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ARTICLE

The Impact of Secondary Mortuary Practices on Representation and Distribution of Commingled Elements from Umm an-Nar Human Skeletons in Communal Tombs

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Abstract

Commingled human skeletons have the potential to reveal information about ancient funerary traditions through detailed bioarchaeological analyses of element representation (via minimum number of individuals, or MNI) and postmortem distribution. While MNI estimates are often presented in a perfunctory way, calculations using more nuanced methods may offer insight into taphonomic alteration and mortuary practices no longer visible to archaeologists. At the Early Bronze Age communal tombs of Unar 1 and 2 at the Shimal Necropolis in Ras al-Khaimah, United Arab Emirates (UAE), MNI counts using skull, leg, and foot fragments varied dramatically, probably a result of differences in cortical bone density but also of cremation practices. Additionally, the presence of more elements from the left side of the skeleton suggests continuity with Neolithic interments in which individuals were preferentially laid on their right sides. Complex arrays of internal tomb chambers likewise demonstrate no particular preference for certain skeletal elements, indicating bone was not intentionally relocated to different areas of the tomb following cremation. These patterns differ from other tombs in the region, highlighting the need to more critically assess mortuary practices through "back-to-basics" approaches involving MNI estimates, particularly when involving large numbers of individuals represented by commingled and fragmentary bone.

Resumen

Los entierros humanos colectivos, tienen el potencial de revelar información sobre antiguas tradiciones funerarias, a través de, análisis bioarqueológicos detallados de la representación de elementos (mediante un número mínimo de individuos, o MNI por sus siglas en inglés) y la distribución post mortem. Si bien las estimaciones del MNI a menudo se presentan de manera superficial, los cálculos que utilizan métodos más matizados pueden ofrecer información sobre la alteración tafonómica y las prácticas mortuorias que ya no son visibles para los arqueólogos. En las tumbas comunales de la Edad del Bronce Temprano de Unar 1 y 2 en la Necrópolis de Shimal en Ras al-Khaimah, Emiratos Árabes Unidos, los recuentos de MNI corresponden a fragmentos de cráneo, piernas y pies que variaron dramáticamente, probablemente como resultado de diferencias en la densidad del hueso cortical, pero también de las técnicas de cremación. Además, la presencia de más elementos que corresponden al lado izquierdo del esqueleto sugiere una continuidad con los entierros neolíticos en los que los individuos eran colocados preferentemente sobre su lado derecho. Los complejos conjuntos de las cámaras internas de la tumba, tampoco demuestran una preferencia particular por ciertos elementos óseos, lo que indica que el hueso no fue reubicado intencionalmente en diferentes áreas de la tumba después de la cremación. Estos patrones difieren de otras tumbas en la región, lo que resalta la necesidad de evaluar de manera más crítica las prácticas mortuorias a través de "metodologías tradicionales" que involucren estimaciones de MNI, particularmente cuando contemplen un gran número de fragmentos y huesos mezclados, correspondientes a diversos individuos.

Keywords: Arabia; bioarchaeology; minimum number of individuals; mortuary practices; taphonomy

Palabras clave: Arabia; bioarqueología; número minimo de individuos; practices mortuorias; tafonomía

Despite their prevalence across the ancient world, commingled skeletal assemblages are often overlooked in bioarchaeological studies due to the difficult nature of osteological analysis in the absence of articulated individuals. Articulation in and of itself represents context, across which patterns of morphology, degeneration, stress markers, and lesions provide key clues to estimations of sex, age, activity patterns, differential diagnoses, and more. Conversely, when dealing with single bones or even bone fragments with varying degrees of anthropogenic or taphonomic alteration, the context of the individual can be lost, forcing bioarchaeologists to think more creatively about aspects of identity that can be gleaned from a limited pool of informational but often isolated markers—whether macroscopic, microscopic, or even biogeochemical.

Estimating representation through the minimum number of individuals (MNI) from a group of commingled skeletons interred within a communal space can prove far more complicated than when discrete, articulated individuals are present at an archaeological site. Such analyses require skill, attention to detail, determination, and, most importantly, a clear strategy of analysis that must oftentimes be developed based on the particulars of that burial group, including assemblage size, primary and secondary mortuary treatment in antiquity, degree of fragmentation, and other taphonomic modifications occurring within the postmortem environment. As such, unlike many publications in which MNI may be mentioned only in passing before moving on to what are considered more legitimate research questions, compiling the most accurate MNI counts possible for commingled mortuary groups becomes a central research question itself. This is particularly the case at a time when commingled skeletons are increasingly recognized for the wealth of information they contain about past peoples. Delving into this topic through discussions of more complex approaches and applications of multiple strategies for determining MNI amid variable preservation conditions is therefore critical to advancing bioarchaeological methods.

To this end, this study implements zonation and landmark analysis on four bone types for assessing skeletal representation by examining MNI among the heavily fragmented, commingled, and variably cremated skeletons recovered from Umm an-Nar (2700–2000 BC) tombs Unar 1 and Unar 2, located in the Shimal Necropolis within the modern borders of the Emirate of Ras al-Khaimah, United Arab Emirates (Figure 1). Concomitantly, we explore the potential for redistribution of nearly 12,000 fragments across the multichambered tomb Unar 2. In doing so, we demonstrate how aspects of primary interment, secondary mortuary practices, and taphonomic alteration that would otherwise remain obscured by postmortem modification can be revealed.

Umm an-Nar Mortuary Practices

Those who lived and died during the Umm an-Nar period experienced a complex, multistage funerary process in which individual bodies underwent a variety of intentional disturbance and secondary mortuary treatments. Mortuary activities variably occurred both outside and inside these circular stone tombs, which ranged in size from 4 to 14.5 m in diameter and up to 3 m in height (Blau 2001a). Unlike prior Hafit-type cairns (3200–2700 BC), which were easily visible due to their placement along ridges throughout the foothills of the Hajar Mountains (Cleuziou et al. 2011; Deadman et al. 2015; Williams and Gregoricka 2019), Umm an-Nar tombs sat at ground level; subsequently, they have been discovered throughout southeastern Arabia, including on islands, adjacent to coastlines, and even among inland oases with access to fresh water (Blau 2001a; Munoz 2019). While earlier Umm an-Nar tombs at such sites as Umm an-Nar Island (Frifelt 1991), Ras al-Jinz (Munoz 2014), and Al Sufouh (Benton 2006) contained fewer than 100 individuals, by the late third millennium BC, hundreds were interred within the chambers of a single tomb.

