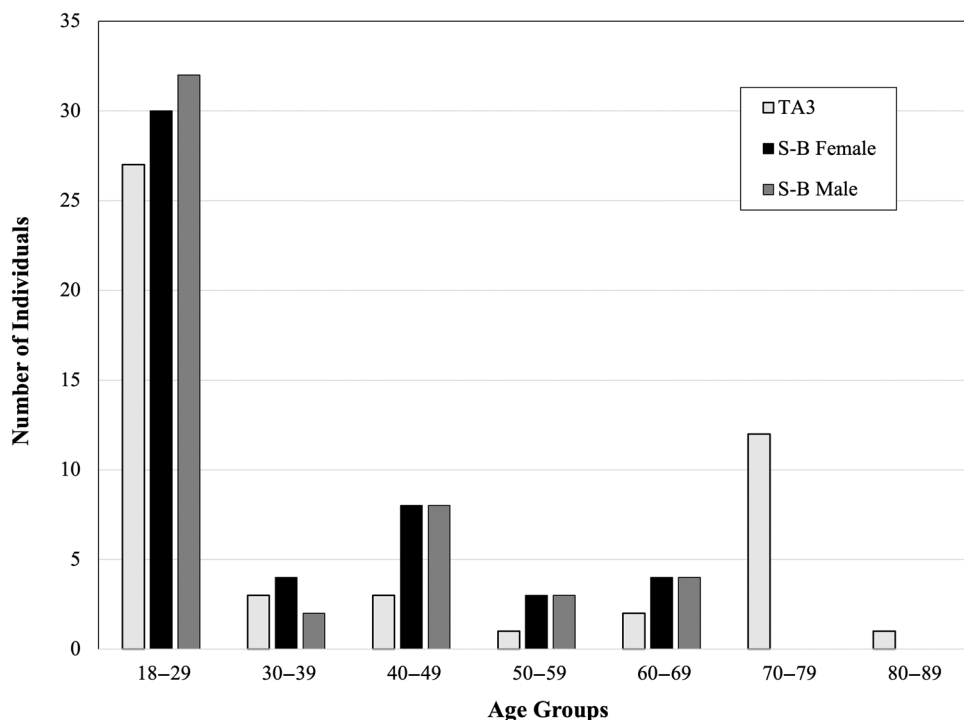


FIGURE 3 Estimated age of individuals by method using the pubic symphysis for tombs Unar 1 and Unar 2 combined, all sides included.

be attributed to a heightened degree of sensitivity within the TA method for identifying older-age individuals, particularly those beyond 60 years of age (Figures 3 and 4). This claim has also been supported in previous validation experiments (e.g., Maaranen & Buckberry, 2018; Milner & Boldsen, 2012) for TA2, in which it appears that the accuracy of age estimation actually gets better after the 70-year mark (with the most variability seen between the ages of 40 and 70). With

the addition of new skeletal features in TA3, comparisons have shown that TA3 is even more precise in estimating both young adult (not overestimating) and old adult (not underestimating) age groups (also seen in previous TA iterations, e.g., Kim & Algee-Hewitt, 2022; Lopez-Cerquera & Casallas, 2018). On average, age interval lengths decreased from 34.2 years in TA2 to 17.2 years in TA3 (Getz, 2021). Getz (2021) did not find a significant difference in accuracy of age

FIGURE 4 Age estimates by decade, all sides included. Suchey–Brooks/Hartnett age estimates are mean ages-at-death for males/females. Transition analysis 3 (TA3) age estimates are maximum likelihood point estimates.



estimates between the TA1 system and TA3 overall, but later (Getz & Galimany, 2022) documented a 93.7% rate of accuracy for estimating *older* age categories using TA3 (compared with only 57% for those under 40). As seen in our results, even when dividing our MA interval into two (35–39 years and 40–49 years), we still observed differences in age frequencies between traditional and TA3 age estimation. This indicates that the higher frequency of middle and older aged adults identified using TA3 is likely not a result of inaccuracy in the weakest points of the system, as the pattern persists when pulling out those in this lower middle age interval. Although TA3 remains in beta testing, the ability to accurately estimate older age categories from these new, nontraditional elements, such as the femur and humerus (Galimany & Getz, 2023; Getz & Galimany, 2022) appears promising for the estimation of adult age frequencies to assess lifeways among past communities, particularly in contexts like those found at Unar 1 and Unar 2.

To further illustrate the difference in old-age estimation between traditional methods and TA3, the maximum mean estimated age of one bone for this sample using Suchey–Brooks/Hartnett (male) was 61.2 years (individual U2.37.512), compared with the maximum likelihood point estimate using TA3 (also pubic symphysis) of 85.9 years (individual U2.37.619) (see Table S1). The maximum Δ age estimate for any one individual (U1.37.417) between Suchey–Brooks/Hartnett and TA3 was 47.5 years—the difference between a 26.1 year old male when using Suchey–Brooks/Hartnett (YA) and a 73.6 year old individual when using TA3 (OA). However, it is also important to note that both traditional methods and TA3 generate wide age ranges, and taking age estimates or maximum likelihood points at face value can ignore the overlap between two estimated age ranges. For instance, individual U1.37.417 had a Suchey–Brooks/Hartnett-generated age

