EXPLORING THE USE OF ACTUALISTIC FORENSIC TAPHONOMY IN THE STUDY OF (FORENSIC) ARCHAEOLOGICAL HUMAN BURIALS

An actualistic experimental research programme at the Forensic Anthropology Center at Texas State University (FACTS), San Marcos, Texas

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Introduction

The recovery of buried human remains from both forensic and archaeological contexts involves careful excavation with the aim of securing as much evidence as possible pertaining to the circumstances surrounding the death and burial of the deceased individual(s). Understanding
The use of actualistic forensic taphonomy

the formation processes of human burials and distinguishing the effects of human modification of the remains and their surroundings from taphonomic processes is key to reconstructing the sequence of events leading up to death and burial. This requires careful consideration of the effects of taphonomic processes on the depositional environment and the remains.

The taphonomy of the grave and buried body has become an increasingly important area of research within mortuary and funerary archaeology. The French-developed field of archaeothanatology combines taphonomic principles with knowledge of anatomy and human decomposition to interpret the spatial configuration of bones in a deposit. Archaeothanatology has developed hypotheses of the relative sequence of joint disarticulation during decomposition and the spatial displacement of the bones in the burial environment to distinguish natural processes from funerary treatment. The anatomical relationships of the bones (articulated or disarticulated) and the direction and distance of bone displacement are carefully assessed and used to infer, among others, whether or not bones are in a primary or secondary position (Duday, 2009), distinguish collective burials (bodies accumulated over time) from multiple burials (simultaneous deposition of bodies) (Castex and Blaizot, 2017), reveal the presence of decayed body containers (Harris and Tayles, 2012; Ortiz et al., 2013), determine body treatment and/or stage of decomposition upon burial (e.g. mummification; Maureille and Sellier, 1996), identify post-mortem and post-depositional manipulation of the body and grave (e.g. intentional removal of bodies/body parts) (e.g. Valentin et al., 2010), and establish if burial occurred immediately after death or was delayed (Nelson, 1998).

The basis of archaeothanatological principles, understanding how taphonomic processes affect the preservation and spatial patterning of human remains, is a premise that is shared with the field of forensic taphonomy, a subfield of forensic anthropology. With regards to buried human remains, forensic anthropology and archaeothanatology have two important objectives in common: (1) distinguishing taphonomic alterations from human modification of the remains and their context, and (2) reconstructing the sequence and chronology of events surrounding death and deposition. Archaeothanatology has the potential to aid forensic investigation by helping to reconstruct the sequence of events that gave rise to a burial, helping determine the medico-legal significance of remains, assisting with identifying the modus operandi of perpetrators, and by providing highly detailed information on the manner and timing of treatment of the body. In medico-legal contexts involving clandestine burials (e.g. homicide cases) or mass graves, information on body treatment can be informative with regard to the methods and means of killing and burial, attempts to conceal or destroy evidence, and potentially as an aid to identify the perpetrator(s). Because of this capacity, some researchers have argued for the use of archaeothanatological methods in medico-legal contexts (Duday and Guillou, 2006; Castex and Blaizot, 2017). However, this use is impeded by the fact that its methods are currently not validated by data collected under controlled conditions (Mickleburgh, 2018; Schotsmans et al., Chapter 27, this volume). For archaeothanatology to be used in medico-legal contexts, its methods must be tested. Systematic studies that control conditions to measure the effects of specific variables and use robust sample sizes are needed. Sizable samples and repetition/replication of experiments reduces the effects of chance variation on the results, making statistical inferences more reliable (Simmons, 2017; Mickleburgh, 2018; Mickleburgh and Wescott, 2018). The use of body analogues (e.g. pigs) in human disarticulation studies is not an option since studies of non-human disarticulation sequences indicate that they differ by species (Hill, 1980).

This chapter reviews some of the experimental forensic taphonomic research to improve the interpretation of human remains in both traditional and forensic archaeological contexts, and present the findings of an innovative on-going research programme undertaking actualistic
taphonomic experiments to improve and develop archaeothanatological methods. The research programme is the first systematic study of the joint disarticulation sequence and spatial patterning of human remains allowed to decompose under controlled conditions. The ultimate aim of the programme is to lay the foundations for an actualistic framework to further develop archaeothanatology for application in both traditional archaeological as well as medico-legal contexts. Furthermore, this chapter presents the method and research protocol of 3D documentation and analysis that was developed specifically to study the spatial relation and movement of human remains throughout the process of soft tissue decomposition and skeletal disarticulation. Finally, the important avenues for future development in this area of research are outlined.

