Journal of Archaeological Science: Reports 10 (2016) 263–271

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Bioarchaeological approaches to looting: A case study from Sudan

Katherine M. Kinkopf [a,*], Jess Beck [b]

[a] Department of Anthropology, University of California, Berkeley 232 Kroeber Hall, Berkeley, CA 94270-3710, United States
[b] University of Michigan Museum of Anthropological Archaeology, 1109 Geddes Avenue, Ann Arbor, MI 48109-1079, United States

ARTICLE INFO

Article history:
Received 2 January 2016
Received in revised form 24 August 2016
Accepted 24 September 2016
Available online xxxx

Keywords:
Bioarchaeology
Looting
Ancient Nubia
Taphonomy
Funerary archaeology
Mortuary archaeology
Fragmentation

ABSTRACT

Looting is a significant destructive force at archaeological sites; grave robbing, in particular, leaves human remains and cultural heritage irreparably damaged. *Al-Widay*, a necropolis excavated by the Oriental Institute Nubian Expedition near the Fourth Cataract region of the Nile River, is a site with important implications for understanding the taphonomy of archaeological looting. Over 60% of the tumuli excavated at Al-Widay were disturbed in antiquity, making the site an ideal case study for examining the effects of looting on ancient human skeletal remains. Our research applies bioarchaeological methods of quantifying fragmentation to an assessment of "Culturally Significant Anatomical Regions" in order to evaluate the nature and degree of human disturbance activity at this necropolis. At Al-Widay, site reports document looted graves (n = 22), unlooted graves (n = 14), and a sample of graves (n = 42), for which the level of disturbance is unknown. Fisher's exact test showed significant differences in the bioarchaeological patterning of looted versus unlooted contexts, and a cross-validated logistic regression model was used to sort five unknown graves into looted and unlooted categories, providing a quantitative bioarchaeological method for the identification of looting.

1. Introduction

Burial disturbance in the form of revisitation, looting, and bioturbation is ubiquitous in the archaeological record. However, burial disturbance activities are not restricted to contemporary practices and processes. Law 25 of the Hammurabi Code (Roth, 1995) and later New Kingdom Egyptian texts (Botti and Peet, 1928) describe some of the first recorded instances of criminal burial disturbance. The collection of New Kingdom (1100 BCE) papyri, translated and collected as "The Great Tomb-Robberies of the Twentieth Egyptian Dynasty" details looting activities, compiles inventories of materials looted, and describes the punishments of each looter (Botti and Peet, 1928; Peet, 1930). It is evident that grave robbing is not an isolated activity for which people are occasionally punished, but rather a long-standing and wide-reaching social and political issue.

Archaeologists typically find ways of working around looting activity at archaeological sites, and more recent work has attempted to account for looting and disturbance of the material past in the framing of research design and questions, which produces valuable insight into looting as a social practice for heritage management as well as archaeological research (Al-Houdalieh, 2012; Conlee, 2011; Kaulicke et al., 2012; Kersel and Chesson, 2013; Sneddon, 2002; Stone, 2008; van Velzen, 1996; Webb and Frankel, 2009). Examining disturbance activity (e.g., looting) at archaeological sites provides a long-term geopolitical perspective on occupation and landscape use, and the addition of bioarchaeological indicators provides valuable information on the interactions between archaeological bodies, funerary material culture, and living people.

Working with human remains from disturbed or unknown contexts can be an obstacle to archaeologists seeking to interpret funerary practices. The absence or extreme fragmentation of the cranial and postcranial regions of the skeleton also present obstacles to reconstructing aspects of prehistoric identity and lived experiences. However, research on historical contexts has demonstrated that anthropogenic post-mortem disturbance of graves has the potential to produce identifiable patterns of skeletal preservation (Goff, 2011; Tward and Patterson, 2002). For example, during the salvage excavation of Fort Craig, archaeologists documented a peculiar pattern of anatomical preservation in historic graves. Fort Craig is former military post in New Mexico, where cemetery burials were moved by personnel before the post was decommissioned. Archaeologists found that supposedly "empty" graves actually contained many small bones of the hands and feet, as well as ribs, vertebrae, hyoids, clavicles, sternums and scapulae. This pattern of recovery is likely related to personnel targeting the largest and most recognizable elements of the body (e.g. the skull, femur, tibia, pelvis, humerus and larger ribs) for removal, while missing or ignoring smaller, less recognizable bones (Goff, 2011; Kimberly Spurr, pers. comm.) The timing of post-mortem disturbance also affects the patterning of skeletal preservation; during the heyday of anatomical grave-

* Corresponding author.
E-mail address: kinkopf@berkeley.edu (K.M. Kinkopf).

http://dx.doi.org/10.1016/j.jasrep.2016.09.011

robbing during the 19th century, bodies were removed from graves before decomposition was greatly advanced (Tward and Patterson, 2002), leaving a signature of disturbance in which all skeletal elements were missing from the grave.

Our research uses recent developments in the study of skeletal taphonomy, particularly fragmentation-zonation recording methods and analyses of skeletal completion, to differentiate looted and unlooted graves (Osterholtz et al., 2014; Stodder and Osterholtz, 2010; Knüsel and Outram, 2004). The taphonomic patterning of looting activity is distinctive from ritualized skull removal (Bonogofsky, 2003; Kuijt et al., 2009; Millaire, 2004; Strouhal, 1973), amputation (Bricker, 1976), and burial relocation (Goff, 2011; Heinlen and Gray, 2010); and although the congenital absence of bones is well documented in many human populations, congenital absences were accounted for during initial osteological analyses (Ingvoldstad, 2009).

This research refines bioarchaeological methods of analyzing commingled and fragmentary human remains in order to illustrate a method for incorporating human remains from looted contexts into archaeological investigations in the prehistoric or historic periods. The methodology developed and discussed in this paper allows bioarchaeologists to determine whether preservation and presence-absence of skeletal elements is due to looting activity or non-human related taphonomic processes. This approach is especially relevant for scholars and professionals who are increasingly working within museum contexts where stratigraphic evidence or information on disturbance are largely unavailable due to historical contingencies, or proximity to excavations and communication with original excavators may not be possible. Using a sample of burials from Kerma-period Nubian contexts, we develop a model to predict grave context (e.g. "looted" or "unlooted") based on a combination of qualitative and quantitative methods. While our sample of 36 burials is small, this study provides a guide for future bioarchaeological research concerned with looting, and it is our hope that future studies will expand and elucidate the taphonomic patterning in human skeletal remains observed in this research.

