The Slice is Right: Medical Imaging for Authentication of West African Ceramics

ABSTRACT

An important group of West African earthenware figures at the Art Institute of Chicago was dated by thermoluminescence (TL) subsequent to the application of computed tomography (CT) scanning. The results of these analyses confirm the superiority of this combined methodology for the authentication of ceramics and affirm that radiological examinations need not interfere with dating by TL. The present study also serves as a caution against over-reliance on imaging techniques more commonly employed in the examination of ceramics, such as ultraviolet-induced visible fluorescence, and demonstrates several general challenges inherent in imaging three-dimensional objects. By publishing the instrumental parameters used in this study and offering access to the original datasets, the authors hope to assist in establishing a formal reference standard for the CT scanning of ceramics toward its wider use for materials characterization.

AUTHORS

Rachel C. Sabino*
Objects Conservator
Art Institute of Chicago
rsabino@artic.edu

Michael W. Vannier
Professor Emeritus of Radiology
University of Chicago
mvannier@radiology.bsd.uchicago.edu

**Corresponding Author*

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INTRODUCTION

The Art Institute of Chicago (AIC) has in its collection of African art a quintet of red earthenware figures consisting of a mounted horseman, two seated males, and two seated females (Figure 1). Their style is known as Bankoni in reference to a village near Bamako, the present-day capital of modern Mali, where similar figures and fragments have been unearthed since the 1940s. This so-called Bankoni style fits into a larger corpus of figural ceramic sculpture spanning a sizeable region known as the Inner Niger Delta (IND). Archaeological evidence and local oral tradition indicates that highly developed urban centers existed in the region as early as 200 BCE, and all ethnic groups in the IND created variants of these figures (de Grunne 1980). A few notable centers of production dominate the genre, in particular Djenné, the seat of the powerful Mali Empire from the 13th to 16th centuries (de Grunne 2014). Wearing accoutrements like bangles, pendants, and sheathed knives, the sculptures bear witness to the tremendous prosperity of the region. The manufacture of such luxury goods requires a robust economy with access to a wide variety of resources and commodities. The horse, fitted with a bridle and ceremonial adornment around its neck, is noteworthy because equines in this part of the world require a high degree of care and maintenance, indicating a society with sufficient wealth and resources to ensure their well-being (Law 2018; Zeuner 1963). The equestrian subject also speaks to the necessity of a

Figure 1. *Bankoni equestrian and four figures, 13th or 16th century CE, terracotta, From left to right: H 28.5 cm × W 14.6 cm × D 19.3 cm; H 70 cm × W 21 cm × D 48.5 cm; H 46 cm × W 14.7 cm × D 19 cm; H 44 cm × W 10.2 cm × D 18.5 cm; H 44.5 cm × W 12.7 cm × D 18.4 cm. Art Institute of Chicago, 1987.314.1-5 · Courtesy Art Institute of Chicago*

cavalry for expansion, control, and security across a vast territory. While it is likely that artistic production of the period utilized an array of materials, the durability of ceramic, as opposed to wood, fiber, or leather, ensured that these figures survived, making them among the earliest known art forms from sub-Saharan Africa. By the 15th or 16th century, this tradition of figural ceramics appears to have disappeared, but the legacy of the horse and rider can be seen throughout sculpture of later periods (Chemeche 2011).

Among Bankoni figures, the Chicago examples are extremely significant. For one, they are quite large for their type and are finely detailed with intricate cross-hatched patterns. Most importantly, the figures have remained as a group; most others have been separated and dispersed, existing in museums and collections as single objects. For these reasons, the Art Institute received a request to loan the group to a ground-breaking traveling exhibition on medieval trans-Saharan trade (Berzock 2019). Organized by the Block Museum of Art in collaboration with an international, interdisciplinary advisory team of specialists, the exhibition showcases more than 250 artworks, many of which are displayed in North America for the first time. This recent interest in the Chicago Bankoni group presented an exciting opportunity to revisit the figures, taking advantage of the 30 years of advances in technical examination methods since their purchase in 1987.

In addition to summarizing the findings from technical study of the Bankoni figures, this paper introduces a protocol for computed tomography (CT) scanning of earthenwares, with evaluation of X-ray irradiation impact on thermoluminescence (TL) measurements.

THERMOLUMINESCENCE

Sculptures of the type represented by the Chicago group can be stylistically dated between the 12th and 16th centuries. Prior to acquisition, one sample taken from the horse was subjected to TL analysis, with a resultant firing date approximately 500 years prior, corroborating a 14th- or 15th-century attribution.

