Field Conservation of Skeletal Remains: Stabilization Treatment Techniques and Implications for Future Analysis

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ABSTRACT

The information potential of human skeletal remains—as for any excavated material—is impacted by the conditions of archaeological burial, and the environments and actions experienced during subsequent excavation, laboratory processing, study, and storage. A conservation approach emphasizes the mitigation of threats to material stability and integrity, which for excavated collections are often most critical at the point of archaeological exposure and recovery. Conservation techniques involving application of modern synthetic materials for stabilizing skeletal remains in the field are discussed, using case examples primarily from terrestrial archaeological projects in Mesoamerica. The potential effects of the use of various conservation materials on results of biomolecular instrumental analysis are included.

Keywords: human remains, field conservation, consolidation, facing, jacketing, lifting, biomolecular analysis

El potencial informativo de los restos humanos, como todo tipo de material excavado, se ve afectado por las condiciones del enterramiento arqueológico y por los contextos y acciones a los que estuvieron expuestos durante la excavación, procesamiento de laboratorio, estudio y almacenamiento. Un enfoque de conservación enfatiza atenuar los riesgos a la estabilidad e integridad del material, factores que para las colecciones excavadas son más críticos en el momento de la exposición y recuperación arqueológicas. En este artículo se discuten técnicas de conservación que incluyen la aplicación de materiales sintéticos modernos para estabilizar los restos óseos en el campo, utilizando ejemplos de casos principalmente de proyectos arqueológicos terrestres en Mesoamérica. Se discuten los posibles efectos del uso de diversos materiales de conservación en los resultados del análisis instrumental biomolecular.

Palabras clave: restos humanos, conservación en campo, consolidación, reforzado, encamisamiento, extracción, análisis biomolecular

The information potential of human skeletal remains—as for any excavated material—is impacted by the conditions of archaeological burial and the environments and actions experienced during subsequent excavation, laboratory processing, study, and storage. Alterations are inevitably introduced at each of these stages, the potentially most destabilizing of which can occur with archaeological exposure and recovery, with their rapid transition and disruption from burial to ambient environments. To preserve the potentially valuable information of these collections, a conservation approach emphasizes the mitigation of threats to material stability and integrity at each of these stages. This article—written from a conservator's perspective but intended for use by osteologists and others involved in the excavation of human skeletal remains—focuses on several key interventions employing the application of modern synthetic materials for stabilizing bone and teeth elements in preparation for lifting.

Examples are drawn from my participation in a number of terrestrial archaeological projects at precontact sites in Central America. In the cited locations, all excavated materials are the property of the national archaeological institute, but permit processes currently do not include specific regulations governing the handling of archaeological human remains, other than in-country curation and required permissions for sampling and export. As yet there are no mandates for consultations and collaborations with descendant communities, as has become accepted practice in the United States, especially as a result of the 1990 Native American Graves Protection and Repatriation Act. The latter has, however, strongly influenced contemporary conservation practice, bringing renewed emphasis on a collaborative decision-making process that engages key stakeholders in determining appropriate care (American Institute for Conservation of Historic and Artistic Works 2018).

With regard to human remains, the perspectives of osteological and bioanthropological specialists, archaeologists, and conservators, as well as descendant and/or deeply invested local communities, can all significantly shape specific choices about whether and how they are uncovered during archaeological

Advances in Archaeological Practice 7(1), 2019, pp. 23–29

DOI:10.1017/aap.2018.36

excavations and about subsequent handling and curation (Cassman and Odegaard 2004, 2007; Cassman et al. 2007; McGowan and LaRoche 1996; Williams 2001). Within the conservation profession, which has long articulated the importance of clear treatment plans and the thoughtful choice of methods to achieve them, these collaborations have sharpened scrutiny of the potential impact of any conservation intervention. This article includes an update on research carried out by conservation scientists and others, examining the effects on biomolecular analysis of various treatment materials that have been used, past and present, for these interventions.