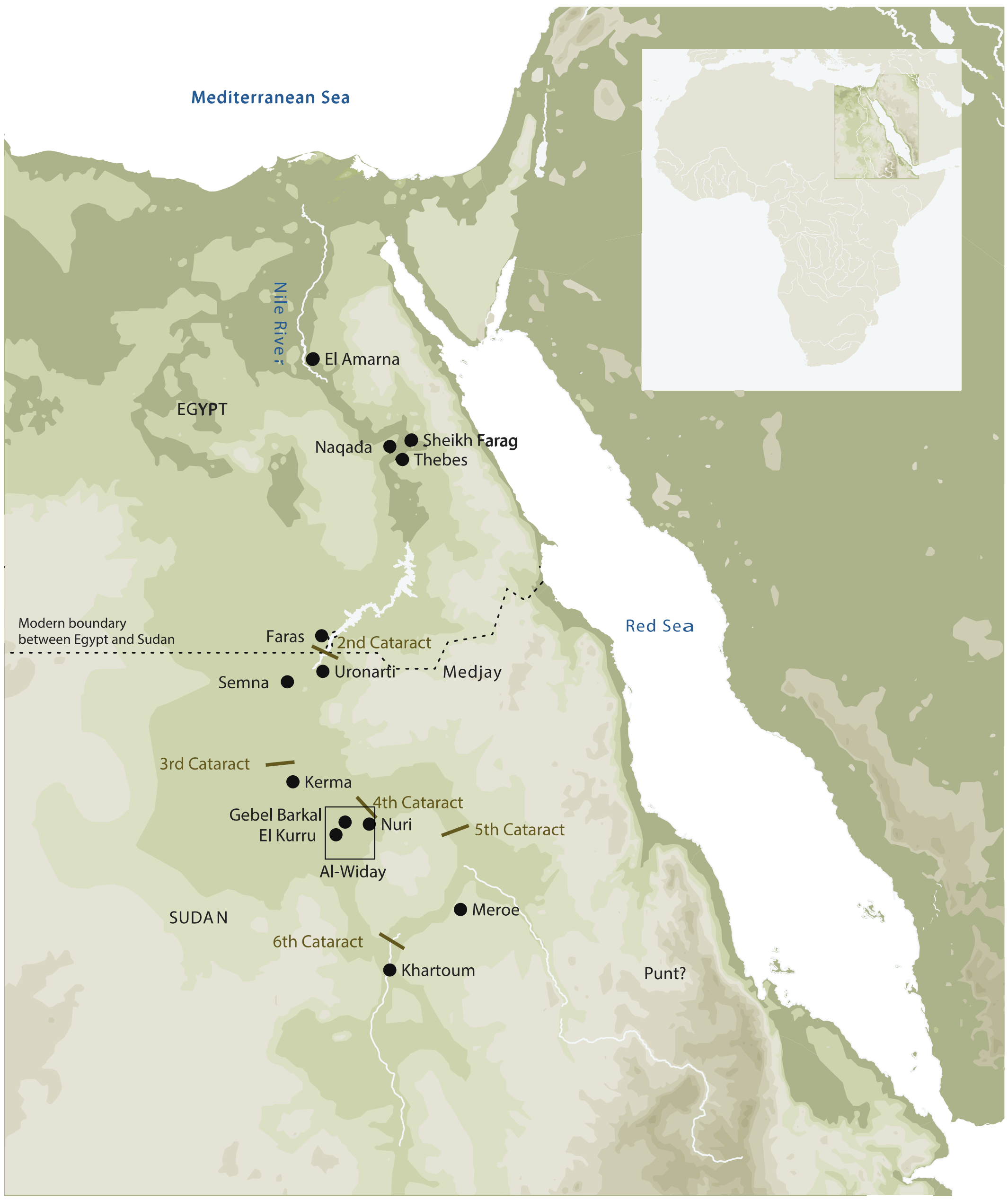

Fig. 1. Map of location of Al-Widay I in relation to other sites.
Adapted from Emberling, 2011.

Though other archaeological methods, including stratigraphic assessment and remote sensing, are also appropriate to examining the taphonomy of looting, our method is targeted towards the many contexts in which such archaeological information is unavailable or missing. This includes analyses of collections excavated prior to the development and implementation of modern recording methods, and materials that have been disassociated from their provenience information due to civil or political unrest in their country of origin. Overall, this study seeks to develop a model for quantitative skeletal approaches to looting that will be useful for bioarchaeologists and archaeologists seeking to identify evidence of looting in contexts where osteological materials are some of the best-preserved remains, or the only materials available.

2. Materials

2.1. The excavation of Al-Widay I

Al-Widay I was excavated under the direction of Geoff Emberling and Bruce Williams during the Oriental Institute Nubian Expedition (OINE) of 2007 and 2008, as part of an international salvage project in response to the construction of the Merowe Dam in the Fourth Cataract region of northern Sudan (Fig. 1, Emberling, 2011). The 2007 and 2008 seasons included excavations and surveys of additional sites (i.e., Al-Widay II, Umm Gebir, and Hosh el-Goruf, *see* Emberling and Williams, 2008).

In 2007, 32 graves were excavated with aim of identifying mortuary deposits at the periphery of each of the tombs; these tumuli were primarily from the later *Kerma Moyen* period (2000–1750 BCE) and early *Kerma Classique* periods (1750–1550 BCE) (Emberling et al., 2014; Emberling and Williams, 2008; Paner et al., 2010). Seventy-six burials were excavated during the 2008 season, primarily from the *Kerma Moyen* period. A single Napatan period burial was also excavated but is not discussed in this paper. These sites are currently submerged under the Nile River as a result of the construction of the Merowe Dam.

2.2. The cemetery and skeletal sample from Al-Widay I

Excavations at Al-Widay I yielded 114 individuals in 105 graves. Burials containing multiple individuals were composed of either two adults, or an adult and juvenile/neonate, which were all primary burials (Emberling and Williams, 2008; Emberling et al., 2014; Ingvoldstad, 2009). The age distribution of individuals follows the expected age distribution for an archaeological cemetery; this mortality curve suggests a growing population with high fertility, which is reflected in the mortuary population as high juvenile mortality (Ingvoldstad, 2009). Nearly 40% of the individuals from Al-Widay I are juveniles, and the proportion of male to female individuals is approximately 1:1, which is expected in a normal population (Bocquet-Appel and Naji, 2006).

The Kerma Moyen circular tumuli dominate the northern part of the Al-Widay I necropolis, whereas Kerma Classique rectangular burials are primarily constrained to the southern part of the site. Emberling and Williams (2010) suggest that as time passed new burials were added to the southern side of the necropolis. The large mortuary structure in the northernmost portion of the necropolis is dated to the Napatan Period due to the presence of distinctive Napatan-style beads and amulets within the structure (Emberling and Williams, 2008). Kerma Moyen and Classique burials were dated using burial and ceramic typologies corroborated by local radiocarbon dates (Emberling and Williams, 2008).