The research programme of experimental forensic taphonomy for (forensic) archaeological applications

The on-going forensic taphonomy research programme at the Forensic Anthropology Center at Texas State University (FACTS) comprises a series of controlled actualistic taphonomic experiments developed to examine the effects of different variables on human decomposition, skeletal disarticulation and spatial patterning of bones within their depositional environment. This programme uses documented (i.e. with known demographic and health data) human bodies donated to FACTS in its experiments. FACTS receives whole body donations for scientific research purposes under the Texas Revised Uniform Anatomical Gift Act (National Conference of Commissioners on Uniform State Laws, 2009, Chapter 692A). Body donations are exclusively acquired through the expressed and documented willingness of the donors and/or their legal next-of-kin. Body donations are made directly to FACTS, and donors and/or their next-of-kin are aware that donations are used for taphonomic studies. Demographic, health and other information are provided through a questionnaire completed by the donor or legal next-of-kin. The data are securely curated by FACTS. The body donation programme complies with all legal and ethical standards associated with the use of human remains for scientific research. Body donations are placed at the Forensic Anthropology Research Facility (FARF), an outdoor human decomposition research facility managed by FACTS and located in the Texas Hill Country, near San Marcos.

The programme focuses on replication of two distinct medico-legal/archaeological contexts: depositions of individuals and mass depositions. The programme examines fundamental taphonomic models used in archaeothanatology to reconstruct the original mode of deposition and ultimately aims to improve recognition of human and taphonomic alterations of a grave.

The programme uses an actualistic methodology. Actualism posits that contemporary knowledge can be applied to understand the past (uniformitarianism) and that there is a relationship between process and product. Actualistic studies have a long history in forensic anthropology, archaeology and palaeontology (; Behrensmeyer and Kidwell, 1985; Lyman, 1994; Bass, 1997; Pobiner and Braun, 2005; Shirley et al., 2011; Wescott et al., 2018). Actualistic studies can take different forms, but they often control for chosen observational parameters and examine the link between natural processes that permit deductive interpretation (Sorg and Haglund, 2002). Such studies replicate the taphonomic effects by reproducing hypothesised causal events in a relatively controlled situation. Since the programme studies the effects of different deposition types and stages of decomposition at placement on disarticulation and spatial bone patterning, variables known or thought to affect these processes, including body position, soil type, presence and type of clothing, and burial pit shape and dimensions, are controlled. Precautions are taken to ensure that these variables are the same for each experiment.
Archaeothanatological models

In this contribution, a distinction is made between sequences of joint disarticulation that have been defined based on post-hoc examination of a burial, as in traditional archaeothanatology (Duday, 2009), and observations of the actual process and sequence of disarticulation that are made during forensic taphonomic experiments on human decomposition.

Archaeothanatology makes use of a hypothesised sequence of joint disarticulation to distinguish natural from anthropogenic or bioturbation/scavenging processes (Duday, 2009). In the absence of actualistic taphonomic observations on the variables influencing the final bone position in the grave, this sequence is based on inferences resulting from repeated observation of patterns in the archaeological record and on the hypothetical understanding of joint durability based on their strength and type and amount of soft tissue in life. This model distinguished between ‘labile’ and ‘persistent’ joints. Labile joints are considered to be relatively unstable and disarticulate relatively soon after death and are therefore frequently found out of anatomical position, unless there is supporting burial soil. They include joints held together primarily by soft tissue attachments, such as the hyoid, temporo-mandibular, patellar, scapulo-thoracic, costo-sternal joints and the small bones of the hands and feet (Roksandic, 2002; Duday, 2009; Knüsel, 2014). The labile articulations, in particular, are used to assess if a burial is a primary or secondary one because, if these articulations are preserved, it is considered that burial occurred rapidly after death (Duday, 2009). Persistent joints are major weight-bearing joints with ligaments that are thought to resist disarticulation and frequently maintain their anatomical position. Notable exceptions to the labile/persistent distinction have been identified. The wrist is considered to be a strong joint in life due to the numerous ligaments connecting the carpal bones, but the ligaments are thought to decompose rapidly after death. The acetabulo-femoral (hip) joint was originally considered to be persistent due to its important weight-bearing function, but is now considered to be labile as the joint is maintained by thin capsular ligaments that can decay rapidly (Duday, 2009; Knüsel, 2014; Knüsel and Robb, 2016). In sum, the hypothetical sequence of joint disarticulation used in archaeothanatology is based on: 1) repeated post hoc observation of the anatomical relationships of bones in archaeological burials, and 2) the hypothesis that durability during decomposition is (partly) determined by the nature of soft tissue structures and biomechanical function. The use of post hoc observations of archaeological burials is problematic, however, since the precise variables that produced them are unknown. Appleby (2016) has argued that the hypothesised joint disarticulation order is problematic since the status of joint articulation is used to distinguish primary from secondary burials, but at the same time, the distinction between labile and persistent joints is based on repeated observations in burials interpreted as either primary or secondary. The hypothesis that the durability of joints during decomposition is related to their structure and biomechanical function in life is, as yet, not supported by actualistic taphonomic observations. The archaeologically observed exceptions discussed above (wrist and hip joints) furthermore indicate that the relation between joint strength and function in life and durability after death is not straightforward.