CONDITION CONSIDERATIONS—PRELUDE TO FIELD CONSERVATION

By the time human remains are uncovered, they reflect the cumulative effect of a number of alterations in soft tissue and bone, from life events (diet, trauma), mortuary practices (including body preparation and interment), and most aggressively, conditions provided by the burial environment. The latter include aspects of soil chemistry (acidity/alkalinity and salt content), water and oxygen, temperature (affecting, among other things, the rates of chemical reactions), and the macro and micro flora and fauna that these conditions support. Except in extreme environments (e.g., those with very cold temperatures, very low humidity, or reduced oxygen/waterlogged conditions), in which normal organic decomposition is variously suppressed, what remains in most other archaeological contexts will be the skeletal bone and teeth. Those found in the Central American subtropics exhibit a range of conditions reflecting qualities of the burial environment as well as mortuary practice.

Excavations beneath the so-called Scribe's Palace in Las Sepulturas, a residential area outside of the site core at Copán (Honduras), identified a Middle Preclassic cemetery with primary and secondary interments dug directly into a clayey soil matrix (Webster et al. 1989). Its acidic constituents and poor groundwater drainage contributed to the degraded, softened condition of the bone. A similar set of conditions prevailed in the elite mortuary complex at El Caño (Panama), where burial installations of multiple individuals, laid out on different levels, often disrupting earlier interments and in turn disturbed by later ones, were dug deeply into the earth in a riverine flood zone (Mayo and Carles 2015).

Some buffering and protection can be provided by tomb enclosures, such as the stone cyst containing a Middle Preclassic royal burial found underneath a residential compound in the Jabalí group at San Bartolo (Guatemala), with crushed but not fully degraded bone elements (Estrada-Belli 2010:62). Among the Classic period royal burials at Copán, the skeletal remains found in sealed masonry chambers encased within the Hunal and Yehnal structural phases of Temple 16—believed to be those of Ruler 1 and a related female—were also in relatively sound condition, liberally covered with cinnabar powder (Bell et al. 1999; Buikstra et al. 2004). Another burial chamber, located within Temple 26 (that of the Hieroglyphic Stairway), contained similarly robust bones of two youths, found on the floor next to the burial dais of the principal individual, believed to be Ruler 12. The remains of this important individual, by contrast, survived as tiny thin flakes of bone intermixed with paint fragments and other evidence of elaborate furnishings (Fash et al. 2001). This poor condition was likely due to acidic degradation accelerated by wrapping within a clay-coated mat, the remains of which were found in the body region of the dais.

FIELD CONSERVATION TECHNIQUES AND MATERIALS

However altered physically, chemically, and biologically over the course of long-term burial, skeletal remains achieve a relative state of equilibrium that is potentially upset by archaeological exposure. Excavation marks the point at which there is potential to control the nature and rate of alterations that can impact preservation—from entry into a different ambient environment with initial exposure to the removal process itself and subsequent processing.

From a conservation perspective, mitigating threats to material stability and integrity is the first priority at every step, favoring non- or minimally invasive approaches whenever possible and conservation materials selected for their known stability over time and reversibility, among other criteria to be met (American Institute for Conservation of Historic and Artistic Works 2018; Cronyn 1990, Pedelì and Pulga 2013; Sease 1994). In the context of an individual's remains, however, these guidelines may not be easily interpreted, nor compromises easily navigated. Particularly if more invasive treatments are under consideration—such as extensive cleaning, consolidation of fragile elements, and reassembly with adhesives—discussions with key stakeholders need to explicitly address the issues of choice of materials and methods and extent of intervention and impact (e.g., Johnson 1994, 2001; Odegaard and Cassman 2007; Roberts and Eklund 2007).

In the examples presented here, I discuss several types of stabilization treatments that involve the use of modern materials for stabilizing bone and teeth in situ. These methods generally prioritize the preservation of physical aspects of the skeletal remains, whether strengthening powdery or disintegrating bone surfaces, holding fragments together, or protecting the association of elements, and can be used not only in field situations but also in the field laboratory. The suggested conservation materials have proved to be effective in these functions, but the risk of interference with future biomolecular analysis is a serious consideration, as discussed in the subsequent section. In these cases, it is important to retain untreated elements as a precaution.