Ingvoldstad (2009) noted that the skeletal material excavated was extremely friable and fragmentary. While the bones remained in situ, many were considerably more intact than they were when processed in the laboratory. The result of these destructive taphonomic processes is confounding fragmentation, as many of the bones were difficult to remove from the matrix. Aside from this taphonomic fragmentation, a sample of burials were categorized as "looted in antiquity" by the excavators. Some of the human remains were transformed and distorted by the weight of the stones placed above the cranium on top of the burial (Fig. 2). This placement has a compression effect on the bones that caused deformation, crushing, and breakage in many of the bones, although during excavation the anatomical region remained intact (Ingvoldstad, 2009). This breakage resulted in some human remains being too fragmentary for age or sex estimation.

2.3. Previous identifications of "looted" and "unlooted" burials

Using ArcGIS and base layers produced by the OINE project (James, pers. comm.) the distribution of looted and unlooted tombs at Al-Widay I was visualized in order to better understand how potential looting affected different areas of the cemetery (Fig. 3). Known data points were coded as "looted," "unlooted," or "unknown," where no data was available; these designations were based on the grave condition noted by the excavators during the field season. It is evident from the distribution of grave conditions that although looting is ubiquitous across all regions of the cemetery, the unlooted graves were spatially constrained to the southernmost part of the cemetery (Fig. 3). Burial typologies also suggest that this southern portion witnessed the latest use of the cemetery. During excavation, "digging sherds" were recovered in some of the looter's cuts and shafts that perforated the cemetery. The excavators present these re-worked sherds as looters' tools, which were presumably left behind at the time of the disturbance activity. Out of the 11 instances where looting paraphernalia was recovered, 8 (~70%) locations co-occurred with the looted burial contexts. Additionally, 7 of these 11 instances cluster in the southeast corner of the

Fig. 2. Photo of remains from Al-Widay I, Emberling, pers. comm.

cemetery. Predictably, the digging sherds are associated with looted contexts; in the case of the unlooted context finds, the sherds were associated with the surface level or were found in close proximity to the grave, but not in the grave or in its fill.

3. Methods

3.1. Bioarchaeological methods: evaluating culturally significant anatomical regions

Before recording information on bone fragments, we identified regions of the body most likely to be affected by looting using the ethnographic and archaeological literature (Bianchi, 2004; D'Auria, 1982; Emberling, 2011; Emberling and Williams, 2008; Emberling and Williams, 2010; Kennedy, 1978; Nielson and Nouchiravan Dianaty, 1970; Reisner, 1923). The data available suggested that regions of the body where valuable adornments may have been placed or worn were those most likely to be looted in antiquity. We constructed a profile of Culturally Significant Anatomical Regions (CSAR) relevant to pre-Islamic Nubian burials based on the ethnographic data available on Old Nubians (Kennedy, 1978), and archaeological data from Kerma (D'Auria, 1982; Reisner, 1923) and Al-Widay I (Emberling, 2011; Emberling and Williams, 2008; Emberling and Williams, 2010). The results of the ethnographic data were then combined with known archaeological components in order to be as comprehensive as possible with our analysis and interpretation. Culturally Significant Anatomical Regions for pre-Islamic Nubian burials include the cranium, mandible, neck, hands, and feet (Table 1): these directly correspond to areas of the body that were typically adorned during burial throughout pre-Islamic Nubia and are still adorned currently in some rural areas of Sudan (D'Auria, 1982; Kennedy, 1978; Reisner, 1923). Although the preservation of extremities is often variable and incomplete in archaeological contexts due to various non-human taphonomic processes (Nelson, 1998), we chose to include these regions in our analysis because they are important sites of adornment at death, and deepening our understanding of some of the differences between non-human taphonomic activity and human taphonomic activity is an important component of the study.

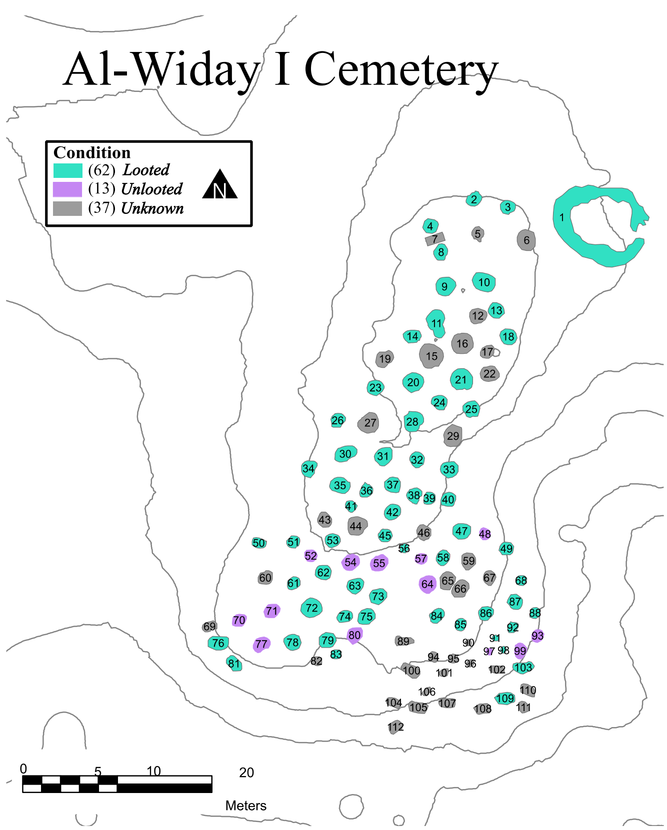

Fig. 3. Map of looted and unlooted tombs.

Table 1
Culturally Significant Anatomical Regions.

CSAR	Elements included[a]
Cranium	Cranial bones, except facial bones (vomer, ethmoid, palatines, lacrimals) and auditory ossicles
Mandible	Mandible, without dentition
Neck	Atlas, axis, and cervical 3–6
Hands	Scaphoid, lunate, triquetral, pisiform, trapezium, trapezoid, capitate, hamate; metacarpals 1–5; proximal, intermediate, and distal manual phalanges
Feet	Calcaneus, talus, navicular, cuboid, 1st–3rd cuneiform; metatarsals 1–5; proximal, intermediate, and distal pedal phalanges

[a] Right and left sides where applicable.