No burials took place within these monumental structures. Instead, corpses were inserted into the tomb through a side entrance, and then placed directly atop paved floors or exposed bedrock and allowed to decompose within the tomb (Blau 2001a). As soft tissue was quickly lost in this semiarid climate,

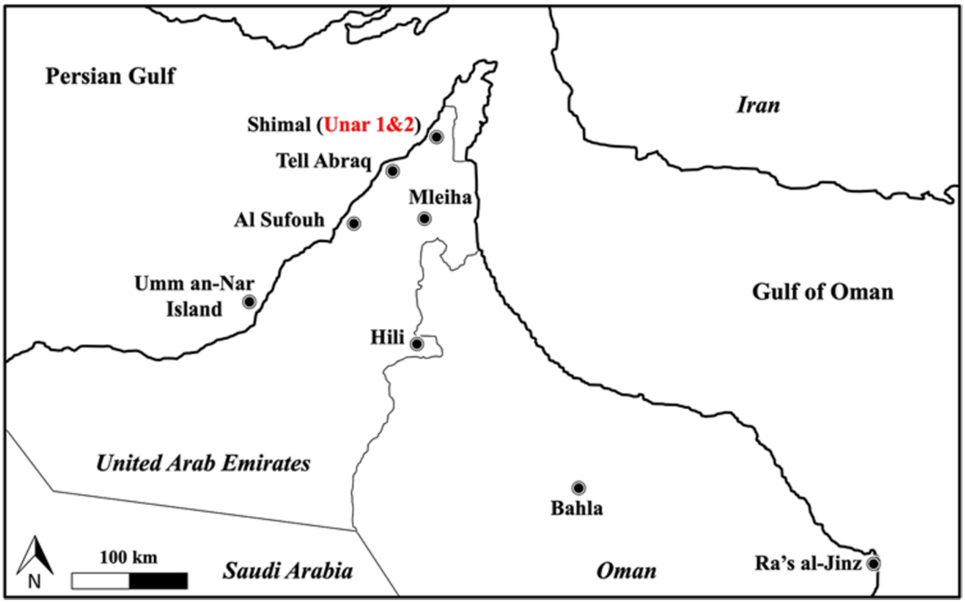

Figure 1. Map of southeastern Arabia showing the location of tombs Unar 1 and 2 at Shimal, alongside other Umm an-Nar sites mentioned throughout the text.

bones were pushed aside to make room for more recently deceased individuals (Blau 2001a; Frifelt 1991; Gregoricka 2020; McSweeney et al. 2010)—an intentional act that would have been immediately evident to those living individuals responsible for navigating the tomb's interior to insert a fresh corpse—and disarticulation of the decomposing/skeletal dead followed. Over the course of centuries, the successive accumulation and intentional disturbance of the dead resulted in tens or even hundreds of thousands of commingled bone fragments.

Beyond disarticulation and fragmentation, skeletal manipulation also included cremation at some (but not all) Umm an-Nar sites. Small, confined areas of burning within tombs have been noted but are not considered cremation per se; various explanations for such behavior have included burning incense or decomposed bodies to help reduce the strong odors inevitably emanating from the tomb, or by candles or oil lamps (Martin and Potts 2012; Potts 2000). At other sites, however, some bodies appear to have been interred until some degree of decomposition had taken place before being removed for intentional cremation practices, which transpired outside the tomb's walls on pyres at some unknown location. Then, cremated and highly fragmented bones were gathered and reinterred into the tomb. This was the case at sites like Tomb A at Hili North, Umm an-Nar Island, Mleiha, and Unar 2 at Shimal, all of which possessed a short lower story where decomposition of primary interments may have occurred, topped by a taller second story where cremated bone would be reinterred (Blau 2001a, 2007; Bondioli et al. 1998; Frifelt 1991; McSweeney et al. 2008; Vogt 1985). Cremation may have served as a practical means of reducing the space taken up by skeletonized bodies to ensure the tomb's continued use for future generations or, alongside commingling and fragmentation, to ritualistically destroy the individual while advancing a mixed-ancestor collective (Gregoricka 2020).

Secondary mortuary practices recorded among Umm an-Nar human skeletal assemblages are not limited to bone movement during subsequent interments or cremation. Cut marks have also been noted at three sites, including "a small number of cutmarks" from Tell Abraq (Baustian and Martin 2010:58); a mandible displaying cutmarks along its inferior border at Hili North Tomb A, interpreted as evidence of disarticulation (Bondioli et al. 1998:233); and on six skulls or cranial fragments from Bahla, Oman, variably attributed to scalp removal or superficial scraping to clean the skull's surface (Munoz 2014:279–280). Previously unpublished cutmarks were also discovered on a distal femur in tomb Unar 2. All of these authors interpret such cutmarks as postmortem and ascribe their purpose to disarticulation or defleshing.

Such acts could have been performed as a means of hastening decomposition and disarticulation, perhaps prior to other secondary mortuary practices such as cremation. In particular, at Bahla, the removal of the scalp, denoted by deep cuts to the frontal bone, as well as more superficial cleaning of the cranial surface, coupled with the marks found on the mandible at Hili, could indicate some special meaning conferred upon the processing of skulls. While the ratio of male-to-female cranial fragments is approximately equal, Osterholtz and others (2014:45) noted the possible ritualistic removal of male skulls at the Umm an-Nar tomb at Tell Abraq, as postcranial elements exhibited higher frequencies of elements with male features (65:35 M to F ratio)—similar to patterns preliminarily found at Shimal in both tombs Unar 1 and Unar 2 when comparing the mastoid process (Calvin et al. 2021) to measurements of the distal humerus (Downey et al. 2021). Nevertheless, forced disarticulation through cutting appears to be rare, as rapid decomposition in this arid environment meant that body parts would naturally detach without requiring intentional dismemberment. Still, the extreme fragmentation and commingling in Umm an-Nar tombs probably masks additional evidence of cutmarks on these bones.

Tombs included adult females and males, as well as representatives from age categories ranging from fetal to the very old (Baustian and Martin 2010; Blau 2001a; Bolster et al. 2024; McSweeney et al. 2008, 2010). As such, they appear to be inclusive of the entire community, who were probably members of extended family groups residing in the area (Alt et al. 1995; Cleuziou and Munoz 2007; Gregoricka 2020). Moreover, strontium and oxygen isotopes from dental enamel reveal that a small number of nonlocals were also interred within some Umm an-Nar tombs but were not segregated from the local community either spatially or in mortuary ritual (Gregoricka 2013a, 2013b).

Archaeological History of the Shimal Plain

Located in the present-day Emirate of Ras al-Khaimah in the United Arab Emirates, the site of Shimal was rediscovered in 1968 as part of an initial British archaeological survey that identified more than 100 monumental tombs (de Cardi and Doe 1971; Vogt et al. 1989). Extensive surveys and excavations from 1976 to 1977 (Donaldson 1984, 1985), 1985 to 1988 (Häser 1991; Kästner et al. 1988; Schutkowski 1988; Vogt and Franke-Vogt 1987), and in 1998 (Velde 2024) revealed an expansive Middle Bronze Age complex of both single and collective tombs, as well as shell middens and a settlement dating to the Late Bronze Age and Iron Age, while more recent excavations (de Vreeze et al. 2022) seek to investigate an Iron Age settlement within the palm gardens of the Shimal Plain.