Consolidation

The application of a consolidant is one of the most common methods used to strengthen and cohere powdering or flaking surfaces and weakened, cracked structures, especially if removal of the surrounding burial matrix during excavation could cause further destabilization (e.g., Pedelì and Pulga 2013:77–78; Sease 1994:11–12; regarding skeletal material: Johnson 1994; Koob 1984; Kres and Lovell 1995). Consolidants—like their adhesive relatives—are typically composed of modern synthetic polymers combined with a liquid. Those that dissolve in organic solvents are referred to as resin solutions and can be resolubilized after drying using the same solvents. Those supplied in water are referred to as emulsions or colloidal dispersions, with larger and smaller particle sizes, respectively; these have been formulated

https://doi.org/10.1017/aap.2018.36 Published online by Cambridge University Press

with additives to maintain the synthetic component in suspension but can only be resolubilized with organic solvents once dried.

The consolidant solutions are mixed to a dilution that suits the condition issue; for a porous material such as bone they are typically very dilute to promote penetration. They are usually applied by brush, pipette, or syringe to a surface that has been carefully cleared of soil or other particulate matter, preferably by gentle dry methods. A consolidant can be applied in stages as surfaces are progressively cleared or in multiple applications if needed. The liquid component then dries by evaporation, leaving the solid compound behind to cohere and toughen the material. Consolidants may be resolubilized with the introduction of appropriate solvents, for example, to release the binding effect or to swab up excess consolidant or adherent soil on a surface; however, given absorption into a porous bone structure, they can never be considered completely "reversible" (i.e., removed).

Key considerations in choosing a specific consolidant include the ambient temperature, which may affect the consolidant's ability to harden in situ and remain so in the anticipated curation location; soil pH, which may influence the consolidant's chemical stability; relative humidity in situ, which may affect the consolidant's ability to dry quickly; moisture in the soil and bone, which may affect its ability to penetrate; techniques for optimal usage, including application and drying, which may require experience; and health and safety considerations (Johnson 2001; Pedelì and Pulga 2013). For skeletal remains, plans for further analysis may also affect consolidant choice, and a sampling strategy should be in place to retain untreated material.

The most commonly used conservation-grade consolidant is Paraloid™ B-72, a Rohm & Haas product, formerly supplied as Acryloid in the United States. It is an acrylic resin (methyl methacrylate/ethyl acrylate copolymer) with excellent stability, durability, and aging behavior, including resolubility. This product is available from conservation suppliers in the form of polymer beads or premixed in organic solvents. It is readily soluble in acetone and other organic solvents, with its dilution adjusted for a range of applications (including as an adhesive). To make a consolidant solution, the resin pellets are typically diluted in acetone to form a 5% to 10% solution (i.e., 5 to 10 g per 100 ml solvent); this is very effective in strengthening degraded dry bone but cannot be used effectively on water-wet materials.

If damp, bone can be strengthened using a water-based acrylic consolidant, such as the colloidal dispersion Acrysol™ WS-24, available from conservation suppliers. Its small particle size enhances its ability to penetrate when diluted equivalently to B-72 solutions. The consolidated material will take longer to dry than with a solvent-based consolidant.

Facing

The facing technique involves the attachment of a fine tissue-like material with an adhesive to temporarily secure fragments together in situ or to provide added protection for fragile components prior to lifting. I have used it with a variety of artifact materials (Beaubien 2011), as well as human skeletal remains, including the badly fragmented bone elements of the San Bartolo burial. The tissue needs to be able to conform closely to irregular surfaces, maintain strength when wetted, and function compatibly with the adhesive to form a sturdy facing once dry. Sensitive surfaces often benefit from consolidation prior to attachment of the facing.