Analyzing the Al Widay I material necessitated the creation of a nuanced methodological approach that assessed the remains with attention to the culturally- and historically-situated phenomenon of looting. In particular, it was important to establish specific parameters for informative fragmentation analysis and inventory. Accordingly, we altered existing methodologies (Karr and Outram, 2012; Knüsel and Outram, 2004; Stodder and Osterholtz, 2010) in order to control for the amount of organic material remaining in bones (a variable which affects fragmentation), as well as to understand the taphonomic processes affecting the remains.

Zonation methods of quantifying presence and absence are increasingly popular in bioarchaeological analyses; for this study two zonation-fragmentation methods of analysis were modified in order to best understand the skeletal remains (Knüsel and Outram, 2004; Stodder and Osterholtz, 2010). For easy comparison to other taphonomic studies, we used language outlined for recording taphonomy in *Standards* when possible (Buikstra and Ubelaker, 1994).

In order to develop a method for assessing fragmentation in a descriptive and quantitative manner, we categorized the visually observable differences between different types of bone breakage. The five resultant categories were "absent," "crushed," "disarticulated," "fragmentary," and "present" (Table 2). The "absent" designation indicated that the majority of an element was not present when assessed in the laboratory. The "crushed" designation required the use of excavation photographs in order to assess the presence of the anatomical element

Table 2
Quantitative and qualitative categorizations of taphonomic conditions.

Category	Quantitative	Qualitative
Absent	<25% of anatomical region/ bone present in the laboratory	Anatomical region/bone absent from the archaeological matrix
Crushed	>25% of anatomical region/bone present in the laboratory	Anatomical region/bone appears present and/or crushed in the archaeological matrix
Disarticulated	>25% of anatomical region/bone present in the laboratory	Anatomical region/bone was not recovered *in situ* during excavations
Fragmentary	25–50% of anatomical region/bone present in the laboratory	Anatomical region/bone is present; damaged post-mortem and prior to excavation
Present	>50% of an anatomical region/bone present in laboratory	Anatomical region/bone appears present and complete in the archaeological matrix
No data	Based on individual's age estimation (<2 lunar years) elements were not expected to be present and/or ossified and therefore not considered for analysis in the above categories; Anatomical region appears present in excavation photographs and in initial osteological reports but could not be located for analysis in the laboratory	

Table 3
Collapsing taphonomic categories for statistical tests.

Original taphonomic categories	Fisher's exact tests	Logistic regression model
Present Crushed	Present (present, crushed)	Present (present, crushed)
Disarticulated Fragmentary	Disturbed (disarticulated, fragmentary	Absent or disturbed (disarticulated, fragmentary, absent)
Absent	Absent	

or region in the archaeological matrix, and was used to describe elements that were >25% present, but appeared to be smashed or pulverized into the archaeological matrix. The "disarticulated" condition refers to the location of the recovered elements, as it designates bones with >25% levels of preservation in the laboratory that were not recovered in anatomical position during excavations. "Fragmentary" includes elements with between 25 and 50% preservation, while "absent" refers to bones that were missing and were not recovered during excavation.

These categories highlight important differences between different types of preservation that are relevant to assessing whether or not burials have been disturbed by looting activity. For example, the "crushed" designation accounted for potentially confounding post-mortem damage to the remains due to non-looting disturbance, such as weighted stones above the burial and the weight of the soil. Regions and bones that appeared crushed during excavation had a high number of fragments relative to weight during laboratory analyses. In contrast, bones that were "disarticulated" reveal post-mortem movement of elements *prior* to excavation.

After the element or region was identified as present during excavation, laboratory analysis was used to evaluate the degree of element preservation as well as the taphonomic condition of the element. To control for categorization bias produced by excavators' designations of burials as either "looted" or "unlooted," the grave condition of each burial was removed from its information file when coding the taphonomic condition of CSAR regions.

The quantitative evaluation of each category was accomplished through a standard skeletal inventory of the remains from Al-Widay, housed at the Osteology Lab at New York University's Center for the Study of Human Origins. Percentage completeness of each anatomical region was calculated through a combination of size sorting and weighing, and feature-based fragment identification building in particular on Stodder and Osterholtz (2010) and Knüsel and Outram (2004). Completeness of the cervical vertebrae, or the neck region, was calculated based on *Standards*, where >75% completeness of the vertebral body and at least two articular facets present for observation constitutes a complete vertebral element (Buikstra and Ubelaker, 1994). Mandible completeness was calculated by dividing the mandible into four portions: two anterior portions and two posterior portions. Cranial, hand, and foot completeness was calculated based on the models provided in Stodder and Osterholtz (2010) and Knüsel and Outram (2004). We account for the expected absence of the hand and foot bones due to excavation and bioturbation by allowing the presence of 75% or more of the phalanges to indicate phalanx completeness,

Table 4
Collapsing anatomical regions for statistical tests.

Original anatomical regions	Fisher's exact tests	Logistic regression model
Cranium Mandible	Cranium Mandible	Skull (cranium, mandible)
Neck	Neck	Neck
Right hand Left hand	Right hand Left hand	Hand (right hand, left hand)
Right foot Left foot	Right foot Left foot	Foot (right foot, left foot)

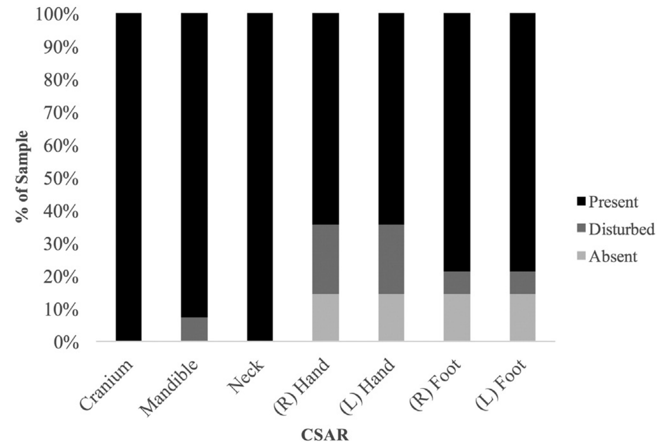

Fig. 4. Taphonomic categories for unlooted graves (n = 14), by anatomical region.

which is used in conjunction with carpals and metacarpals and tarsals and metatarsals to calculate completeness for the hand and foot regions, respectively.

3.2. Statistical methods

One primary objective of this research was to assess whether there were significant differences between the preservation of anatomical regions within a single sample, and whether there were significant differences in the preservation of anatomical regions between the looted and unlooted samples. Assessing the strength and nature of such differences was an important first step in determining whether quantitative bioarchaeological distinctions exist between looted and unlooted graves. First identifying which anatomical regions showed the greatest differences between looted and unlooted contexts also allowed us to make informed choices about the categories used when constructing the logistic regression model.