While over 100 Wadi Suq tombs are scattered along the base of the Jabal Qasr al-Dhaba, two Umm an-Nar tombs are also present: Unar 1 and Unar 2. Excavations at Unar 1 commenced in 1987 by the German Mission to Ras al-Khaimah after the accidental discovery of the tomb during a construction project (Blau 1998; Kästner 1988; Schutkowski 1988). A second campaign in 1988 saw the completion of formal excavations, although a team returned for a third time in 1989 to evaluate the skeletal material (Schutkowski 1988, 1989). Grave goods associated with human remains, including local black-on-red ceramic sherds, soft-stone vessels, numerous copper awls, pins, rings, and a variety of beads, date the tomb to the mid-Umm an-Nar period (ca. 2400–2200 BC; Blau 1998; Sahm 1988; Weeks 2003a, 2003b). This circular tomb was constructed from finely carved ashlars forming its exterior ring-wall, some 11.5 m in diameter, while unworked limestone was used to fashion both the internal ring-wall and cross-walls that created eight chambers used to house the dead (Blau 1998; Sahm 1988; Weeks 2003a).

Excavators divided the tomb into a series of units both outside and inside the tomb's walls. Surrounding the external ring-wall of the tomb, three areas were labeled as L4 (northeastern and southeastern quadrants), L6 (northwest quadrant), and L7 (southwest quadrant). Within the tomb itself, 87 1 m^2 units were assigned labels ranging from L9 to L16, with letters from A to W providing a further designation of unit location (e.g., L10K, L14T). These units cut across the eight internal chambers of Unar 1, which themselves were not numbered or labeled.

Corpses were first interred in a flexed position atop the tomb's floor; then, after some unknown period of decomposition, the living would enter the tomb, remove at least some partially or wholly skeletonized

Table 1. Schutkowski's (1989) Assessment of the Minimum Number of Individuals in Tomb Unar 1 Using Six Cranial and Four Postcranial Regions or Elements.

	Cranial						Postcranial			
	Glabellar Region	Supraorbital Ridge	Petrous Bone	Mastoid Process	Occipital Bone	Mandible	Forearm Distal	R Ulna Proximal	Shoulderblade Ankle	Anklebone
Left	—	178	438	160	—	—	228	199	199	227
Medial	198	—	—	—	244	366*	—	—	—	—
Right	—	199	365	172	—	—	208	248	206	173

Note: Some postcranial designations (e.g., "shoulderblade ankle") in this report remain unclear.
*Regardless of side, so Blau (1998) says treat with caution, recalculating mandibular MNI to 212 (R mandible).

bodies, and cremate them at variable temperatures before returning burnt bone to the tomb. Similar to other Umm an-Nar assemblages, Unar 1's skeletal remains were commingled, fragmentary, and cremated to varying degrees; cremation resulting in calcination occurred in 62% of distal humeri and 26% of tali, while 20% of humeri and 40% of tali remained unburned (Carter and Gregoricka 2019; McGrath et al. 2021). In an unpublished report, an initial assessment of the commingled skeletons within these chambers produced a MNI of 438 individuals based on the petrous portion of the left temporal bone (Table 1; Schutkowski 1989).

Just 200 m north of Unar 1 lies tomb Unar 2, an Umm an-Nar tomb also accidentally uncovered during road construction in 1996. Excavation soon followed in 1997–1998, revealing the largest Umm an-Nar tomb in the Oman Peninsula to date, measuring 14.5 m in diameter and constructed in a similar manner to Unar 1 (Blau 1998, 2001a). Its interior consists of 12 chambers designated as A, B, and C (northeast quadrant); D, E, and F (southeast quadrant, with area N); G, H, and J (northwest quadrant); and K, L, and M (southwest quadrant) (Figure 2). Grave artifacts included soft-stone bowls; shell, stone, and carnelian beads; and local as well as imported ceramics from Iran or Baluchistan; together suggesting a later Umm an-Nar date between approximately 2300 BC and 2100 BC (Blau 2001a; Potts 1990, 1997).

As at Unar 1, the dead were again placed in a flexed position on the tomb floor, although at Unar 2 two stories were present. Based on the recovery of a handful of unburned, articulated individuals placed directly atop the pavement of these lower stories, the recently deceased may have first been interred on the lower tomb level, where they were allowed to decompose for some period of time. Subsequently, partially or fully skeletonized remains would have been removed from the lower story and cremated to varying degrees outside the tomb prior to their reinsertion atop the second level in a commingled and fragmentary state (Blau 2001a; Bondioli et al. 1998; Cleuziou and Vogt 1983; McSweeney et al. 2008; Vogt 1985). Unar 2 contained considerably more burnt bone than Unar 1. Most (70.1%) bones were burned at high temperatures, resulting in fragmentation and calcination (Blau 2001a); among distal humeri and tali, 83% and 63% had become calcined, respectively, while only 2% of humeri and 21% of tali remained unburned (Carter and Gregoricka 2019; McGrath et al. 2021). Blau's (1998) dissertation initially reported a MNI of 235 individuals at Unar 2, based on the right distal humerus, but in Blau (2001a), she proposed a new MNI of 431 individuals (element and side unknown).

Curating Complex Collections

Formal curation of the Unar 1 and 2 skeletal assemblages began in 2017. Prior to this time, analyses of human bone from tomb Unar 2 were the subject of a number of initial reports (Schutkowski 1988, 1989) and featured in various publications (Blau 2001a, 2001b, 2007; Blau and Beech 1999) after Blau's (1998) dissertation. Beyond MNI calculated in an unpublished report (Schutkowski 1989), skeletons from tomb Unar 1 were never analyzed, and only teeth were examined, cast, labeled, and sampled for biogeochemical research related to Early Bronze Age mobility and diet (Gregoricka 2013a, 2013b). Bones from both tombs had never been cleaned (beyond some "dry brushing" for Unar 2 mentioned by Blau 1998:81), sorted, or assigned identification numbers, which makes any replication of previous studies impossible. Indeed, in many cases, it was unclear how bony features, joint surfaces, or pathological lesions could have been adequately observed (or viewed at all) prior to cleaning.

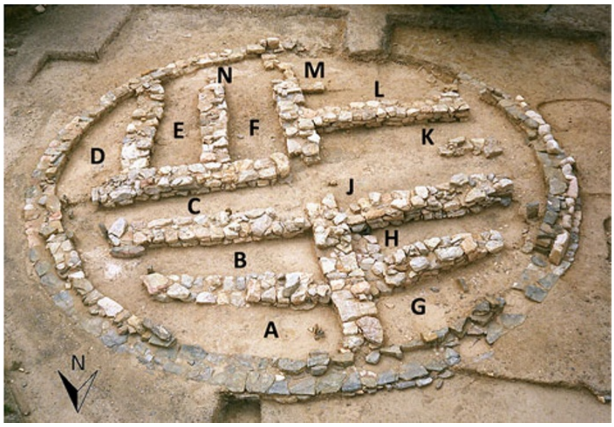

Figure 2. Photo of tomb Unar 2, illustrating its 12 chambers (A–M, excluding I) and one area (N) (photo courtesy of Christian Velde and Imke Möllering).