Another important model used in archaeothanatology concerns the relationship between spatial patterning of the bones and open spaces (voids) in the burial environment. Archaeothanatology uses the pattern of displacement of bones out of anatomical relationships to infer the type of ‘burial architecture’ (i.e. grave structure, body containers). Rotation and movement of bones are

1 That is, the framework of observations and ideas resulting in the hypothesised sequence of joint disarticulation and the proposed mechanisms of joint durability.
possible when there is open space within the depositional environment. Movement can occur due to gravity and normal decomposition processes if empty space is already present in the deposit, referred to as ‘primary voids’. Primary open space can be present due to intentionally leaving the pit open throughout decomposition (Hofman et al., 2012), or can be present within body containers such as coffins or woven baskets. ‘Secondary voids’ are created by the decomposition of soft tissues and structural elements such as wrappings or headrests (Duday, 2009). Bone displacement patterns are considered to differ depending on the type of open space: greater displacement is possible when primary open space is present around the body (Ambroise and Perlès, 1975; Duday et al., 1990; Duday, 2009). The presence of primary open space is inferred based on the displacement of bones ‘outside of the original body volume’. Any displacement within this space, it is reasoned, could result from the creation of secondary voids once the soft tissues of the body have decomposed. However, assessment of the position of the bones as within or outside of the original body volume is complicated due to the fact that the soft tissue volume can differ considerably between individuals of different size/corpulence.

In addition, the presence of both primary and secondary open spaces is related to soil type. As the soft tissues (and perishable burial architecture) decompose over time, they are replaced by soil. Two forms of filling are generally distinguished depending on soil type and are related to specific movements of the bones: (1) delayed filling, in which the decomposition of the soft tissues of, for example, the thorax and abdomen, creates a void in the deposit which is maintained for some time (Duday, 2009: 52–53), and (2) progressive filling, in which sediment continually fills newly formed voids (‘hourglass effect’) (Duday et al., 1990; Duday, 2009: 54). Delayed filling is often associated with the ‘flattening’ of the ribcage and is also suggested to be the cause of ‘hyper-flexed’ burials, in which the skeleton of a body interred in flexed position takes on a very compact and hyper-flexed position due to the ‘closing of the inter-segmental angles’ of the joints as soft tissues decay (Duday, 2009: 53).

Some archaeological studies have suggested that the stage of decomposition of the body upon deposition can affect the order of disarticulation and displacement of bones. Burial in a mummified state is thought to lead to minimal bone displacement when compared to burial in a fresh stage of decomposition because the amount of soft tissue in a mummified body is much reduced and, therefore, will not create substantial secondary open space (Aoudia et al., 2014). Based on this, it can be hypothesised that burial of bloated bodies (i.e. in active decomposition, bloat phase) will result in the creation of a greater volume of secondary open space and thus greater potential bone displacement. Researchers have also identified ‘anomalous’ disarticulation of the bones, where labile joints remain articulated and persistent joints appear disarticulated. This phenomenon is referred to as ‘paradoxical disarticulation’ (Maureille and Sellier, 1996; Sellier and Bendezu-Sarmiento, 2013; Knüsel and Robb, 2016;) and has been suggested to be an indication of desiccation/mummification, which initially prevents disarticulation and bone movement, but can lead to paradoxical disarticulation if mummified remains are subsequently manipulated so that persistent joints become disarticulated, while labile joints are maintained (Maureille and Sellier, 1996; Sellier and Bendezu-Sarmiento, 2013).

The actualistic experiments at the forensic anthropology research facility (FARF)
The actualistic experiments at FARF were designed to collect a body of data suitable for statistical analysis, distinguishing the effects of specific variables and replication studies in other environments. An important objective of the experiments was to test the two fundamental taphonomic scenarios used in archaeothanatology: (1) the sequence of natural joint disarticulation and (2) the relation between spatial displacement of bones and primary and secondary voids in the burial
environment. In addition, the programme examines the effects of the stage of decomposition of the body upon deposition on the disarticulation sequence and spatial patterning of the bones over time. Joint disarticulation and bone movement were documented in bodies placed in open and closed pits (i.e. buried), in different stages of decomposition and in individual deposits and mass graves. Variables that – based on archaeothanatological research – are thought to affect the final position of the bones in the deposit, such as soil type, the position of the body, and the shape and dimensions of the burial, were controlled in the experiments.

The following hypotheses were tested through the actualistic experiments:

1. The process of joint disarticulation of the human skeleton is predictable and ordered.
   a. The order of joint disarticulation during decomposition of the human body is determined by the properties of joint tissues and biomechanical function of the joint.
   b. The order of joint disarticulation differs depending on body position.
2. The spatial distribution of bones is different between decomposition in a void and a closed space (i.e. primary open space vs. secondary open space).
3. The spatial patterning of bones (i.e. amount and direction of displacement of the bones) differs depending on original body position.
4. The spatial patterning of bones is different between bodies interred in an early stage of decomposition and bodies interred in the active decomposition (bloat) stage or mummified.
5. Bone displacement is different between mass graves and individual burials.