Many cells in the unlooted sample (n = 14) contained counts with values <5, and many cells in the unlooted sample contained counts with values <10. Accordingly, multiple 2 × 2 Fisher's exact tests were performed in order to examine whether there were differences between anatomical regions within the looted sample. Fisher's exact tests were conducted in the statistical package R, and P was set at 0.05 before performing the tests. In order to increase sample size, the original taphonomic conditions were collapsed for each statistical test (Table 3).

Fisher's exact tests were also used to examine whether there were significant differences in taphonomic patterning *between* the looted and unlooted samples. In order to increase counts per cell, certain anatomical regions were collapsed for this test, merging the cranium and

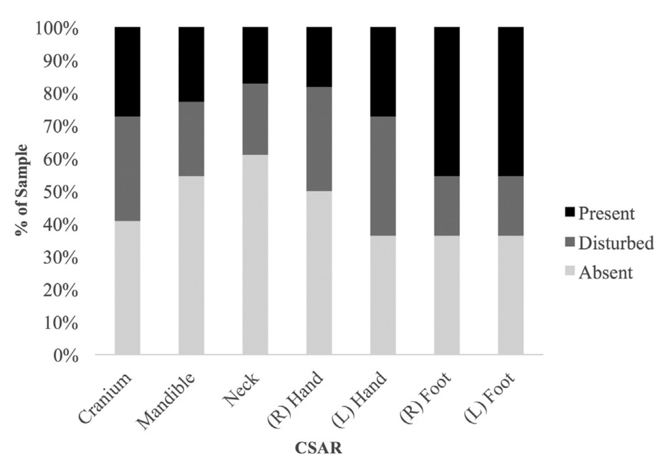

Fig. 5. Taphonomic categories for looted graves (n = 22), by anatomical region.

Table 5
Taphonomic categories for unlooted graves (n = 14), and looted graves (n = 22) by anatomical region.

CSAR[a]	Unlooted			Looted		
	Present	Disturbed	Absent	Present	Disturbed	Absent
Skull	27	1	0	11	12	21
Neck	14	0	0	3	5	14
Hand	18	6	4	10	15	19
Foot	22	2	4	20	8	16

[a] Skull = cranium and mandible; Hand = left and right hands; Foot = left and right feet.

mandible into a "skull" category, the right hand and left hand into a "hand" category, and the right foot and left foot into a "foot" category (Table 4). P was set at 0.05 before performing the test. The taphonomic categories of "present" and "crushed" were collapsed in order to increase counts; we believe the categories of "present" and "crushed" both signify a lack of human disturbance or looting in the taphonomic processes. Elements identified during analysis as "crushed" were likely in that taphonomic state due to the practice of placing large stones above the burial or due to the weight of the soil as described in Section 2.2, because these conditions are not associated with looting, they were collapsed for these statistical analyses.

Finally, a logistic regression was constructed in R using all observations for which grave condition (e.g. looted or unlooted) was known. The script for this model was based on the cv.glm bootstrap function from the R boot package, available online.[1] An annotated version of the R script used to build the logistic regression model, along with the skeletal data set (modified so that tomb numbers and tomb identifiers are obscured) are available as appendices to this article. This model assigned observations to either a "looted" or "unlooted" category based on the pattern of preservation of CSAR regions. A binomial response variable was used to indicate grave condition, with 1 = looted and 0 = unlooted.

Each run of the model was built using 35 of the 36 observations for which grave condition was known, and then tested on the observation not used in the model. This process of "leave one out" cross-validation iterated through all observations to estimate the prediction error rate for the model. The prediction error reflects the percentage of category assignations made in error (i.e. when an iteration of the model assigns an observation to the "looted" category when it is actually "unlooted," or to the "unlooted" category when it is actually "looted"). The cross-validated logistic regression model was then used to sort the five observations for which grave condition was unknown into either the "looted" or "unlooted" categories.

4. Results

4.1. Results of bioarchaeological data collection

Bioarchaeological data collection revealed differences in preservational patterning between the looted and unlooted samples (Figs. 4, 5). Initial exploratory data analysis suggested that the unlooted assemblage was dominated by a high number of elements characterized as present for each anatomical region (Fig. 4). In contrast, the looted sample showed a more even distribution of elements between the present, "disturbed, and absent categories for each anatomical region, with a slight bias towards absent elements for most anatomical regions (Fig. 5).

This distinction was maintained even after individual anatomical regions were collapsed as outlined in Table 4; collapsed anatomical regions within the unlooted sample were largely present or disturbed, while collapsed anatomical regions within the looted sample were overwhelmingly classed as absent (Table 5). Counts of the number of observations in each area are listed in Table 5 (note that skull, hand, and foot categories add up to double the sample size because values from the left and the right were collapsed for these categories).

[1] https://stat.ethz.ch/R-manual/R-devel/library/boot/html/cv.glm.html

4.2. Results of Fisher's exact tests

The Fisher's exact tests conducted for the disturbed sample produced only two significant results (Table 6). There were significant differences between the number of elements present versus absent for the neck and right foot, and between the number of elements present versus absent for the neck versus left foot (p-value = 0.035 in both cases). These results reflect that significantly more neck bones are absent than foot bones in looted contexts.

None of the 2 × 2 comparisons of differences between anatomical regions within the unlooted sample were significant. All results from the Fisher's exact test produced p-values >0.05 (Table 7).

The Fisher's exact test that compared the unlooted and looted samples showed significant differences in the proportions of the present vs. disturbed elements for the cranium, mandible and neck, and significant differences in the proportion of present vs. absent elements for the cranium, neck and right hand (Table 8).

CSAR regions were then collapsed in order to increase counts per cell. A second Fisher's exact test comparing the collapsed categories for the unlooted and looted samples showed significant differences in the proportions of present vs. disturbed elements for the skull, neck, and hands, and significant differences in the proportions of present vs. absent elements for all CSAR regions (Table 9).

4.3. Results of cross-validated logistic regression

The results of the cross-validation for the logistic regression model showed an estimated prediction error rate of 0.166, meaning that approximately 17% of the model predictions for known observations were incorrect, while approximately 83% of the model predictions for known observations were correct. The logistic regression model was then used to sort the five observations for which grave condition was unknown into either "unlooted" or "looted" categories (Table 10). As the response variable for grave condition set 1 = looted and 0 = unlooted, we selected 50% as our prediction threshold. Predictions >0.50 led burials to be classed as looted, while predictions <0.50 led burials to be classed as unlooted. This process classified the unknown burial from Tomb H-j 106 as looted, and unknown burials from Tomb I 46 and Q 60 as unlooted. The remaining burials from tombs W-r 7 and H-f were missing information about the taphonomic condition of the neck or feet, and so predictions could not be established.