Developed in the early 1960s as a means of dating ceramic materials, TL is a highly specialized technique performed by only a few trusted laboratories worldwide (Wintle 2008). For TL analysis, it is imperative that the sample be representative of the object as a whole. Skilled forgers, increasingly sophisticated in the production of counterfeit artifacts, have any number of ingenious ways to circumvent the test. The most common practice is to create a pastiche, an object comprised of unrelated but age-appropriate fragments. The sherds are pieced together with fillers and finished with washes or coatings, also comprised of age-appropriate material ground into a binder. Care is taken to strategically insert the deceptive fragments in areas from which samples are most likely to be taken: backs, bases, and undercuts. Forgers have also been known to fashion an authentic, but much-eroded or damaged artifact, into a more interesting or dynamic one by sharpening details or reconfiguring appendages. Sampling these types of objects without knowing their composition or construction is likely to return a date within the anticipated or desired range and thereby support a false impression of authenticity (Rasmussen 2008).

THE GOLD STANDARD

The determination of authenticity is a priority for artworks across all regions and time periods, but is particularly pertinent to this category of art. A wave of counterfeit West African ceramics that flooded the market in the mid to late 1980s serves as a cautionary tale. When the renowned Kuhn collection of African art was auctioned, the cover of the catalogue was graced by a sculpture in the form of a ram (Sotheby's 1991). TL tests placed the figure between 570 and 1,000 years old. With little doubt as to its nature, the animal sold for $275,000 but was later discovered to be a pastiche, fashioned by a local Bamako potter (Brent 2001).

If TL alone cannot stand as a test of authenticity, supplemental techniques must be put into service. X-radiography has long been a tool in the conservator's arsenal, and X-rays are certainly a tried and reliable means by which to identify breaks in ceramic materials. Radiographs of ceramics generally display poor or limited contrast of the fabric itself and reveal very little about its character because the clay and its inclusions, usually both silicate materials, are of similar densities (Figure 2). Overcoming this inherent limitation typically involves a great deal of trial and error across multiple voltages (Middleton 1997, 60-3). Different voltages may be more successful at individuating and rendering certain features of the ceramic fabric, but it is time consuming and difficult to correlate sets of individual films in an effort to generate a more complete picture of the object. Furthermore, the two-dimensionality of a conventional radiograph results in a superimposition of images from one side of the object to the other, making it challenging to visualize which features belong to which stratum of an object's depth (la Niece 1997, 156). These types of optical distortions complicate the determination of an appropriate site from which to sample for TL.

Conversely, computed tomography, or CT scanning, was specifically designed to measure the internal density distribution of matter in a three-dimensional object. Beyond being a non-destructive technique, its value in the assessment of works of art lies in the fact that physical or chemical changes frequently result in changes in density. CT scanning of antiquities is not a new practice. In 1979, the same year that the team credited with the invention of the CT scanner won the Nobel Prize, the first study of an Egyptian mummy using CT was published. Since then, considerable improvements in computing technology have dramatically improved spatial resolution and image reconstruction times (Hughes 2011). When used under optimal conditions, the spatial resolution of medical CT is approximately 50 microns, sufficient to detect a crack even if it is invisible to the naked eye and does not appear on a conventional X-radiograph (Ghysels 2003, 118). CT scanning of ceramics is a fairly recent development, with the earliest studies appearing in the mid 1990s (Applbaum and Applbaum 2005; Jansen et al. 2001), but tremendous advances in the technique have

Figure 2. *Amphora (left) and conventional radiograph (right). Attributed to the Ixion Painter, Amphora, 340-330 BCE, terracotta, H 86.4 cm × W 36.1 cm × D 26 cm. Art Institute of Chicago, 1889.24 · Courtesy Art Institute of Chicago*

made its use for this purpose more widespread (Bouttiaux and Ghysels 2008). The Art Institute is fortunate to have a long-standing relationship with the Pritzker School of Medicine at the University of Chicago. This collaboration is invaluable because it facilitates access not only to instruments that would be otherwise unavailable, but also to the specialized expertise of trained radiologists who can adapt protocols designed for medical use to nonstandard objects.