**Environment**

The terrain at FARF consists of shallow clay-rich soil overlying deposits of limestone with grassland punctuated by woodlands of primarily oak and cedar trees (Barnes et al., 2000). The region has a semi-humid climate with hot summers and moderate winters. Bodies exposed to the sun and wind commonly desiccate/mummify. Annual precipitation is close to average for the United States but the region experiences droughts and flash flooding. The predominant vegetation consists of scrub bushes, ash juniper and Texas live oak trees. The soils in the Texas Hill Country are primarily shallow, stony and overlay Cretaceous limestone. At FARF, the two types of soils are (1) Rumple-Comfort Association, Ungulating (RUD) and (2) Comfort-Rock Outcrop Complex, Undulating (CrD). Both are characterised by relatively shallow, rocky, clay topsoils. Both soils are also relatively alkaline with high carbonate content and relatively low organic matter. Because of the high clay and rock content, the soils at FARF have relatively low permeability to air and water movement (Carson, 2000; Gillham et al., 2003; Fancher et al., 2017).

As explained above, the type of soil in a grave is thought to affect bone movement by either preserving voids in the grave or not, depending on soil properties (i.e. texture, permeability and moisture carrying capacity). Based on the results of the programme thus far, the clay-rich soil at FARF ensures that secondary voids in the burial environment of shallow single graves are maintained long enough for the body to fully skeletonise within the void, leading to displacement of bones out of anatomical relation within the dimensions of the void (Mickleburgh, 2018; Mickleburgh and Wescott, 2018). The programme currently does not include actualistic study of the effects of different soil types, but to ensure that soil type is the same for each experiment, placements are done only in one area of FARF with RUD type soil. Furthermore, a basic analysis of soil properties was undertaken prior to each cadaver placement to ensure consistency of soil conditions.
Body donations

At the time of writing, 20 human body donations have been studied throughout the complete process of decomposition until skeletonisation and retrieval of the remains from the outdoor decomposition facility (described below). Continuation of the programme will expand the number of individual placements in primary voids as well as burials in both flexed and extended body positions. Furthermore, at least one mass deposition experiment will start in spring 2020. Six individuals were placed simultaneously in a fresh stage of decomposition in overlapping body positions and then covered with soil. Furthermore, photographic data is available from over 200 individuals from the past eight years previously recorded at FARF as a part of the FACTS longitudinal outdoor human decomposition study. These bodies were placed uniformly in an extended, supine position on the surface. Since these data were not collected with the aim to assess joint disarticulation and bone movement, they are used exclusively as an additional resource alongside the experiments in the programme, i.e. to assess potential differences related to seasonal weather, and age-at-death and health status of the body donors.

Methods

Prior to placement of the body donations, anthropometric variables, including stature, body weight, and chest, abdomen and thigh circumference were collected. Bodies that had been autopsied or had conditions that could affect normal decomposition and/or disarticulation were excluded from the programme. The use of obese donors (i.e. BMI >30) is also avoided since obesity can potentially affect the rate of soft tissue decomposition (Zhou and Byard, 2011) and will likely affect bone movement within secondary voids. As a part of the 3D documentation and analysis methods developed for the programme, the mass grave cadavers were scanned using a full-body post-mortem CT scan, which provided highly precise anthropometric measurements as well as 3D models of the entire skeleton.

The dimensions and shape of placement pits were controlled and kept uniform. Individual burial pits for flexed bodies measure 65 cm by 95 cm wide and 70 cm deep. Mass grave pit(s) measure 200 cm by 200 cm wide and 120 cm deep. Cadavers placed in open pits are covered with a wire cage to prevent scavenging by large mammals and birds. While this can be an important taphonomic variable, it is beyond the scope of the current study to examine scavenging effects. Exposed (i.e. unburied) bodies were placed under the tree canopy to reduce solar and wind desiccation, which is common in open areas of FARF (Wescott et al., 2018). Clothing is known to affect decomposition rate, largely because of its restricting effects on insect access (Dautartas, 2009; Card et al., 2015). Clothing can also restrict bone movement, although the precise effects of different types of clothing and textiles on bone displacement are not well understood (Bouquin et al., 2012). In order to restrict the number of variables affecting the spatial configuration of bones, all body donations studied to date have been unclothed.