To remedy this, bone fragments were first cleaned and sorted by element (e.g., talus, femur, temporal). Each fragment was then assigned a tomb number (U1 or U2), element number (e.g., humerus = 31), and unique identification number linked to a database containing contextual information about that bone. Context provided by the original excavators in the form of bag tags and labels included location within the tomb (chamber, quadrant, unit, and/or other notes), area and/or feature present on bone fragment (e.g., distal shaft, tibial tuberosity), and other descriptors (e.g., percent complete, cremation color, pathological lesions present). Bones then underwent the process of labeling so that research could more easily be conducted, and so that repeatability of observations would be possible. If identifiable fragments were too small or did not possess an area appropriate for labeling, they were instead stored within a labeled plastic bag. Labeled bone fragments were then organized by element into small labeled plastic containers, and later further organized by side, features present, or portion (e.g., proximal vs. distal, orbit vs. squama).

Curation at the University of South Alabama in the United States is ongoing but, to date, over 16,000 fragments from both tombs (~5,000 from Unar 1 and over 11,000 from Unar 2) have been identified, entered into the database, and labeled.

Calculating Representation

Second only to determining whether bone is human or nonhuman, the MNI is generally recognized as the most basic calculation needed prior to subsequent bioarchaeological analyses. MNI allows bioarchaeologists to estimate the smallest number of individuals present in a given assemblage by avoiding counting the same individual more than once (Lyman 1994, 2018; Reitz and Wing 2008), typically by tallying only the most frequently occurring element, element side, or element portion, as well as age and sex. In this way, we attempt to approach the actual number of individuals (ANI) represented (Lyman 2019). In these cases, one might count the number of C2 vertebrae (of which there is only one per individual) or right tibiae (with a side designation required for paired elements). If clear morphological differences (e.g., sex, age) are present, further tailoring of MNI counts can be pursued; for example, if an MNI of 38 adult left calcanei is calculated, but two clearly nonadult *right* calcanei are likewise present, MNI can be estimated at 40 individuals.

Such estimates are preferable to using the number of identified specimens (NISP), a method derived from zooarchaeology in which all elements (including identifiable fragments) per taxon are treated as different, independent individuals; this generally results in overestimations of ANI (Lyman 2019). MNI is much more conservative in approaching ANI by acknowledging the coexistence of multiple elements within an individual, and thus often underestimates ANI. Similarly, estimates generated from the minimum number of elements (MNE) count the total number of skeletal elements or parts of elements but—unlike MNI—typically do not take the side, size, or demographics of these elements into account; this is because the goal of MNE is to measure completeness (Lyman 2019).

MNI can be further refined in fragmented, commingled assemblages by dividing each element into a series of designated areas. This method, long established in zooarchaeology as diagnostic zones (DZs; e.g., Dobney and Rielly 1988; Watson 1979), was applied to human skeletal elements by Knüsel and Outram (2004). They provided detailed illustrations depicting these numbered zones in order to improve assessments of MNI in fragmentary and commingled remains. Alternatively, Mack and colleagues (2016) argued that the identification of landmarks represents a more objective and simplified approach to estimating MNI relative to subjective zones whose boundaries may be more difficult to assess. Interestingly, however, these respective methods have rarely been tested against one another to determine which may produce the higher MNI and thus better approach ANI. In one case study, Lambacher and colleagues (2016) used three different methods to calculate MNI and MNE from commingled skeletons and found that the landmark method produced the most conservative MNI, although they also state that it may work best when fragmentation is high and refitting bones is not possible.

Materials and Methods

In taphonomically damaged, heavily commingled skeletal assemblages, selecting cortically dense or small, compact elements for analysis leads to a higher probability of fragment or element survival (e.g., see Osterholtz et al. 2014). Additionally, as previous literature has suggested that secondary mortuary practices may result in biased representation of skeletal elements in Umm an-Nar tombs—including intentional disturbance and commingling (Blau 2001a; Frifelt 1991; Gregoricka 2020), cremation (Blau 2001a; Benton 2006; Bondioli et al. 1998; Munoz et al. 2012), postmortem defleshing as indicated by cutmarks (Baustian and Martin 2010; Bondioli et al. 1998; Munoz 2014), and even the possible removal of male skulls (Osterholtz et al. 2014)—elements from across the skeleton were chosen to account for the possibility that some portion of the body may have been targeted for funerary rites and removed from these tombs in antiquity. Finally, during the curation of skeletons from tombs Unar 1 and 2 beginning in 2017, it became clear that certain elements were better represented than others and could thus offer the most accurate account of tomb membership. For instance, all long bones (including the thick cortical bone of the proximal ulna and femur or distal humerus and femur) were too fragmented and taphonomically damaged to be included.

As such, four elements from each tomb were chosen: the petrous portion of the temporal bone, the mandible, the patella, and the talus. All elements and fragments were first sided; any unsided fragments were not included in this analysis. Subsequently, each element/fragment was evaluated for MNI in at least one of two ways, using the zonation (Knüsel and Outram 2004) or landmark (Mack et al. 2016) methods.

For the temporal, left and right petrous portions from Unar 1 ($n = 890$) and Unar 2 ($n = 807$) were assessed. While some petrous portions were still attached to the squama, the majority were either unfused (i.e., very young nonadults) or had broken away from the cranial vault. According to Knüsel and Outram (2004), the temporal bone consists only of a single zone, and so zonation was deemed inappropriate for evaluating the fragmented nature of these individual skeletons. Instead, after siding, the internal auditory meatus (IAM) was used as a landmark, with petrous portions counted only if >50% of the IAM was present, and given a score of 1. If <50% of the IAM was present (i.e., only the interior portion of the meatus was visible), these portions were scored as 0 and not included in our MNI counts.

No intact mandibles were present in either tomb. Subsequently, over 2,000 mandibular fragments were examined from tombs Unar 1 and 2. In order to clarify the siding of these small fragments, 14 zones used to calculate MNI were adapted from the seven originally outlined in Knüsel and Outram (2004), divided into right ($n = 7$) and left ($n = 7$) sides (Figure 3). Fourteen landmarks were selected from White et alia (2012) to calculate MNI using the landmark method, again divided by right ($n = 6$), medial/center ($n = 2$), and left ($n = 6$) sides. These landmarks included the mandibular condyle, coronoid process, first molar socket, gonial angle, mental foramen, mandibular foramen, mental eminence, and mental spines. By dividing these by side and thus doubling the number of zones and landmarks,

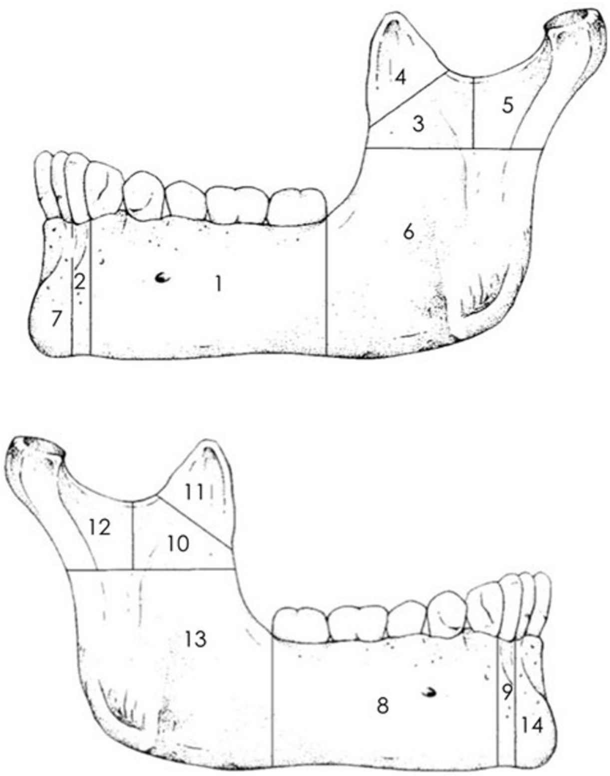

Figure 3. Zonation method for the mandible, adapted from Knüsel and Outram (2004) to include zones 1–7 for the left mandible (*top*) and zones 8–14 for the right mandible (*bottom*).

those mandibular fragments with central or *both* left and right portions present could be more easily and accurately recorded. Zones and landmarks were scored only if >50% of the relevant portion was present. Mandibular fragments that could not be sided were not scored for zones or landmarks, and so were not included in the final analysis of MNI.