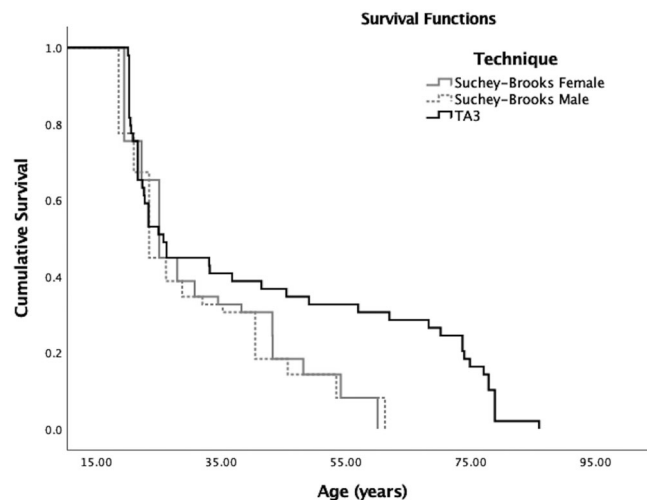


FIGURE 5 Kaplan–Meier survivorship functions by method for the pubic symphysis for Unar 1 and Unar 2 combined (all sides included).

range of 19 to 53 years (combined female and male) and with TA3, a lower 95% CI bound of 47.5 and an upper bound of 99.6 years. Thus, an individual with a mean Δ age estimate of nearly 50 years, such as this one, may more reasonably be estimated as a middle adult when considering their overlapping age ranges (between 47.5 and 53 years of age). Nevertheless, these kinds of differences in age estimation (for all pubic symphyses [$n = 49$], mean Δ age = 12.70 ± 14.59 years and median Δ age = 3.95 years) have significant implications for the analysis of commingled assemblages. For individual U1.37.417, different interpretations and different methods might variably classify them as a young, middle, or old adult—all using the same element.

Overall, looking at the distribution of mean age-at-death estimates created with Suchey–Brooks/Hartnett, it appears that Umm an-Nar communities at Shimal were living into middle-age, but with very few older-aged individuals. When employing TA3, however, the rate of survivorship into old-age increases considerably, pushing back against preconceived notions of high young adult mortality in the Early Bronze Age supported by previous (albeit limited) analyses of other Umm an-Nar tomb assemblages (e.g., McSweeney et al., 2008). Survivorship by methods involving the pubic symphysis at Shimal for tombs Unar 1 and Unar 2 was modeled with a Kaplan–Meier survivorship function in Figure 5. Here, we can clearly see differences in survivorship; for example, at age 40 (where TA3 should begin to be most accurate for middle and older adult age estimation), chances of survival are about 35% when using Suchey–Brooks, and at age 50 (where traditionally we begin to mark “old” age), chances are below 20%. Comparably, using TA3, individuals are calculated to have had a ~40% chance of survival past 40 years, and just-less-than a 40% chance at 50 years. TA3-calculated survival chance does not fall below 30% until an individual surpasses 70 years, which is not even a possible mean age-at-death estimate when employing traditional methods. Understanding that individuals, and their communities, could likely reasonably expect their middle-aged adults to live into old-age changes how we might view the role of so-called elderly persons in Umm an-Nar communities. Thus, for both individuals and entire communities, it is clear that choice of method for age estimation has a great impact on bioarchaeologically derived results and interpretations.

While imperfect (see Hurst, 2010; Simon & Hubbe, 2021), TA has been observed to be more useful in general age-at-death distribution analyses (such as examining population-level mortality profiles) than specific and accurate individual age estimation (Milner & Boldsen, 2012). Further, TA programs have been useful for age estimation in different contexts, requiring some research and practice but not any more inaccessible or difficult than traditional methods (see Fojas et al., 2018; also confirmed by our own observations). With the advent of TA3, extending this application to commingled collections presents an opportunity for more nuanced understandings of survivorship and mortality. Here, we have presented a case study comparing traditional adult aging methods to TA3 for an Umm an-Nar commingled assemblage and identified significant differences in adult age frequencies based on the method chosen. This work revises former demographic analyses of Unar 1 and Unar 2 in the past (Blau, 1998), and illustrates how new methods might be deployed to rethink adult life, aging, and survivorship in the past. Identifying old-age individuals despite the limitations of a commingled assemblage, as we have here, allows us to think more about what it might have meant to be “elderly” in the Bronze Age (e.g., see Boutin & Porter, 2019) and to focus our attention beyond nonadult and young adult mortality to everyday life in this community.

AUTHOR CONTRIBUTIONS

Alyssa L. Bolster: Conceptualization (equal); formal analysis (lead); methodology (lead); writing – original draft (lead); writing – review and editing (equal). **Hannah J. JeanLouis:** Conceptualization (equal);

formal analysis (lead); methodology (lead); writing – original draft (supporting); writing – review and editing (equal). **Lesley A. Gregoricka:** Conceptualization (equal); funding acquisition (lead); methodology (supporting); writing – original draft (supporting); writing – review and editing (equal). **Jaime M. Ullinger:** Conceptualization (equal); funding acquisition (lead); methodology (supporting); writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data that supports the findings of this study are available in the tables contained within this brief communication, the supporting information, and in our open access online repository that can be found at https://jagworks.southalabama.edu/bioarch-reu_bolster/.

ORCID

Alyssa L. Bolster  <https://orcid.org/0000-0002-4601-8666>

Hannah J. JeanLouis  <https://orcid.org/0009-0003-4094-679X>

Lesley A. Gregoricka  <https://orcid.org/0000-0001-6608-7709>

Jaime M. Ullinger  <https://orcid.org/0000-0002-3613-1737>

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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