The combination of a fine cellulosic tissue, such as Japanese tissue, paired with a cellulose ether gel adhesive (either water- or alcohol-based) creates a particularly effective facing. Cellulose ethers, derived from the cellulose molecule, were originally used in paper conservation, forming nontoxic, stable, durable, and easily reversible adhesives. Available in a variety of formulations from conservation suppliers, the most commonly used ones are methyl cellulose, such as Methocel™ A4C (Dow), which is gelled in water, and—if a solvent-based one is needed—a hydroxypropyl cellulose, such as Klucel™ G, gelled in ethanol or isopropyl alcohol. At dilutions of circa 3%, these adhesives are sufficiently strong once dry to hold the tissue tightly to the surface.

The process involves cutting the tissue into small patches, which are secured in place one at a time with gentle tamping using a brush with the adhesive; this relaxes the tissue into place on irregular surfaces. A continuous protective facing is created by overlapping multiple tissue patches. Of particular advantage with this combination is that the adhesive can be released readily with localized brush application of its solvent, allowing the facing to be removed for further cleaning and reassembly of fragments, without affecting any underlying consolidated surfaces.

Jacketing

Components of the deposit can be further immobilized and supported using a jacketing technique, often in conjunction with the stabilization methods discussed above. A thin, rigid protective shell can be quickly created using aluminum foil as a conforming barrier layer and plaster-infused gauze bandages, wetted with water and then wrapped in several layers. This technique was used during the excavation of the cranial deposit of the San Bartolo burial, facing and jacketing it in excavation stages until it was almost completely encapsulated; it could then be lifted and transported safely to the project lab. (Note that plaster bandages are useful to have on hand for stabilizing the pedestaled sides of a deposit being prepared for block-lifting.)

More recently, a synthetic waxlike cyclic alkane called cyclododecane (CDD) has been used to immobilize fragile finds for lifting and transport (Beaubien 2011). It is a chemically stable and inert material, with a significant advantage for this application: it sublimates slowly when exposed to ambient conditions without need for solvents to remove it. In practice, it is most effectively used as a melted material and can be applied directly to the material to be lifted, without requiring prior stabilization treatment or barrier material. It also functions well as a protective layer for the application of plaster bandages to create a strong jacket for lifting. The CDD remains in place if the lifted item is kept securely bagged or can be allowed to dissipate once in a lab situation, where further actions can then be carried out. Currently, CDD (originally supplied by Kremer Pigments) is not easily available, but other sublimating products are being tested for similar use.

Lifting

The stabilization techniques described above may be sufficient to allow skeletal elements to be lifted directly or can be used to

https://doi.org/10.1017/aap.2018.36 Published online by Cambridge University Press

TABLE 1. Conservation Materials, Used as Consolidants and Adhesives, That Have Been Tested for Their Effect on Biomolecular Analysis Techniques.

Proprietary Name	Primary Function	Primary Chemical Composition	Research Citation(s)
Paraloid B-72 Acryloid B-72	Consolidant Adhesive	Acrylic solution	Vuissoz 2004, cited in Vuissoz and Gilbert 2007; France et al. 2015; France, Kaczkowski, and Kavich 2018
Acrysol WS-24 Primal WS-24	Consolidant Adhesive	Acrylic colloidal dispersion	Vuissoz 2004, cited in Vuissoz and Gilbert 2007
Rhoplex AC-33 Primal AC-33	Consolidant Adhesive	Acrylic emulsion	Tuross and Fogel 1994; Vuissoz 2004, cited in Vuissoz and Gilbert 2007
Mowital B60H Union Carbide (various) Vinylite B Vinac B-25	Consolidant Adhesive	Polyvinyl acetate solution	France et al. 2011; France, Kaczkowski, and Kavich 2018; Tuross and Fogel 1994
Mowilith (various) Elmer's (various)	Adhesive	Polyvinyl acetate emulsion	Vuissoz 2004, cited in Vuissoz and Gilbert 2007
Resistol 850	Adhesive	Polyvinyl alcohol solution	Wright 2002
Alvar	Consolidant	Polyvinyl acetal	Moore et al. 1989, cited in Johnson 1994; Wright 2002
Butvar B-98	Consolidant	Polyvinyl butyral solution	France et al. 2015; France, Kaczkowski, and Kavich 2018
Duco Cement HMG	Adhesive	Cellulose nitrate solution	France, Epitropou, and Kavich 2018; France, Kaczkowski, and Kavich 2018
Cyclododecane	Surface stabilizer	Cyclic alkane wax	France, Kaczkowski, and Kavich 2018; Pohl et al. 2009