5. Discussion

Our results suggest that the looted burials from Al-Widay show a quantifiable signature of post-mortem disturbance. In particular, Culturally Significant Anatomical Regions are more likely to be absent or disturbed in looted burials. These results have implications for future research at Al-Widay and in Sudan, and serve as a model for future work on the bioarchaeology of looting.

First, our analyses demonstrated that CSAR elements in looted burials have an equal likelihood of being present, disturbed or absent. Statistically speaking, the cranium, mandible, hands, and feet each preserved a roughly equivalent number of bones in the present, disturbed, and absent taphonomic categories. These results suggest that in the Nubian context, looted burials can be distinguished from unlooted burials by their more variable taphonomic signature. Future research analyzing the patterning of skeletal preservation in looted burials from other regions, and from other time periods will help to establish whether these patterns hold cross-culturally.

Table 6
Results of Fisher's exact test-values for looted sample (p-values).
(P = Present, D = Disturbed, A = Absent, R = Right, L = Left). * = significant.

Cranium	Mandible	Neck	(R) Hand	(L) Hand	(R) Foot	(L) Foot
Cranium PD	1.000	1.000	0.697	1.000	0.252	0.252
Cranium PA	0.712	0.243	0.700	1.000	0.491	0.491
Cranium DA	0.481	0.311	1.000	1.000	0.705	0.705
	Mandible PD	0.664	0.670	1.000	0.403	0.403
	Mandible PA	0.688	1.000	0.478	0.176	0.176
	Mandible DA	1.000	0.725	0.296	1.000	1.000
		Neck PD	1.000	1.000	0.187	0.187
		Neck PA	0.678	0.233	0.035*	0.035*
		Neck DA	0.495	0.179	0.704	0.704
			(R) Hand PD	1.000	0.116	0.116
			(R) Hand PA	0.450	0.158	0.158
			(R) Hand DA	0.730	1.000	1.000
				(L) Hand PD	0.252	0.252
				(L) Hand PA	0.722	0.722
				(L) Hand DA	0.459	0.459
					(R) Foot PD	1.000
					(R) Foot PA	1.000
					(R) Foot DA	1.000

While the cranium, mandible, hands, and feet from looted burials showed similar taphonomic patterning, the cervical vertebrae revealed a different preservational signature when compared to the bones of the feet, with the distribution of neck bones from the looted burials showing a greater number of absent neck bones. This underrepresentation of cervical vertebrae could be related to a number of different factors. Looters may have preferentially targeted the neck region in order to access more valuable or symbolically important jewelry. Cervical vertebrae may have been more susceptible to postmortem looting damage than the bones of the cranium or the mandible, leading to breakage by looters, and subsequent poorer preservation and archaeological recovery. Finally, the functional morphology of the cervical vertebrae, combined with differing stages of bodily decomposition when looters accessed the tombs, may have affected the preservation of the neck region. However, because Fisher's exact tests between the bones of the neck, cranium, mandible, and hands showed no significant differences, analysis of the preservation of the cervical vertebrae in a larger sample of burials is necessary in order to identify the causality behind the potentially greater number of absent elements for this region.

The second significant pattern in our results is that all CSAR elements showed similar patterning in the unlooted burials. The pattern of high numbers of present bones, and lower numbers of disturbed and absent bones held across the cranium, mandible, neck, hands, and feet. These results suggest that taphonomy unrelated to looting (e.g. bioturbation, water action) affected all examined anatomical regions in a similar fashion, as the majority of CSAR elements were present for all unlooted burials.

Finally, there are significant differences in the preservation of CSAR elements that distinguish the looted and undisturbed samples. The expanded CSAR categories (Table 8), showed significant differences between the number of present and disturbed elements for the cranium, mandible and neck. The expanded categories also show significant differences between the number of present and absent elements for the cranium, neck, and right hand. The lack of significance when comparing the CSAR elements that are disturbed, relative to elements that are absent, is likely related to the extremely small counts of disturbed or absent bones in the unlooted burials (Fig. 4).

The differences in preservational patterning between the looted and unlooted burials become even starker when CSAR categories are collapsed to increase sample size. The collapsed categories show significant differences between the number of present and disturbed CSAR elements for the cranium, mandible, neck and hands, and significant differences between the number of present and absent CSAR elements for all anatomical regions. Two important conclusions may be drawn from the results of the collapsed tests. First, that the signature that best differentiates looted and unlooted burials is the number of CSAR elements that are present relative to the number of CSAR elements that are absent.

Table 7
Results of Fisher's exact tests for unlooted sample (p-values).
(P = Present, D = Disturbed, A = Absent, R = Right, L = Left, X = 2 × 2 contained more than one cell with a value of 0).

Cranium	Mandible	Neck	(R) Hand	(L) Hand	(R) Foot	(L) Foot
Cranium PD	1.000	X	0.085	0.085	0.462	0.462
Cranium PA	X	X	0.183	0.183	0.222	0.222
Cranium DA	X	X	X	X	X	X
	Mandible PD	1.000	0.306	0.306	1.000	1.000
	Mandible PA	X	0.199	0.199	0.480	0.480
	Mandible DA	X	1.000	1.000	1.000	1.000
		Neck PD	0.085	0.085	0.462	0.462
		Neck PA	0.183	0.183	0.222	0.222
		Neck DA	X	X	X	X
			(R) Hand PD	1.000	0.590	0.590
			(R) Hand PA	1.000	1.000	1.000
			(R) Hand DA	1.000	1.000	1.000
				(L) Hand PD	0.590	0.590
				(L) Hand PA	1.000	1.000
				(L) Hand DA	1.000	1.000
					(R) Foot PD	1.000
					(R) Foot PA	1.000
					(R) Foot DA	1.000

Table 8
Results of Fisher's exact tests, unlooted vs. looted (p-values).
(Expanded categories, * = significant).

	Cranium	Mandible	Neck	Hand (R)	Hand (L)	Foot (R)	Foot (L)
Present vs. disturbed	0.002*	0.050*	0.004*	0.100	0.130	0.330	0.330
Present vs. absent	0.001*	0.000	0.000*	0.015*	0.099	0.129	0.129
Disturbed vs. absent	1.000	0.333	1.000	0.618	1.000	1.000	1.000

Because all collapsed anatomical regions showed significant differences between the looted and unlooted sample for this comparison, collapsed categories were used when constructing the logistic regression model. Second, the results for the collapsed comparison suggest that our sample of 36 burials of known grave condition was likely too small to identify asymmetrical patterning (i.e. differences between the right and left sides of the body). Further work analyzing larger samples of known condition has the potential to address symmetrical or asymmetrical patterning in skeletal preservation.