Patellae from Unar 1 ($n = 374$) and Unar 2 ($n = 419$) were evaluated using the zonation method, for which there is only one zone defined by Knüsel and Outram (2004). Each patella was assigned a score of 1 if >50% was present and 0 if <50% was present. Patellae that could not be sided or that were scored as 0 were not counted for MNI. Tali from Unar 1 ($n = 498$) and Unar 2 ($n = 516$) were also used in this study. The zonation method uses four zones of the talus: the (1) medial and (2) lateral halves of the trochlea, and the (3) medial and (4) lateral halves of the proximal portion (Figure 4). The landmark system uses four distinct features of the talus: the (1) head, (2) neck, (3) trochlea, and (4) posterior calcaneal surface. Each landmark and zone was assigned a score of 0 if absent, 1 if >50% present, and 2 if <50% present. Tali that could not be sided, and landmarks and zones that were scored as 0 or 2, were not included in the final analysis of MNI. Statistical analyses, including Pearson Chi-square (χ^2), was performed using Statistical Analysis Software (SAS) version 9.4.

Results and Discussion

MNI across the Skeleton

MNI counts can be found in Table 2. The petrous portion of the left temporal bone provided the largest estimate for MNI at 459 for Unar 1 and at 411 for Unar 2—closely mirroring previous MNI estimates of 438 for Unar 1 (Schutkowski 1989) and 431 for Unar 2 (Blau 2001a). This is perhaps unsurprising, as the petrous portion possesses the densest bone in the human skeleton (Pinhasi et al. 2015). Landmark MNI

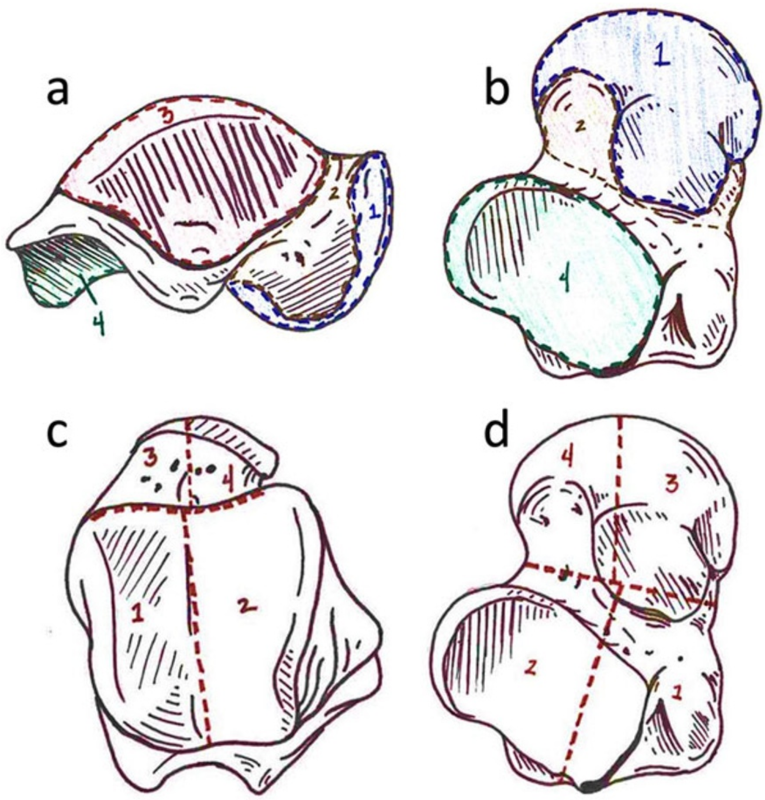

Figure 4. Lateral (a) and inferior (b) views of landmarks 1–4; along with superior (c) and inferior (d) views of zones 1–4 (adapted from Knüsel and Outram [2004]).

Table 2. MNI Counts based on Side (L = left, R = right, C = center) and Method (Z = zonation, L = landmark) for Umm an-Nar Tombs Unar 1 and Unar 2.

		Unar 1		Unar 2	
		Zonation	Landmark	Zonation	Landmark
Petrous portion	L	—	459	—	411
	R	—	405	—	364
Mandible	L	157 (Z1)	145 (L6)	198 (Z2)	218 (L6)
	C	221(Z7)	251 (L7/8)	298 (Z7)	323 (L7)
	R	164 (Z12)	150 (L14)	174 (Z9)	201 (L9)
Patella	L	163	—	183	—
	R	141	—	166	—
Talus	L	171 (Z2)	175 (L3)	234 (Z2)	233 (L3)
	R	165 (Z2)	158 (L3)	198 (Z2)	193 (L3)

between left and right sides for Unar 1 differed by 54 individuals (Figure 5), while for Unar 2, differences in landmark MNI between left and right sides was 47 (Figure 6).

Conversely, the smallest MNI estimates were derived from the patella for both Unar 1 (MNI = 163) and Unar 2 (MNI = 183). Zonation MNI between left and right sides for Unar 1 differed by 22 individuals. For Unar 2, zonation MNI between left and right differed by 17 individuals.