The process of decomposition and disarticulation in an open pit and surface placements is documented on a daily basis using photography and a written form, providing disarticulation sequence data that is used to test hypotheses 1, 1a and 1b. The written form includes documentation of the stage of decomposition, joint disarticulation and taphonomic factors such as insect activity and weather conditions. Decomposition is quantified using the total body score (TBS) method following the guidelines in Megyesi et al. (2005) since this method is the most commonly used in forensic cases as well as for the collection of longitudinal decomposition data at most outdoor decomposition facilities worldwide. The joints are examined and recorded as articulated, expanded, or disarticulated each day for the duration of the study, or until all bones are in stable positions following Mickleburgh and Wescott (2018).
To determine if there is a correlation between disarticulation sequence and joint properties, the individual joints are classified according to their structure (i.e. synovial, fibrous or cartilaginous), functional classification (i.e. diarthrosis, synarthrosis or amphiarthrosis) and joint type (i.e. synovial, sutural, syndesmosis, symphysial, gomphosis and synchondrosis) using Standring (2015). These categories are used in statistical analyses of the disarticulation sequence data in order to test the hypothesis that the order of joint disarticulation is determined by the structure or biomechanical function of the joint in life (hypothesis 1a).

Documentation of bone movement over time is achieved using a combination of 3D techniques to preserve, visualise and analyse spatial data. The research protocol used, described in detail above, is used to test hypotheses 2, 3, 4 and 5. In addition, time-lapse videos were recorded of both flexed body open pit placements throughout the first months of decomposition.

**Body placement**

*Open pit placement:* two individuals were placed in a fresh stage of decomposition in flexed positions in small, oval-shaped pits that remained open throughout the duration of the experiment to study the effects of a primary open void. The dimensions of the pits were approximately 65 cm by 95 cm and 70 cm deep. One of these two body donations was placed in an upright, seated position (for a full explanation of this experiment, see Mickleburgh and Wescott, 2018), and the other in a flexed supine position (Figure 28.1). Both body donations were recovered from FARF once skeletonisation was complete and bones had moved into stable positions (i.e. displacement had ceased; after approximately 7 months and 2 years, respectively).

*Surface placement:* Fifteen fresh stage body donations were placed in extended supine positions on the soil surface and observed from January to June 2018.

*Burial:* Two fresh stage body donations were placed in small, oval-shaped pits (65 cm by 95 cm and 70 cm deep) and were immediately covered with soil. One was placed in a seated position, the other in a flexed supine position. These placement modes permit examination of the effects of secondary voids and body position on bone displacement. A third body donation was allowed to mummify by solar and wind desiccation in a flexed body position by placing the body on a raised platform in an exposed area of FARF. The raised platform permitted maximum sun exposure and airflow around the body and consisted of coarse metal mesh to permit fly maggots to fall off the body but not crawl back up onto the body (insect activity is a major factor in soft tissue loss before desiccation occurs). Once the body donation was fully desiccated, it was buried in a flexed supine position in a small, oval-shaped pit (65 cm by 95 cm and 70 cm deep). All three burials were excavated after approximately two years.

**3D documentation and analysis**

Crucial to understanding the movement and patterning of bones is the recording of spatial information on the position and movement over time of the different body/skeletal elements. The documentation methods used in this study were designed to preserve spatial information and provide 3D data that can be used for both quantitative and qualitative analysis, visualisation and virtual animation (Mickleburgh et al., 2018). The research protocol for spatial documentation and analysis of skeletal disarticulation and bone movement over time that was developed for the purposes of this research programme and used to date is presented here. Modifications to this research protocol for ongoing and future research have been made based on the initial research results, as well as on the specific research requirements of the mass grave context (see above).
Bone position over time was recorded using a combination of 3D techniques to preserve, visualise and analyse spatial data. Digital photography provided data for the production of 3D models using Structure from Motion (SfM) photogrammetry (Figure 28.2). Agisoft Photoscan software was used to produce 3D models from 2D digital images. These models permitted non-destructive and highly detailed (re-)analysis of taphonomic data and the sequence of disarticulation and movement of bones. A grid was established around the burial pits and surface donations, with fixed geo-markers. Open pit and surface placements were documented in this way at weekly intervals. Open-pit experiments were intended to examine the effects of 'primary voids' around the body during decomposition (as in cases where the body was left to decompose in an open

Figure 28.1  The body positions used for the individual body placements (©2020 sarahgluschitz.com)
pit or natural depression). Burials with soil were documented using SfM photogrammetry upon placement and during and after excavation to permit examination of the effects of filled space and ‘secondary voids’ around the body during decomposition.

The sequential 3D models (collected weekly or at placement and excavation of the body) were overlaid to assess spatial changes over time using distance and heat maps in open-source software packages such as Cloudcompare and Meshlab (Mickleburgh et al., 2018). This method was found to be particularly effective in the later stages of decomposition, when the majority of the soft tissue had decomposed. Heat and distance maps provide both qualitative and quantitative information on bone movements and were found to support visualisation of the bone movement very well. However, particularly in earlier stages of decomposition, bone movement is obscured by changes in the soft tissue mass. Understanding bone movement and disarticulation early on in the decomposition process is very important to be able to test and substantiate archaeothanatological insights because the status of ‘labile’ joints is significant in archaeothanatological analysis.