Finally, the low estimated predicted error that resulted from cross-validation of the logistic regression model supports the patterns identified by the Fisher's exact tests. Using only presence and absence data for the four collapsed anatomical regions, the model was able to correctly sort 83% of the observations into looted and unlooted categories. The high level of accuracy in differentiating looted and unlooted burials, combined with the rapidity of skeletal inventory of CSAR elements, make this an important method for archaeologists and bioarchaeologists working in contexts where looting is a concern. Based on these statistical results it is possible to reconstruct grave condition ("looted" or "unlooted") using excavation photographs of in situ human remains, skeletal inventory, or preferably a combination of both lines of evidence.

Within the context of Nubian archaeology and bioarchaeology in Sudan, the ability to reconstruct burial condition is key; looting is a common occurrence throughout antiquity and greatly affects both excavations and laboratory analyses of mortuary sites. However, this method was tested on a small sample, and multi-site future comparative multi-site tests would strengthen this model. Examining variability in the impact of looting on skeletal preservation is another much-needed step, and future work assessing the taphonomic effects of looting in culturally and geographically distinct regions is necessary. Recent interest in looting due to regional civil unrest, military occupations, and governmental changes has already begun to increase scholarly inquiry into complex looting practices (Casana, 2015), and we anticipate continued anthropological research will yield ethnographic and archaeological data on the variability of looting practices and their historical trajectories. Additionally, if this approach is extended to sites where levels of skeletal preservation are high, similar analyses that assess fracture patterns in conjunction with absolute and relative dating could be used to investigate the timing of looting relative to local and regional historical trajectories, allowing archaeologists to develop a more nuanced understanding of the economic, political, and social factors that precipitated looting activity in the past.

6. Conclusions

The study of looting in the recent and archaeological past has the potential to inform bioarchaeological understandings of burial taphonomy and anthropological approaches to heritage management and preservation. The taphonomic patterning of looted human skeletal remains is directly related to the relationship between looters' expectations and the material they loot (i.e. their understanding of past cultural practices), in addition to the nature of the material remains deposited as part of mortuary practices in the past. Aside from contributions to the study of looting practices, archaeologists are making substantial contributions to the study of destruction and looting associated with contemporary political movements (Al-Houdalieh, 2012; Azam, 2002; Casana, 2015; Emberling and Hanson, 2008; Keenan, 2005).

We provide a targeted bioarchaeological method that assesses looting using the taphonomic condition of specific regions of the human skeleton. Identifying Culturally Significant Anatomical Regions is a cornerstone of this method as it allows the approach to be tailored to temporally and geographically distinct archaeological contexts. The CSAR approach has the additional benefit of minimizing osteological data collection as full skeletal inventories are not required. Our method uses a basic statistical test to identify significant differences in looted and unlooted burials where grave condition is known. The results of these tests were then used to build a logistic regression model capable of categorizing unknown observations. The CSAR model provides a template that can be used in a broad range of archaeological contexts, and compliments the recent advances in archaeological methodologies in remote sensing, which are focused on approaches to looting in the historic and contemporary past (Contreras, 2010; Contreras and Brodie, 2010; Casana, 2015; Stone, 2008).

Table 9
Results of Fisher's exact tests, unlooted vs. looted (p-values).
(Collapsed categories, * = significant).

	Skull	Neck	Hands	Feet
Present vs. disturbed	0.000*	0.004*	0.021*	0.086
Present vs. absent	0.000*	0.000*	0.001*	0.026*
Disturbed vs. absent	0.382	1.000	0.481	1.000

Acknowledgements

The authors thank Geoff Emberling at the University of Michigan for access to unpublished excavation data and comments on a previous draft of this paper, Susan Antón at New York University for facilitating collections access, the project's field osteologist Megan Ingvoldstad, Thomas James for unpublished spatial data and kite photographs, Corey Powell at the University of Michigan for statistical consultation and assistance with the cross-validation script in R, Kimberly Spurr at Past Peoples Consulting, LLC for references on patterns of skeletal completion at military cemeteries, the University of Michigan Department of Anthropology for travel grant support, and two anonymous reviewers for their thoughtful comments and suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2016.09.011.

Table 10
Linear regression prediction for unknown observations.
(Empty cells indicate missing data.)

Grave Condition	Tomb ID	Skull	Neck	Hand	Foot	Prediction
Unknown	H-j 106	A	A	A	A	1.000
Unknown	I 46	P	P	P	P	0.080
Unknown	Q 60	P	P	A	A	0.250
Unknown	W-r 7	P	P	A		NA
Unknown	H-f	P		P	A	NA

References

Al-Houdalieh, S.H., 2012. Archaeological heritage and spiritual protection: looting and the Jinn in Palestine. J. Mediterr. Archaeol. 25, 99–120.

Azam, J.P., 2002. Looting and conflict between ethnoregional groups: lessons for state formation in Africa. J. Confl. Resolut. 46, 131–153.

Bianchi, R.S., 2004. Daily Life of the Nubians. Greenwood Press, Westport, Connecticut.

Bocquet-Appel, P., Naji, S., 2006. Testing the hypothesis of a worldwide Neolithic demographic transition: corroboration from American cemeteries. Curr. Anthropol. 47, 341–365.

Bonogofsky, M., 2003. Neolithic plastered skulls and railroading epistemologies. Bull. Am. Sch. Orient. Res. 331.

Botti, G., Peet, E.T., 1928. Il giornale della necropoli de Tebe. Fratelli Bocca, Turin, Torino.

Bricker, H., 1976. Upper Palaeolithic Archaeology. Annu. Rev. Anthropol. 5, 133–148.

Buikstra, J., Ubelaker, D., 1994. Standards for data collection from human skeletal remains. In: Buikstra, J.E., Ubelaker, D.H., Aftandilian, D. (Eds.), Proceedings of a Seminar at the Field Museum of Natural History. Fayetteville, Arkansas.

Casana, J., 2015. Satellite Imagery-Based Analysis of Archaeological Looting in Syria. Near East. Archaeol. 78, 142–152.

Conlee, C., 2011. An exploration of looted Middle Horizon tombs from Nasca. Ñawpa Pacha 31 (1), 45–54.

Contreras, D., 2010. *Huaqueros* and remote sensing imagery: assessing looting damage in the Virú Valley, Peru. Antiquity 84, 544–555.