COMPUTED TOMOGRAPHY IMAGING

In November 2017, scans were obtained at the University of Chicago Center for Care and Discovery using a 256-slice iCT 256 CT scanner from Philips Medical Systems, with scan times of five to ten seconds per object using slice thicknesses of 0.7 mm and slice intervals of 0.35 mm. Data set sizes of the scans totaled 21.2 GB, and more than 40,000 total slices were created, roughly 675-1159 slices per object. For this study, the in-plane voxel size for 512 x 512 slices in a 20 cm field of view was approximately 400 microns. The scans were done with variations of skull/brain protocols adapted to the material characteristics of the ceramic.

Data was visualized and analyzed using Philips Brilliance Workstation 3.0, RadiAnt DICOM Viewer 4.6.9, and MITK Workbench 2018.4.0. The raw projection data sets were archived in Digital Imaging and Communications in Medicine (DICOM) format, as were multiple reconstructions of each spiral CT scan (ACR and NEMA 2019). Each image frame contains detailed metadata constituting a complete record of the experiment, i.e. instrument setup, data acquisition, and

Figure 3. *Bankoni female figure (left) and coronal slice (right). 13th or 16th century CE, terracotta, H 46 cm × W 14.7 cm × D 19 cm. Art Institute of Chicago, 1987.314.3 · Courtesy Art Institute of Chicago*

image reconstruction, enabling its replication and serving as complete documentation of image acquisition and creation. Establishing a set of CT standards for ceramic studies is dependent on the availability and accessibility of these datasets to other researchers.

RESULTS

This protocol proved highly informative for the examination of the figures. Foremost, because CT permits such a detailed examination of the ceramic body, it was possible to discern almost instantaneously whether or not the granulometry and global density of the clay are constant, indicating that the objects were created from the same stock of clay, as was the case with all five figures in the study. The CT images demonstrated that the Bankoni group potter used a course clay with a high percentage of large, high-density aggregates. The scans also revealed the precise contours of the breaks, and the fill material used for the restorations appears uniformly gray (Figure 3).

Women dominate the production of pottery in Africa today, and the ethnographic record is replete with references to divisions of labor based on gender. While there is still no research to confirm if women created these figurative ceramics (Berns 1993), pottery techniques have remained little changed across the centuries, and it is reasonable to assume that the figures would have been made in the same way as contemporary ceramics. In the case of these five objects, CT bears out this assumption, revealing that hand-building techniques like rolling, coiling, and pinching were used in their creation.