In order to study bone movement throughout all stages of decomposition, a method of 3D reconstruction was developed that enables qualitative and quantitative analysis of the displacement of bones over time from the start of the experiment (i.e. when the body is still fully fleshed). At the end of each actualistic experiment, once the bones of each individual body donation have been cleaned and brought to the osteological lab, 3D models of each individual bone are produced using SfM photogrammetry. In collaboration with an anatomist, the 3D bone models are ‘re-fitted’ into their anatomical position within the soft tissue volume of the body in the 3D models developed weekly during the experiment (Figure 28.3). This technique works well for individuals with normal to low BMI. This permits reconstruction of the position of the bones at weekly intervals throughout the experiment, visualising the position of the bones early on in the experiment when soft tissue is still present. The resulting weekly snapshots of the position...
of the bones of the body are suitable for comparative qualitative analysis. The models also allow for 3D animation of the process of bone movement for over time. Using Maxon Cinema 4D, a comprehensive 3D modelling, motion graphics and animation software studio, 3D animations of the process of disarticulation and bone movement were produced for visualisation, education and outreach purposes (Mickleburgh et al., 2018).

The 3D models created in this manner are also suitable for quantitative analysis of the distance and direction of movement of the bones over time. This is done using 3D GIS analysis. The 3D models are imported into ESRI ArcGIS, ArcScene 10.6 software. 3D polylines are created between pre-defined joint landmarks in order to map the distance between the points of articulation between contiguous bones in the 3D models as well as the same bones in sequential models. The relative displacement of the individual skeletal elements is calculated in distance, direction and rotation of bone displacement. These quantitative data permitted a comparison of displacement patterns between the different test cases (Figure 28.4). As a part of the ongoing actualistic experimental programme, consistent measurements across a large sample will be used to test whether ‘signature’ disarticulation patterns related to specific variables, such as body position, exist.

Results and discussion

Disarticulation sequence

Based on information derived from archaeological burials in temperate climates, it is thought that labile joints disarticulate within a few weeks while persistent joints are maintained for months or years (Duday et al., 1990; Knüsel, 2014). The observations made in 15 body donations placed supine on the soil surface over a period of six months were therefore expected to provide particular insight into the disarticulation of the joints considered to be ‘labile’. However, soft

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Two short prototype examples of such 3D animations can be viewed online at: https://www.youtube.com/watch?v=70GX_NAtthM&feature=em-share_video_user and https://www.youtube.com/watch?v=4YcPZrNnPIc
tissue decomposes more rapidly in Central Texas than in temperate climates (Suckling, 2011), and based on the first results of this research programme skeletal disarticulation appears to progress more quickly in this environment as well, so the results may also inform on disarticulations later in the sequence. The sequences of disarticulation observed in these individuals are visualised in Figure 28.5. Each line in the figure represents one body donation. If disarticulation sequences were similar over time, the lines would be expected to show a similar curve. It is clear from the figure that there is significant variation in the precise timing and sequence of joint disarticulations. Overall, the majority of body donations do show that the temporo-mandibular joints tend to disarticulate first or (in three bodies) as one of the first joints. This observation concurs with models based on archaeological burials. The overall observations and sequences do not appear to concur with the labile-persistent joint model (cf. Schotsmans et al., Chapter 27, this volume).

Study of the two body donations placed in flexed body positions in open pits indicates that body position and architecture (i.e. the shape and dimensions of the pit) affect joint disarticulation due to the associated differences in pressure, gravity and support of the different body parts and bones during decomposition. The sequence of disarticulation observed in the flexed seated body donation (described in detail in Mickleburgh and Wescott, 2018) showed distinct differences from sequences described in the literature. Some joints considered to be labile, such as costo-sternal and left gleno-humeral joints, disarticulated relatively late in the sequence, while...
other joints considered to be persistent (both superior tibio-fibular, right inferior tibio-fibular and atlanto-occipital joints) disarticulated relatively early in the sequence. In the case of the seated body donation, the effects of gravity and pressure related to the vertical body position appeared to be the main variable associated with the sequence of joint disarticulation. Relatively early disarticulation of the temporo-mandibular joint, predicted by the labile/persistent joint model, and also observed in the 15 supine surface donations, was not observed in this seated donation since the upright body position and movement (forward slumping) of the head and upper body throughout decomposition provided support for the joint, thus preventing disarticulation by the effects of gravity (Mickleburgh and Wescott, 2018). The late disarticulation of the costo-sternal joints can be explained both by the body position – the joints were supported in position on the pit floor after forward slumping of the thorax – as well as by age-related ossification of these joints, which maintained the articulations (Figure 28.6).