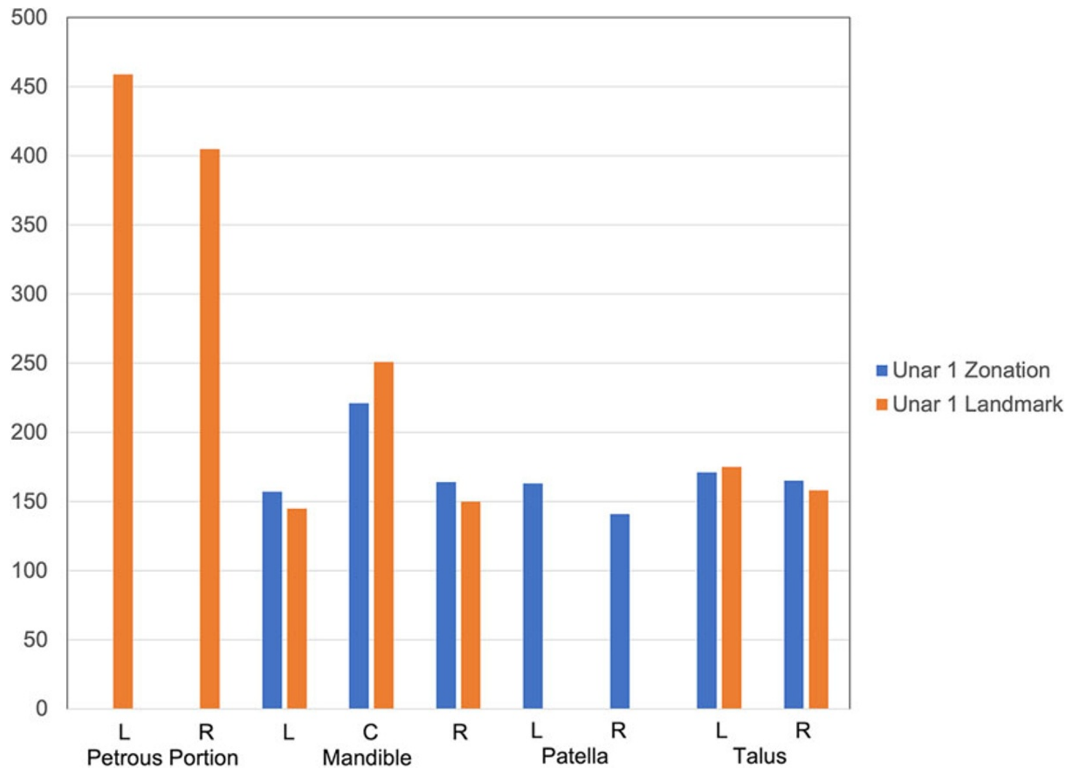

Figure 5. Comparison of zonation or landmark MNI counts by element and side for tomb Unar 1.

For the mandible, zonation MNI between left, central, and right sides for Unar 1 differed by 64 individuals. For Unar 2, zonation MNI between left, central, and right differed by as many as 124 individuals. Landmark MNI between left, central, and right sides for Unar 1 differed by as many as 106 individuals, while for Unar 2, differences in landmark MNI between left, central, and right sides was 122. Altogether, differences between side and method ranged from as few as 64 to as many as 124 individuals, a much wider range of estimates when compared with the petrous or patellae. Regardless of method, the center of the mandible (zone 7 or landmark 7—mental spines and landmark 8—mental protuberance) consistently produced the highest MNI in both tombs. This is probably a reflection of the density of bone comprising the mental eminence relative to other portions of the mandible. Other denser areas, including those directly surrounding the mental eminence and the mandibular condyles, also produced higher MNI counts, while gonial angles and coronoid processes were not as well represented.

For the talus, zonation MNI between left and right sides for Unar 1 differed by only six individuals. For Unar 2, zonation MNI between left and right differed by 36 individuals. Landmark MNI between left and right sides for Unar 1 differed by 17 individuals, while for Unar 2, differences in landmark MNI between left and right sides numbered 40. Altogether, differences between side and method ranged between as few as 6 and as many as 40 individuals—a relatively tight range of estimates. Regardless of method, the trochlea of the talus (zone 2 = lateral half of the trochlea or landmark 3—trochlea) consistently produced the highest MNI in both tombs. This suggests that the trochlea may be more resistant to taphonomic processes than other portions of the talus, or that it was simply more easily identifiable when more extreme fragmentation had occurred.

For elements in which both zonation and landmark techniques were utilized (i.e., mandible, talus), landmarks tended to produce the highest MNI. The exception to this was the Unar 2 left talus; here, the zonation method produced just one more individual than the landmark method. It may be the case that landmarks are more easily identifiable or sided in highly fragmented contexts, and so this method

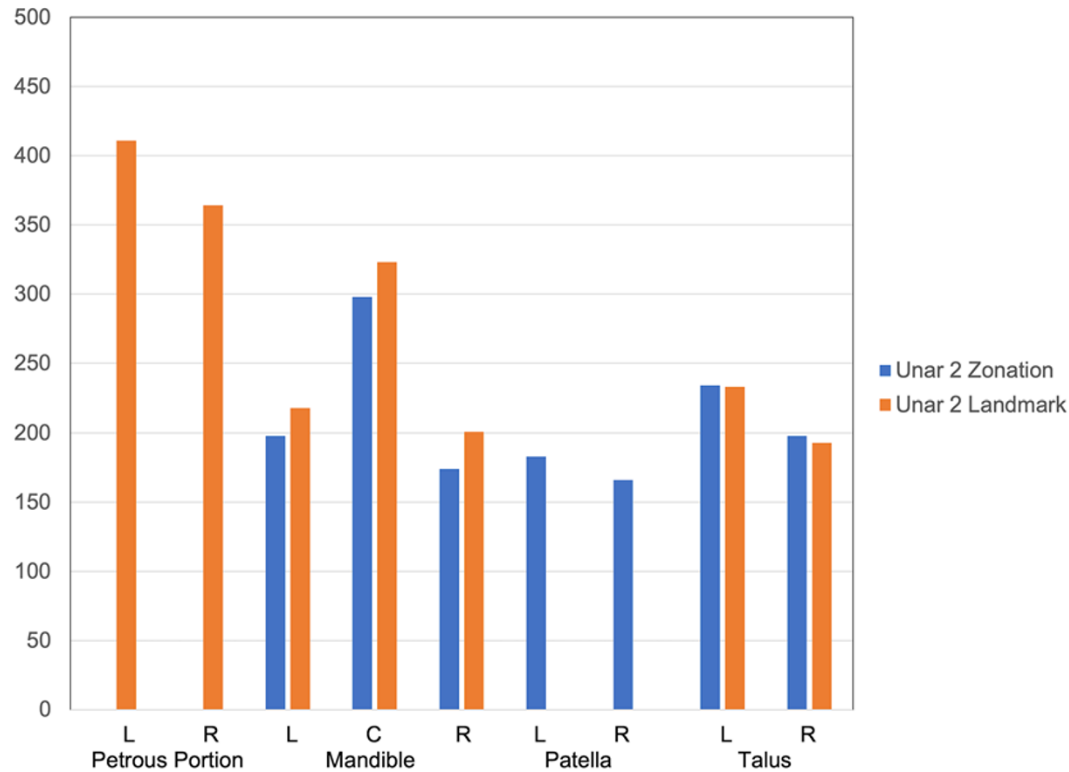

Figure 6. Comparison of zonation or landmark MNI counts by element and side for tomb Unar 2.

may be preferable. Nevertheless, no statistically significant differences were found between zonation and landmark counts between left, center, and right sides for the mandible for either Unar 1 ($\chi^2 = 2.42$, $df = 1, p = 0.12$) or Unar 2 ($\chi^2 = 0.24$, $df = 1, p = 0.63$). Similarly, for the talus, there were no significant differences between methods for both Unar 1 ($\chi^2 = 0.18$, $df = 1$, $p = 0.67$) and Unar 2 ($\chi^2 = 0.02$, $df = 1, p = 0.88$).