immobilize the exposed components of a skeletal deposit that are then excavated using block-lifting techniques. Various block-lifting techniques, well described by Payton (1992) and Sease (1994:21–27), among others, can be adapted for deposits of human skeletal remains, in conjunction with updated surface stabilization materials and methods described above. In general, block-lifting retains the spatial organization of the skeletal elements and "buys time," allowing the challenge of determining the best way to extricate the skeletal elements from the matrix to happen later in a more controlled laboratory-type setting. It does, however, require considerable advance planning, including determining the appropriate archaeological strategy, suitable support materials, and provision for subsequent laboratory attention by osteological specialists.

Block-lifting was used to remove several individuals buried in a clayey matrix at Las Sepulturas (Honduras). The skeletal remains were generally in poor condition and prone to powdering on exposed surfaces but could be removed in small blocks without encasing materials because of the cohesive nature of the matrix. Aluminum foil used as a conforming support around individual soil-encased bones was a quick solution, but with some drawbacks: it is somewhat abrasive, obscures contents (inviting rough handling), and oddly, not stable if poor-quality local products are used. It also did not prevent the clay from drying to rock-hardness, an issue that would be a significant problem for any block-lifted or jacketed remains left unexcavated.

IMPLICATIONS OF FIELD TREATMENT FOR FUTURE ANALYSIS

With increasing interest in the use of biomolecular analytical techniques in recent decades, conservators and researchers have become much more aware of the potential impacts of actions, conditions, and alterations set into motion with excavation on the research value of human skeletal collections. Normal handling and ambient environmental conditions, as well as specific practices that are designed to preserve morphological information—such as washing, removing soil or accretions, reassembly of fragments, and especially consolidation—may run counter to those designed to preserve molecular information obtained from stable isotope, DNA, or radiocarbon dating analyses (e.g., Cooper et al. 1994; Eklund 2007; Koch et al. 1997; Tuross 1995; Tuross and Fogel 1994; Wright 2002). Effective distribution of a consolidant at the surface or throughout the structure of skeletal elements can immeasurably enhance their durability for morphological studies but may complicate biomolecular analysis through contaminating or degrading the target component or by inhibiting some aspect of the test procedures. Fortunately, the development in recent years of more stringent sample cleaning protocols, and experimental work targeting the specific effects of conservation products on biomolecular analyses, may alleviate some of these concerns, especially for researchers studying skeletal material in curated collections that may have undergone treatment in the past.

A variety of products, used in the past and the present as consolidants (dilute formulations) and adhesives (more concentrated formulations), have been tested for their effect on specific types of scientific investigation (Table 1). These include (1) polymer-based resin solutions (mixed in organic solvents), (2) polymer-based emulsions and colloidal dispersions (mixed in water), and (3) a synthetic wax. It is notable that many of the more recent experiments have been undertaken by researchers and conservators working in collaboration, with the latter contributing details of specific products, their formulations, and techniques of application reflecting actual conservation practice. (For more information about the chemical, physical, and visual characteristics of historic and contemporary materials used in the production and conservation of artistic, architectural, archaeological, and anthropological materials, see the MATERIALS database, cameo.mfa.org [CAMEO: Conservation and Art Materials Encyclopedia Online 2018; Horie 1992].)

https://doi.org/10.1017/aap.2018.36 Published online by Cambridge University Press

Two specific conservation materials are summarized as examples, with comments about their effects on specific biomolecular analysis.

Paraloid B-72®

Paraloid B-72—an acrylic resin (methyl methacrylate/ethyl acrylate copolymer)—is solubilized in acetone and other organic solvents and used as a consolidant and adhesive.