Contreras, D., Brodie, N., 2010. The utility of publicly-available satellite imagery for investigating looting of archaeological sites in Jordan. Journal of Field Archaeology 35 (1), 101–114.

D'Auria, S., 1982. Excavations at Kerma: Subsidiary Nubian Graves Excavated by the Late George A. Reisner in 1915–1916, Not Included in His Excavations at Kerma, I-III and IV-V, Published by Him in the Harvard African Studies, V and VI, 1923, Part 6. Department of Egyptian and Ancient Near Eastern Art, Museum of Fine Arts.

Emberling, G., 2011. Nubia: Ancient Kingdoms of Africa. The Institute for the Study of the Ancient World. NY, New York.

Emberling, G., Hanson, K., 2008. Catastrophe! The Looting and Destruction of Iraq's Past. Print. ed. Oriental Institute Museum Publications 28, Chicago.

Emberling, G., Williams, B.B., 2008. Annual Report 2007–2008: Nubian Expedition Chicago.

Emberling, G., Williams, B.B., 2010. The Kingdom of Kush in the 4th Cataract: archaeological salvage of the Oriental Institute Nubian Expedition 2007 Season. Part I. Preliminary report on the sites of Hosh el-Guruf and El-Widay, African Reports. Proceedings of the International Conference, The Fourth Cataract Archaeological Salvage Projects 1996–2009. Wloclawek, Poland.

Emberling, G., Williams, B.B., Ingvoldstad, M., James, T.R., 2014. In: Anderson, J.R., Welsby, D.A. (Eds.), Peripheral vision: identity at the margins of the Early Kingdom of Kush. The Fourth Cataract and Beyond: Proceedings of the 12th International Conference for Nubian Studies. British Museum Publications on Egypt and Sudan, Leuven - Paris - Wapole, MA, pp. 329–336.

Goff, A., 2011. Report of skeletal remains excavated at Fort Craig Post Cemetery. Fort Craig Project, New Mexico, Upper Colorado Region. USDI Bureau of Reclamation, Denver.

Heinlen, M., Gray, M.A., 2010. Deathways and Lifeways in the American Southwest: Tucson's Historic Alameda-Stone Cemetery and the Transformation of a Remote Outpost into an Urban City Tucson.

Ingvoldstad, M.E., 2009. Manuscript Report: Human Skeletal Remains from Al-Widay I, Al-Widay II, and Umm Gebir Island Cemeteries, Sudan.

Karr, L., Outram, A., 2012. Tracking changes in bone fracture morphology over time: environment, taphonomy, and the archaeological record. J. Archaeol. Sci. 39, 555–559.

Kaulicke, P., Fehren-Schmitz, L., Kolp-Godoy, M., Landa, P., Loyola, Ó., Palma, M., Tomasto, E., Vergel, C., Vogt, B., 2012. Implicancias de un área funeraria del Periodo Formativo Tardío en el departamento de Ica. Boletín de Arqueología 13, 289–322.

Keenan, J., 2005. Looting the Sahara: the material, intellectual and social implications of the destruction of cultural heritage (briefing). J. North African Stud. 10, 471–489.

Kennedy, J., 1978. Nubian death ceremonies. Nubian Ceremonial Life, pp. 224–251.

Kersel, M.M., Chesson, M.S., 2013. Looting matters: early bronze age cemeteries of Jordan's Southeast Dead Sea plain in the past and present. Oxford Handb. Archaeol. Death Burial.

Knüsel, C.J., Outram, A.K., 2004. Fragmentation: the zonation method applied to fragmented human remains from archaeological and forensic contexts. Environ. Archaeol. 9, 85–97.

Kuijt, I., Özdoğan, M., Pearson, M., 2009. Neolithic skull removal: enemies, ancestors, and memory. Paléorient 35, 117–127.

Millaire, J., 2004. The manipulation of human remains in Moche society: delayed burials, grave reopening, and secondary offerings of human bones on the Peruvian North Coast. Lat. Am. Antiq. 15, 371–388.

Nelson, A., 1998. Wandering bones: archaeology, forensic science, and moche burial practices. Int. J. Osteoarchaeol. 8, 192–212.

Nielson, V., Nouchiravan Dianaty, T., 1970. The Nubian Skeleton Through 4000 Years: Metrical and Non-metrical Anatomical Variations. Andelsbogtrykkeriet, Odense, Denmark.

Osterholtz, A.J., Baustian, K.M., Martin, D.L., 2014. Commingled and Disarticulated Human Remains: Working Towards Improved Theory, Method, and Data. Print. ed. Springer, New York.

Paner, H., Pudlo, A., Borcowski, Z., 2010. In: Godlewski, W., Lajtar, A. (Eds.), Funerary customs in the GAME Fourth Cataract concession in the light of radiocarbon analysis. Between the Cataracts: Proceedings of the 11th Conference of Nubian Studies. PAM Supplement Series 2.1, Warsaw, Poland, pp. 61–76.

Peet, E.T., 1930. The Great Tomb-Robberies of the Twentieth Egyptian Dynasty; Being a Critical Study with Translations and Commentaries of the Papyri in Which These are Recorded. First. ed. Clarendon Press, Oxford.

Reisner, G.A., 1923. Excavations at Kerma: Parts IV–V. 2. Peabody Museum of Harvard University.

Roth, M.T., 1995. Law Collections From Mesopotamia and Asia Minor. Scholars Press, Atlanta.

Sneddon, A.C., 2002. The Cemeteries at Marki: Using a Looted Landscape to Investigate Prehistoric Bronze Age Cyprus. BAR International Series. Archaeopress, Oxford.

Stodder, A.L., Osterholtz, A.J., 2010. Analysis of the processed human remains from the Sacred Ridge site: methods and data collection protocol. In: Perry, E.M., Stodder, A.L., Bollong, C.A. (Eds.), Animas-La Plata Project: XV-Bioarchaeology. SWCA Environmental Consultants, Phoenix, pp. 243–278.

Stone, E.C., 2008. Patterns of looting in Southern Iraq. Antiquity 82, 125–138.

Strouhal, E., 1973. Five plastered skulls from pre-pottery Neolithic B Jericho: anthropological study. Paléorient 1, 231–247.

Tward, A., Patterson, H., 2002. From grave robbing to gifting: cadaver supply in the United States. JAMA 287 (9), 1183.

van Velzen, D.T., 1996. The world of Tuscan tomb robbers: living with the local community and the ancestors. Int. J. Cult. Prop. 5, 111–126.

Webb, J.M., Frankel, D., 2009. Exploiting a damaged and diminishing resource: survey, sampling and society at a Bronze Age cemetery complex in Cyprus. Antiquity 83, 54–68.