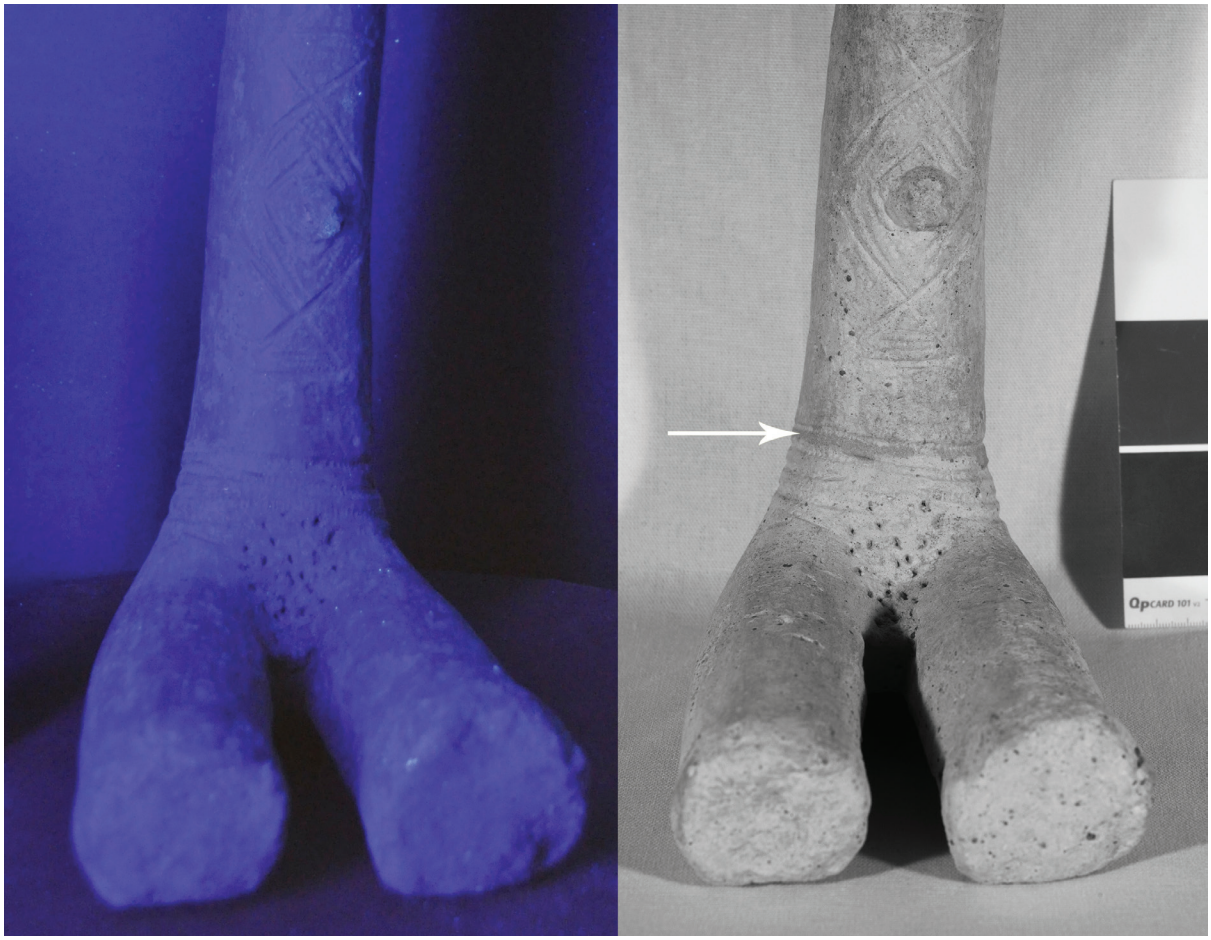

Figure 4. *Bankoni female figure UVF detail (left) with repair not visible and IRR detail (right) showing previous repair. 13th or 16th century CE, terracotta, H 44 cm × W 10.2 cm × D 18.5 cm. Art Institute of Chicago, 1987.314.4; UVF: Nikon D5000 body; AF-S DX NIKKOR 18–55 mm f/3.5–5.6G VR lens; Kodak Wratten 2E filter; CLE Design Vertical Luminaire UV/BLB UVVTL440 lights. IRR: Fujifilm S5 Pro camera; X-Nite 1000B/2 mm (1.0–1.1 µm) filter · Courtesy Art Institute of Chicago*

Multiple avenues for future research stem from the work done thus far. All the figures were scanned at four different accelerating potentials, 80, 100, 120, and 140 kVp, a process described as multi-spectral CT scanning. The use of differing voltages has a number of advantages: compensation for artifacts such as beam hardening, which causes the edges of an object to appear brighter than the center, and visualization of components and inclusions within the ceramic fabric that attenuate radiation in the same way that metals do. For these materials, the higher energy scans were particularly effective. Multi-spectral CT also promises to discriminate between materials using their energy-dependent attenuation characteristics by sampling the same scene with different X-ray source potentials (McCollough et al. 2015). This can be done by comparing mean values of object histograms and region of interest (ROI) measurements with those of reference materials, facilitating evaluation of material homogeneity and composition of the ceramic fabric. Further, the data can also be used for materials characterization based on the elucidation of the morphology of inclusions within the ceramic fabric (Maire and Withers 2014).

IMAGING CHALLENGES

Upon their acquisition in 1987, the objects were understood to be fragmentary and previously fully reintegrated by an unknown restorer, including a complete reconstruction of the equestrian's proper right arm. However, the absence of treatment records allowed only an imprecise sense of their condition. Moreover, the repairs had been done to such a high aesthetic standard that they escaped detection in visible light, during ultraviolet (UV) examination, and with UV-induced visible fluorescence (UVF) photography. The number of breaks and the extent

of the repairs became fully apparent only during CT scanning. Galvanized by this revelation and perplexed by the failure of UV examination, a standard technique that sometimes serves as the only examination a ceramic will receive beyond inspection in visible light, the objects were imaged with infrared reflectography (IRR), a technique more commonly employed for the examination of paintings. The repairs were readily visible with IRR (Figure 4). Although imaging standards have been established by the conservation community (Frey 2011), the tremendous variability in both the material and form of three-dimensional artwork presents unique obstacles to the development of a standardized protocol for technical imaging. It is inadvisable to rely on a single imaging technique, and a sufficient buffer of time should be factored into the workflow for multi-spectral examination and imaging, particularly when matters of authenticity are at stake.