Stable Isotope Analysis. In tests on modern whale rib samples for effects of Paraloid B-72 consolidation and solvent removal on $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ values from bone collagen and hydroxyapatite, France and colleagues (2015; France, Kaczkowski, and Kavich 2018) found that the $\delta^{13}C$ and $\delta^{15}N$ values of isolated bone collagen were unaffected by B-72 treatments and by solvent exposure, provided the collagen extraction incorporates a heated acidic gelatinization step, and that the $\delta^{18}O$ values from the bone hydroxyapatite phosphate and the $\delta^{13}C$ values from the bone hydroxyapatite carbonate were unaffected by B-72 treatments and by solvent exposure. However, the $\delta^{18}O$ values from the bone hydroxyapatite carbonate from treated samples are altered in an unpredictable manner; the researchers recommend that $\delta^{18}O$ in hydroxyapatite structural carbonate should not be used in stable isotope studies if bones have been treated with B-72.

DNA Analysis. Paraloid B-72 was included in a study of the inhibiting effects of common conservation treatments, using old and new cow leather (Vuissoz 2004, cited in Vuissoz and Gilbert 2007); amplifiable DNA appeared to be retrievable but required dilution of up to a hundredfold prior to amplification.

Cyclododecane

CDD—a waxy cyclic alkane solid—is heated to melt for use as a temporary surface stabilization and jacketing material.

Stable Isotope Analysis. In tests on modern whale rib samples for effects of CDD application and after sublimation on $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ values from bone collagen and hydroxyapatite, France, Kaczkowski, and Kavich (2018) found that there appears to be a minimal effect of CDD on isotopes, with Fourier transform infrared spectroscopy showing no traces of CDD after a couple of months of sublimation.

Carbon-14 Dating. Modern and archaeological gourd rind samples—treated, sublimated to various levels, and untreated—were analyzed by accelerator mass spectrometry dating (Pohl et al. 2009). CDD was determined to be radiocarbon-free, indicating that the chemical is synthesized from petroleum-derived, rather than modern hydrocarbon, sources; either it does not leave behind carbon-containing contaminants with C-14 signatures, or any residual contaminants are removed by the stringent sample cleaning protocols, sufficient to reduce CDD residues to levels that would not interfere with radiocarbon dating.

CONCLUSION

The challenge of determining what constitutes appropriate conservation care is raised by every new encounter with human skeletal remains beginning at the time of excavation and by interaction with those in collections generated by previous archaeological efforts. As noted, normal handling and ambient environmental conditions, as well as conservation practices intended to preserve morphological information, may be in conflict with practices intended to preserve molecular information, and these in turn may be in conflict with the wishes of descendant communities, who have taken their rightful place as key stakeholders.

In recent decades, there have been a number of developments in the broader field of conservation, including emphasis on collaborative decision making, increased scientific scrutiny of the effects of standard (invasive) conservation treatments, and a mandate to seek the least invasive strategies possible to achieve preservation goals. To the extent that these are implemented in the field excavation of human remains—with archaeologists and osteologists, conservators, and community stakeholders engaged in the process—we have the opportunity to set a respectful, ethical, and careful course for their long-term preservation.

Acknowledgments

Among the many colleagues from archaeological projects with whom I have had the privilege of working, I gratefully acknowledge those from the site of Copán (Honduras), whose commitment to the preservation of the remains of its ancient inhabitants has been an inspiration, especially Loa P. Traxler, Jane Buikstra, the late Robert J. Sharer, Barbara W. Fash, and William L. Fash. I am also grateful to colleagues from the Smithsonian Institution's Museum Conservation Institute, who—with Christine A. M. France's leadership—continue to investigate the effect of conservation materials past and present on the biomolecular analysis of bone.

Data Availability Statement

The article describes general conservation practice and published references, based upon my work in a variety of archaeological contexts. For further information, associated field reports are available upon request from the principal investigators of the university-sponsored archaeological projects cited in the article and are also available at the Museum Conservation Institute, Smithsonian Institution, Suitland, Maryland, http://www.si.edu/mci.

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https://doi.org/10.1017/aap.2018.36 Published online by Cambridge University Press