Overall, blocky, cube-like skeletal elements such as the talus and patella appear to deteriorate more readily than the thicker cortical bone of the petrous portion (temporal) and mental eminence/spines (mandible). This is probably owing to the relatively thin cortical plate of these bones, which surrounds more dense but still fragile trabecular bone. Interestingly, however, MNI counts are higher for the mandible (251 vs. 323), patella (163 vs. 183), and talus (175 vs. 234) for tomb Unar 2, despite this tomb having demonstrably fewer individuals (MNI = 411) than tomb Unar 1 (MNI = 459) according to the petrous portion. At the same time, we have also observed that bones are cremated at considerably higher rates and temperatures in Unar 2. Carter and Gregoricka (2019) found that around 83% of distal humeri in Unar 2 exhibited calcination, while only 2% remained unburned; this differed dramatically from bones within tomb Unar 1, in which 20% remained unburned while 62% were completely calcined. Similarly, Blau (2001a) estimated that 70.1% of all bones in tomb Unar 2 were burned to calcination. This could suggest that burning bones to calcination serves to preserve bone relative to unburned bone or bone burned at lower temperatures, which would explain the disparity in MNI counts for more friable bones such as the patella and talus. This supposition is supported by experiments demonstrating greater survivability of calcined bone fragments due to increases in crystallite size at high temperatures that enhance overall stability and hardness relative to charred and carbonized bone, which were found to be more vulnerable to diagenetic processes, including exposure to water (e.g., Gallo et al. 2021; Kalsbeek and Richter 2006).

This does not explain, however, why MNI for the nearby Umm an-Nar tomb at Tell Abraq was largest for the right talus, followed closely by the patella (Baustian 2010; Osterholtz et al. 2014), as the Tell Abraq individuals were not cremated. If cremation cannot account for the differential preservation between elements, some other taphonomic influence must be at play. One potential explanation may lie with the history of land use at Shimal. During the medieval period, for instance, tombs Unar 1 and 2 were covered by a large palm garden, which would have been watered daily and flooded for hundreds of years (Christian Velde and Imke Möllering, personal communication 2024), while the Tell Abraq bones were not exposed to groundwater or seawater from the nearby coast (Daniel Potts, personal communication 2024). Additionally, while the Umm an-Nar tomb at Tell Abraq was buried shortly after it was sealed around 2000–1950 BC and therefore protected from looters (Potts 1993; Schrenk et al. 2016), the commingled skeletons from tombs Unar 1 and 2 had been disturbed as a result of the removal of the ashlar façade in antiquity. This enhanced the exposure of bone to the elements, leading to the augmented destruction of blocky (but cortically thin) bones like the talus and patella.

Thus, for disturbed tombs like Unar 1 and 2, we recommend that elements possessing a thicker cortical structure be favored for MNI counts when bone has undergone significant postmortem alteration. Beyond the petrous portion, thicker, higher-density cortical structures are found in the femur and other long bones, which seemingly makes these elements more ideal for MNI selection (Galloway et al. 1997; Kendell and Willey 2014; Willey et al. 1997). Unfortunately, however, thicker cortical bone found in such long bones often does not include clear features but only fragments of the diaphysis, which make MNI counts using any method more challenging and less effective. Moreover, we observed considerable damage to many long bone epiphyses, probably caused by the regular movement and manipulation of bone within and outside the tombs as part of secondary mortuary practices. Again, then, without clear features or undamaged areas present on these epiphyses, MNI counts using such elements remain ineffective.

Side Discrepancies

Discrepancies in MNI counts between right- and left-sided bones required further investigation. For the petrous portions, tali, and patellae, all demonstrated higher MNI on the left side by numbers ranging from 6 to 54. These side differences are not statistically significant between tombs for the petrous portion (landmark $\chi^2 = 0.001$, $df = 1$, $p = 0.97$), talus (zonation $\chi^2 = 0.81$, $df = 1$, $p = 0.37$; landmark $\chi^2 = 0.34$, $df = 1$, $p = 0.56$), or patella (zonation $\chi^2 = 0.09$, $df = 1$, $p = 0.76$), or even within tombs by side between methods (talus Unar 1: $\chi^2 = 0.18$, $df = 1$, $p = 0.67$; talus Unar 2: $\chi^2 = 0.02$, $df = 1$, $p = 0.88$), indicating that the left side has been better preserved regardless of bone examined or technique used.

One of two explanations may be at work here. First, the intentional removal of bones from the right side of the body is a possibility, as part of secondary mortuary practices that also involved the intentional movement, fragmentation, and cremation of hundreds of decomposed corpses within these communal tombs, or even as some kind of ancestor veneration. Whatever the motivation, these lengthy rituals were important to the living community, perhaps as a means of transforming the dead into an ancestor collective, and so the removal of particular body parts cannot be ruled out. This differs from observations made at Tell Abraq, where no bias based on side was discerned from postcranial elements (Osterholtz et al. 2014).

Secondly, and more probably, this side discrepancy may be the result of taphonomic processes stemming from the initial placement of the dead on their right side. This practice probably originated from mortuary traditions first observed in the Neolithic, when individuals were typically buried on one side (usually the right) in a flexed position (Bondioli et al. 1998; Bortolini and Munoz 2015; Charpentier and Méry 2010) within a larger cemetery. Umm an-Nar primary interments are more rare but also appear to have commenced with laying down the dead on either side, evidenced by a handful of partially or still-intact individuals in some Umm an-Nar tombs (e.g., two individuals in Chambers D [left side] and G [right side], Unar 2; Blau 2001a). If individuals were preferentially laid on their right side (as in the prior Neolithic) and left to decompose prior to disarticulation and other postmortem secondary funerary treatments, bones from this side of the body would be in direct contact with the limestone bedrock or stone-cobbled floor. Such exposure to limestone would result in more rapid diagenetic changes to bone in which it absorbs or replaces its original structure with minerals from the surrounding postmortem environment, while also losing its organic proteins and lipids (de Sousa et al. 2020; Maurer et al. 2014; Nielsen-Marsh and Hedges 2000). Such a loss of flexibility from deteriorated collagen proteins and lipid content, alongside enhanced porosity, leads to a more brittle and thus more easily breakable structure (Nielsen-Marsh et al. 2000; Turner-Walker and Parry 1995). Such differential preservation potential might explain the sometimes stark differences between left- and right-side MNI counts (as large as 54 for petrous portions).

Total Element Distribution by Chamber

Element distribution can also be examined by chamber (although it should be noted that chamber designations were not recorded for all elements during the original excavations). Unlike MNI counts, which were centered around the petrous, mandible, talus, and patella, *all* curated skeletal elements throughout the skeleton were included to evaluate bone distribution by chamber. These elements were grouped into four categories—skull, arm, os coxa, and leg—prior to statistical analyses to improve sample size across chambers.

Only around half of the Unar 1 assemblage is housed at the University of South Alabama; the remainder continues to be held in a storage facility maintained by the Department of Antiquities and Museums in the Emirate of Ras al-Khaimah. While those skeletons in Ras al-Khaimah have been assessed for MNI using the petrous portion, mandible, patella, and talus, all other bones have not been curated or inventoried. As such, total element distribution from Unar 1 is not representative of the true number of elements recovered from this tomb, and so are not discussed further here.