THE POST-SCANNING PERIOD

With regard to the CT data, tremendous advances in processing software make it possible to analyze the images obtained during the scanning phase with great accuracy and to generate a wide variety of models and multi-planar reconstructions (MPR). Several opaque modalities were exceptionally useful in differentiating materials, making it possible to pinpoint the precise location and extent of the restorations. Transparent models permitted the visualization of internal components and surfaces, in this case, the dimensions and orientations of the metal tubing used to make the repairs (Figure 5). MPR proved invaluable in mapping the sample locations and drill paths for a new round of TL tests. Ten samples were taken, two from each figure, and each sample returned a firing date between 500 and 800 years ago, possibly 200 years older than previously thought. Until recently, there was concern that both conventional radiography and CT contributed a quantity of radiation sufficient to interfere with the ability to do subsequent TL testing (Middleton 1997, 62). However, recent experiments have demonstrated this is not the case (Gyhsels 2003, 121-25). For this project, full radiation dose summaries were forwarded to the TL testing facility alongside the samples (Figure 6). Because CT dosimetry is more complex than for conventional X-radiography, support and guidance from the radiology team was crucial in delivering comprehensive, appropriate, and useful information to the TL testing lab (AAPM 2008).

THE WIDER PICTURE: EXHIBITION AS CONTEXT

The cultural heritage of West Africa, and Mali in particular, like that of many nations, has been profoundly and adversely affected by the practice of looting, removing artifacts from their burial sites without formal records or proper documentation (McIntosh 1996; Brent 1996; Sidibé 1996). While the absence of this all-important context certainly complicates a full understanding of an object's meaning and function, some archaeologists argue that such objects have no value whatsoever (McIntosh 1996, 45), even going so far as to suggest museums are complicit in the violation (McIntosh and McIntosh 1986, 49-50). This attitude would mute the very real contributions that "orphaned" objects can make to the study of the arts of this region with respect to materiality, fabrication, and form (van Dyke 2007).

A notable feature of the Block Museum exhibition is that the organizers agreed to include only objects that have been legally exported from their countries of origin, and the Art Institute's Bankoni group is unique in having been acquired along with the required export documentation. Consequently, the only other Malian items appearing in the exhibition are three works on loan from the National Museum in Bamako, as well as a few vessels and archaeological fragments from the sites of Gao and Tadmekka. Several excavated, heavily-corroded knife blades, the shapes of which mirror those worn by the Bankoni figures, are displayed alongside more modern variants with extant armbands. Collectively, these objects speak to the longevity of a regional tradition of wearing knives on the arm, and this recent technical study allows the Bankoni group to occupy a point along this historical continuum with certainty. At the same time, placing the figures together with objects from the Malian museums and archaeological sites serves to contextualize them. Similar ceramic sculptures have been found in the foundations of houses during excavations in the city of Djenné, and figures of people and horses have been found buried alongside horse skeletons at sites in Natamatao (Berzock 2019, 33-35). In the absence of archaeological context, this research has enabled the objects to speak for themselves.