The sequence of disarticulation in the flexed supine body donation concurs more closely with the labile-persistent joint model, with the temporo-mandibular joint and the cervical vertebrae disarticulating early in the sequence. Nonetheless, this body donation also showed relatively early disarticulation of the right gleno-humeral and tibio-femoral joints (considered persistent). The supine position and open space around the body permitted closing of the inter-segmental angles between the flexed lower limbs as well as the distribution of the smaller bones of the hands and
feet throughout the open pit. The latter was the result of the unstable position of these elements as well as two incidents of heavy rainfall during the experiment.

The fact that burial environment and body position are likely to affect the relative timing of joint disarticulation has been acknowledged previously (Duday et al., 1990; Duday and Guillon, 2006; Duday, 2009). It has been pointed out that there is likely no 'single sequence' to speak of, but varying sequences depending on body position and burial environment (Peressinotto, 2007). Since the archaeological burials on which the model is based largely concern individuals in supine positions with primary voids around the body (i.e. coffin burials), caution must be applied when using it to interpret other burial modes. Despite this, the labile-persistent joint model has been widely applied in the field. The results of actualistic experimental research not only underscore the fact that body position is likely a very important variable affecting joint disarticulation, but also that sequences can be highly variable and complex, and are likely influenced by a number of other variables.

Other observations made during the course of the research thus far indicate that current knowledge and models derived from archaeological burials may not capture the entire process of skeletal disarticulation and account for all variables (Mickleburgh, 2018; Mickleburgh and Wescott, 2018). Some cases of ‘re-articulation’ after initial disarticulation of joints were observed, a process that is not accounted for in the labile/persistent disarticulation model. In some joints, stretching of the connective soft tissues (‘joint expansion’) was observed for a number of days before disarticulation. Stretching was influenced by body position, gravity and moisture/humidity in the depositional environment. Bones were no longer in anatomical relation and orientation but remained connected and supported in position by soft tissues. The lack of anatomically correct relationships between bones does not, therefore, always mean connective tissues were completely decomposed. These observations are significant because during excavation, the factors that determined the final position of the bones would not be discernible. The fact that disarticulation had taken place prior to re-articulation could not be established based on the final

Figure 28.6  A portion of the upper thorax of body donation 1 showing the posterior aspect of the sternum (right arrow) and articulated left 5th–7th costo-sternal joints (left arrow) on day 51 of the experiment
position of the bones, meaning that archaeological burials may not always accurately reflect the joint disarticulation sequence. Furthermore, archaeothanatology relies, among other things, on the ‘unsupported’ position of bones to determine the presence of primary/secondary voids in the grave, and/or to determine whether or not the body was wrapped or placed in a container. The fact that bones found out of anatomical order may be supported in position by soft connective tissues is not taken into account in the existing models of disarticulation.

**Bone displacement**

The relationship between bone displacement and voids was examined in five flexed body donations: two buried, two placed in open pits and one mummified prior to burial. Bones were observed to displace over greater distances when open space was present around the body from the start of the experiment, supporting the existing archaeothanatological model. As expected, based on archaeothanatological research, primary voids around the body facilitated displacement of some bones outside of the original soft tissue mass of the body. Immediate burial in soil resulted in secondary voids developing as a result of decomposition of the soft tissues. The clay-rich soils at FARF maintained secondary voids around the buried body donations for over two years, at which point the skeletonised remains were excavated. Upon excavation, clear impressions of the soft tissue mass of the body were observed in the soil (Figure 28.7). Body position was again

![Figure 28.7](image_url)

*Figure 28.7* The secondary voids around the skeletonised remains of two buried body donations (delineation of the voids marked by arrows). Top left and right: supine flexed burial; bottom: upright, seated burial; the contours of the soft tissue body mass can be observed in the soil.
observed to be an important factor in the spatial patterning of bones in both open and closed pit body placements. Differences were observed between supine flexed body positions and upright, seated body positions. The supine body position permitted less vertical bone displacement, and displacement was most prominent in the lower limbs and thorax (Figure 28.8).

Larger voids, particularly voids that allow a great degree of vertical displacement of bones due to gravity (both primary and secondary), result in greater distances of displacement of the bones than smaller voids or voids with smaller vertical dimensions. The dimensions of potential secondary voids are determined by both the soft tissue mass of the body as well as the body position. The amount of vertical bone displacement in the buried upright, seated body was very similar to the seated body placed in an open pit, due to the dimensions of the secondary void created by the vertical body position. Bones were able to move within a large secondary void that was maintained throughout skeletonisation. Buried bodies of emaciated individuals and desiccated bodies with a relatively small soft tissue mass show less displacement of the bones due to smaller secondary void development.