The entire Unar 2 assemblage is housed in the United States, and so *all* curated skeletal elements throughout the skeleton could be included to evaluate bone distribution by chamber. Chamber A and area H/J were removed, owing to small sample sizes, which precluded statistical analyses. While some chambers were generally favored over others for disposal of the dead (e.g., F, J, K), no significant differences ($\chi^2 = 47.6$, $df = 39$, $p = 0.16$) existed between grouped skeletal elements and tomb chamber (Figure 7). This indicates a lack of preference for secondary placement of particular bones back into the tomb.

However, when broken down by body portion, whereas bones within the skull ($\chi^2 = 43.7$, $df = 33$, $p = 0.1$) and arm ($\chi^2 = 22.1$, $df = 24$, $p = 0.57$) appeared similar in distribution between chambers, bones within the leg—including the femur, patella, tibia, and talus ($\chi^2 = 77.8$, $df = 33$, $p = 0.00002$), and even just the femur, patella, and tibia ($\chi^2 = 69.0$, $df = 33$, $p = 0.0002$)—did not. Only the relationship between the femur and tibia ($\chi^2 = 15.5$, $df = 11$, $p = 0.16$) and the talus and patella ($\chi^2 = 17.2$, $df = 11$, $p = 0.1$) were not statistically significant. Significant differences between bones of the leg may therefore be a product of the inclusion of the talus and/or patella—which MNI counts show did not preserve well—in statistical analyses also involving the better-preserved femur and/or tibia. Together, these data suggest that certain elements were not intentionally moved to certain chambers.

MNI-Based Element Distribution by Chamber

The distribution of elements specifically used to calculate MNI—including the left petrous portion, the central mandible (landmark 7—mental spines), the left talus (zone 2—lateral half of the trochlea), and left patella—was similarly examined by chamber. In doing so, we could evaluate MNI-based bone distribution by chamber for Unar 2. Chambers A, D, G, H/J, M, and area N were removed due to small sample sizes, which precluded statistical analyses. This left 10 chambers (or shared areas between chambers as designated by the original archaeologists) for comparison: B, C, E, F, H, J, J/K, K, L, and L/M. As above, no significant differences ($\chi^2 = 29.26$, $df = 42$, $p = 0.93$) existed between MNI skeletal elements and tomb chamber. Once again, then, this indicates a lack of preference for secondary placement of particular bones back into the tomb.

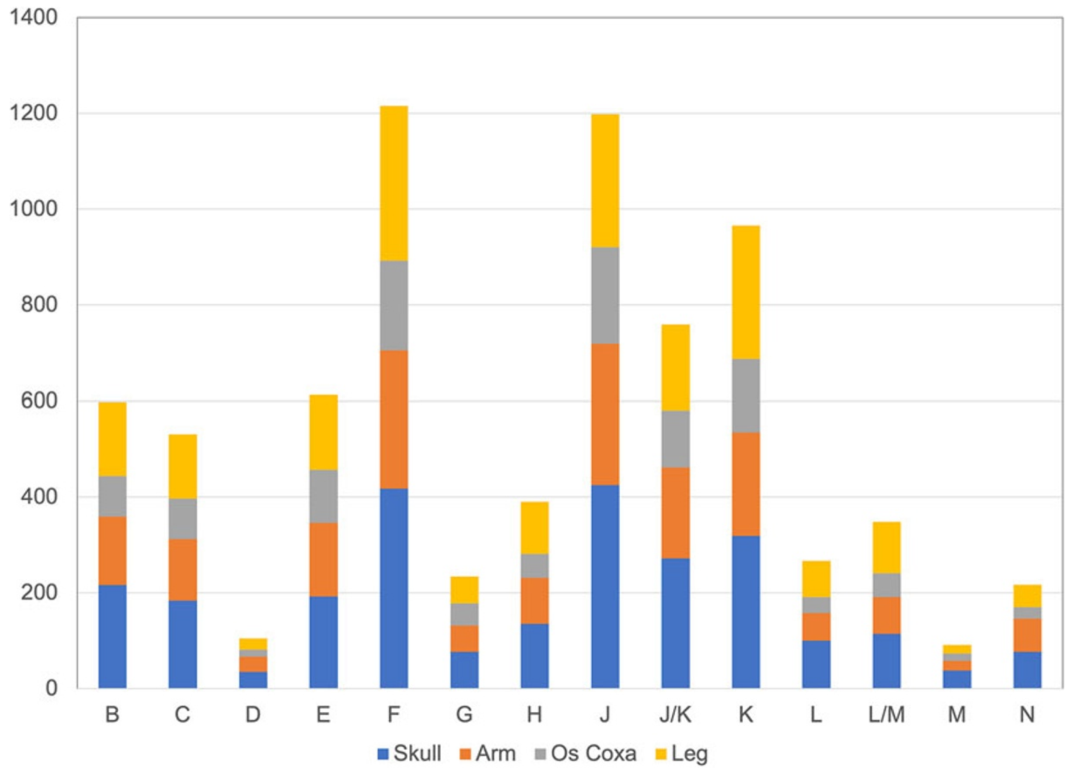

Figure 7. Grouped skeletal elements (skull, arm, os coxa, and leg) by chamber for tomb Unar 2. Chambers A, D, and M were removed from comparison owing to small sample sizes.

Conclusions

Counting MNI within commingled and fragmentary contexts is a necessary first step in the bioarchaeological study of communal tombs such as those from the Umm an-Nar period in southeastern Arabia. In doing so, this practical phase of work can reveal much more than just how many individuals were interred within such structures. Using case studies from tombs Unar 1 and 2, we discovered vast differences in MNI counts, although not because of differences in the methods used. Instead, it suggests that the selection of dense cortical bone from areas of the skeleton such as the petrous portion and mandible may be preferable when determining what elements of a commingled and fragmentary group of skeletons should become the focus of an investigation. Conversely, small, blocky elements such as the patella and talus may work well for MNI counts at other sites, but can deteriorate more quickly, owing to their thin cortical plates. Nevertheless, cremation at high temperatures that leads to calcination of bone may in fact lead to enhanced preservation of such elements.

Beyond the practicality of assessing MNI, the information gleaned from the study of multiple skeletal elements reveals additional information about secondary mortuary practices and taphonomic processes that would otherwise remain hidden. Differences in side counts, for example, can uncover information about primary interment traditions that would later be erased by secondary movement of bone. Here, we found that the left side of the skeleton was preserved more readily than the right, indicating that individuals were preferentially placed on their right sides prior to decomposition and disarticulation—a practice observed in the prior Neolithic cemeteries across southeastern Arabia. Additionally, a detailed comparison of bone distribution between tomb chambers—using both the skeletal elements selected for MNI calculations and elements from across the skeleton—revealed that bone does not appear to have been intentionally moved to different areas of the tomb after cremation took place.

This is not to deny that such movement occurred in other tombs from the same time period, such as at Tell Abraq, but instead emphasizes that Umm an-Nar tombs are not one-size-fits-all, and that detailed MNI counts using elements from across the skeleton should be completed on all Umm an-Nar tombs to ensure that we can see how treatment of the dead may have changed over time.

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Data Availability Statement. All data that support the findings of this study are available in the tables contained within this manuscript and in our open-access online repository, which can be found at https://jagworks.southalabama.edu/bioarch-reu_gregoricka/.

Competing interests. The authors declare none.

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