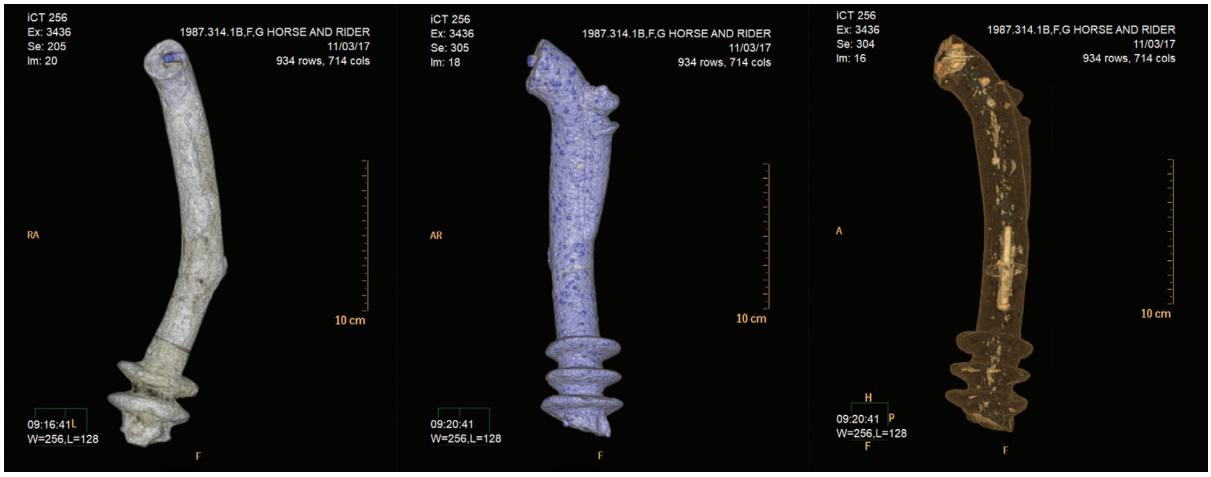

Figure 5. *Bankoni equestrian figure, 1987.314.1, opaque models highlighting material differences between the restored arm (left) and the original arm (center); transparent model of the original arm revealing the internal pin (right) · Courtesty Art Institute of Chicago*

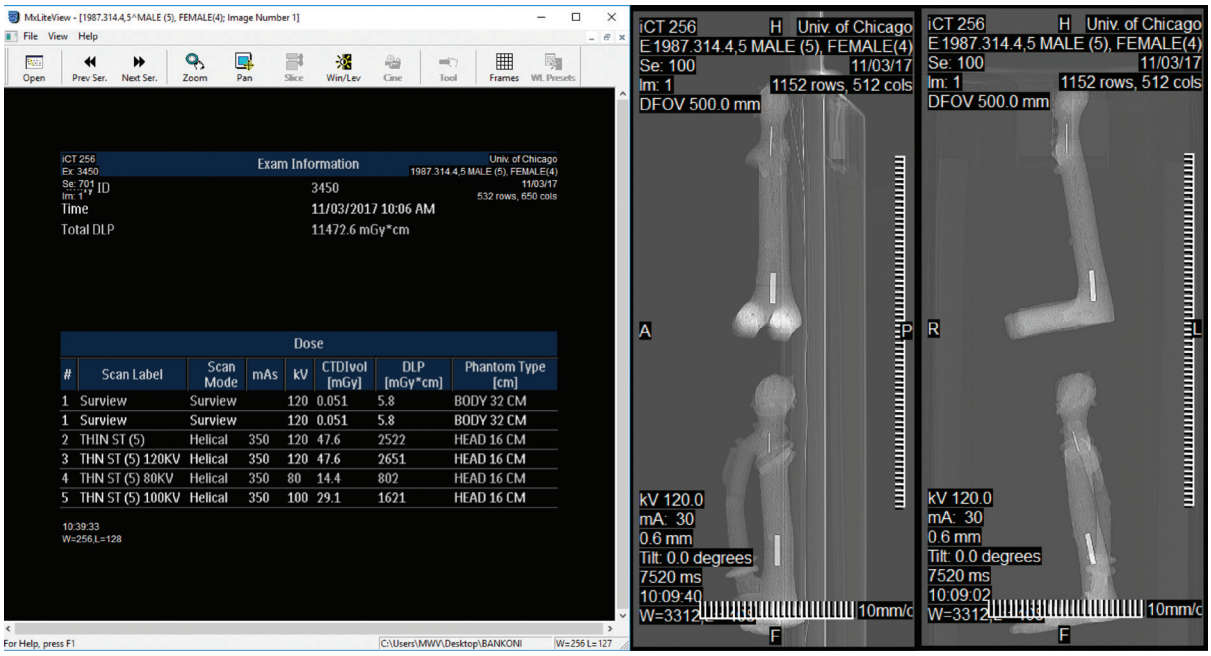

Figure 6. *Bankoni female figure, 1987.314.4, and Bankoni male figure, 1987.314.5, full dosimetry package alongside scout or surview scans as forwarded to Oxford Authentication Ltd. · Courtesy Art Institute of Chicago*

CONCLUSION

This study affirms the enhanced value of combined CT scanning and TL testing, and has allowed the Art Institute to confirm its Bankoni group was made with the same clay body and the same fabrication techniques, assuring the five were conceived as a group and are not composed of unrelated figures from different makers. This work adds to the existing body of knowledge demonstrating that CT scanning is not contraindicated for TL testing, particularly when comprehensive dosimetry information is forwarded along the with the samples. The new round of TL testing led to a revised attribution of 13th–16th-century manufacture. When authenticity is at issue, it is imperative that conclusions not be based on a single imaging or analysis technique, to ensure that no relevant information is missed. Technical study of these figures makes an important contribution to both a material and a region that has been significantly understudied, and complements their exhibition's contextualization within a larger corpus of formally excavated and documented objects.

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