**The role of insects**

Insect activity is known to play a significant role in the loss of soft tissue during decomposition (Rodriguez and Bass, 1983; Simmons _et al._, 2010). Observations made during this research highlight the fact that insects also play a role in the disarticulation and displacement of the small – and possibly also larger – bones of the body. While fly maggots focus primarily on the natural orifices and abdomen early in decomposition, their mechanical removal of soft tissues progresses rapidly throughout the body and can contribute to the loss of the tissues that maintain articulations between bones. Multiple instances of maggot activity associated with bone movement were observed in the 15 surface body donations, as well as in the two flexed open-pit body donations. Maggots attracted to the oral cavity were observed to cause post-mortem loss of single-rooted teeth from their sockets. Phalanges of the hands and feet of one donation, which were placed...
in a supported position on the bottom of the pit, became displaced by a large maggot mass (Mickleburgh and Wescott, 2018; Figure 28.9). In addition, in open pit placements, maggots attracted small animals such as birds and lizards, observed in time-lapse recordings, which may have contributed to the displacement of smaller bones.

The role of insects, including potential joint preference and seasonal variation in their activity, is not accounted for in current disarticulation sequences (cf. Schotsmans et al., Chapter 27, this

*Figure 28.9*  A. Left second metatarsal (top arrow) and proximal phalanx (bottom arrow) observed being displaced by maggot mass on day 14 of the experiment; B. left second metatarsal (left arrow) and a phalanx (right arrow) observed being displaced by maggot mass on day 16 of the experiment
volume). Based on observations thus far in this research programme, it is unclear whether or not insects have a preference for particular joints of the body, such as those close to natural orifices and the abdomen, or for particular joints based on their structural, functional classification, or joint type.

**Future avenues and further developments in this field of research**

The initial results and outcomes of this research programme emphasise the fact that actualistic forensic taphonomy provides an exceptional and important opportunity to observe the entire process of decomposition, disarticulation and bone movement within a framework of clearly defined data collection protocols and controlled conditions. Observing the effects of different variables on the final outcome can help to identify taphonomic markers that can be used to distinguish between human actions and natural processes and to reconstruct the sequence of events from death to burial. Actualistic experiments provide information that cannot be derived from the archaeological record (cf. Schotsmans et al., Chapter 27, this volume). For example, actualistic research could help resolve the question of whether or not particular joints are preferred by insects due to differences in accessibility or soft tissue mass and structure between joints. Experiments could likewise provide insights into the effects of different types of voids, clothing and coverings (this programme) or containers (cf. Alfsdotter, 2021) on disarticulation and bone movement. In order to develop and improve archaeothanatological methods and models, it is important to collect actualistic data from robust sample sizes that include control groups and to conduct replication studies in different environments (cf. Schotsmans et al., 2017). Due to the fact that archaeothanatology relies on close observation and interpretation of the spatial distribution of bones within the burial environment, further development of both qualitative and quantitative analysis of actualistic spatial data represents an important area for continued research. The 3D GIS method developed in this research programme shows great potential, but for this method to generate the required data to assess if specific spatial patterns can be associated with specific variables, sample sizes must be increased.

Based on the results of the programme thus far, an important improvement of the 3D documentation and analysis protocol developed is the use of full-body post-mortem computed tomography (PMCT) to document the 3D soft tissue mass as well as the complete skeleton of human body donations at the start of the experiments. The method developed for this programme using retrospective positioning (‘re-fitting’) of the bones in the 3D models of the bodies during decomposition was found to be very cost-effective and successful in the analysis of individually placed bodies with normal or low BMI. However, greater corpulence poses a problem for re-fitting. In addition, this method is time-consuming because creating 3D models of each bone using SfM requires a large number of photographs and lengthy image processing, and is therefore not optimal for analysis of larger samples. Furthermore, for the mass grave experiment initiated in spring 2021, accurate retrospective positioning of the bones in the 3D models of the soft tissue mass is not feasible due to the close, commingled position of the bodies. The distinct taphonomic environment of a mass grave can lead to the displacement of bones over relatively large distances, in particular small bones which can fall into voids created by soft tissue decomposition (Sutherland, 2000; Tuller et al., 2008; Duday, 2009; Cabo et al., 2012). In order to accurately and precisely document the initial position of each individual bone within its soft tissue mass, all nine body donors in the mass grave experiment were fully CT scanned prior to placement.

Finally, it is important that the continued development of actualistic forensic taphonomic experiments for (forensic) archaeological contexts is rooted in an interdisciplinary approach.
While a major focus of the forensic taphonomy research programme described in this chapter is the collection of disarticulation and bone displacement data, the broader programme includes (among other studies) research on the effects of decomposition and diagenesis on the isotopic composition of different body tissues over time (Kootker et al., 2020), research on the potential of using protein biomarkers for assessing the post-mortem interval and age-at death estimations (Mickleburgh et al., 2021), and research on the use of the thanatomicrobiome for human identification and post-mortem interval estimation. Each of the human body donations are of immeasurable value to science and medico-legal investigation, and the interdisciplinary approach of the project is intended to achieve in the greatest possible scientific gain. The collection of a range of data on the same body donations means that data can be studied and interpreted within the context of a highly detailed set of taphonomic observations, as well as to address other lines of enquiry.

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**References**


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