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DECOYS X-RAYED: WHAT VOLUME RAD TOMOSYNTHESIS AND COMPUTED TOMOGRAPHY CONTRIBUTE TO TECHNICAL STUDY

NANCIE RAVENEL

This article will examine some of the issues of adapting medical radiography to the examination of wooden artifacts, and explore and compare the usefulness of two three-dimensional radiological techniques, VolumeRAD tomosynthesis and computed tomography, for revealing tool marks and marks within joints on wildfowl decoys in Shelburne Museum's collection. While digital radiography equipment has become more affordable for museums, the price tag still is out of reach for smaller labs. The conservators at Shelburne Museum turn to the radiological technologists at the University of Vermont Medical Center Hospital to assist with non-destructive examination of composite objects and paintings. Because of their size, decoys are well suited for transport from the museum to the hospital for study. At the hospital, the equipment used by the technologists to take standard radiographs for the conservators also can be used for VolumeRAD tomosynthesis, rendering the technique more accessible and convenient than computed tomography, which requires separate scheduling. The advantages and disadvantages of each technique will be explored.

KEYWORDS: Radiography, Computed tomography, Digital x-ray tomosynthesis, Wildfowl decoy

1. INTRODUCTION

The craft of making wildfowl decoys in North America has a rich and varied history. As demand for feathers for fashion and wild game for restaurants increased in the mid-19th century, decoy carving went from being the individual pursuit of hunters working to feed themselves or a small community to one that was also undertaken by professional woodworkers and commercial factories supplying professional wildfowl hunters serving a growing commercial market. Professional wildfowl hunters were referred to as "market gunners." It is said that in the 1870s, it was not uncommon that 15,000 ducks were taken by market gunners in a single day on the Chesapeake Bay (Grinnell 1901). Market gunners used hundreds of decoys in order to create the illusion of tranquility within their hunting blinds (Barber 1954).

The Migratory Bird Act of 1913, enacted to stem the rate at which wildfowl were being killed, brought the market-gunning industry to a screeching halt in the United States. While decoys were and continue to be produced for sport, professional decoy makers responded to the change by making decorative carvings. This industry was bolstered beginning in the 1920s thanks to collectors like Joel D. Barber and William J. Mackey, who arranged exhibitions and decoy carving competitions and wrote books and articles, and through increased interest in American folk art from museums and initiatives such as the Index of American Design.

Collectors of wildfowl decoys have been using x-radiography to learn more about the objects in their own collections for decades. Most often, collectors look for evidence of past repairs, especially replacement heads. Since not all makers marked their work, collectors take note of patterns and choices of fasteners within the decoys and, occasionally, marks hidden within joins to attribute decoys to specific makers. Working with medical or veterinary systems, radiographs of decoys can be found in exhibition pamphlets and catalogs at least since the mid-1980s (James 1988; Andresen and Dudley 2011).

The shape and manner in which these sculptures were assembled is regional, relating to available materials and the water conditions in a given hunting area. Decoys used for hunting show evidence of being set out on the waters, being shot over, and the manner of storage. Rigs of working decoys are commonly repainted and repaired in response to damage incurred in the field. Wooden keels and lead weights attached to the underside of the birds may be moved or exchanged in response to water conditions in a different region.

In 1981, a group of collectors and dealers was invited to Shelburne Museum to help assess the collection of 1,400 wildfowl decoys. Occasionally, the attribution of decoys to specific makers was questioned by the group, and they offered suggestions as to what to look for in the way of internal marks or features of construction. In other instances, the group had questions about the degree to which the decoy had been restored—specifically, whether heads had been replaced. In concert with a renovation of the exhibition building that houses the collection, I began to work with Shelburne Museum's decoy collection in 2014. In addition to wanting to resolve questions about the collection raised in 1981, other questions emerged about tools used to construct specific decoy and history of repair.

I solicited the assistance of radiological technologists at the University of Vermont Medical Center Hospital (UVMMCH), formerly Fletcher Allen Hospital, to radiograph selected decoys from the collection. While most questions could be answered through standard radiography, occasionally we found that when the feature we wanted to see was obscured by surrounding radiopaque material, clearer images could be achieved through a three-dimensional radiographic technique, VolumeRAD digital tomosynthesis (VolumeRAD). Because the instrument we were using for standard radiography was a VolumeRAD machine, digital tomosynthesis sweeps were undertaken on all decoys following a quick examination of the standard radiograph on the technologist's monitor. Computed tomography (CT) is a more common 3D radiographic technique that has been used to examine works of art and artifacts. In order to understand the value of information gleaned from images produced using the VolumeRAD technique, two decoys were examined using CT and VolumeRAD. This article will describe the advantages and disadvantages of each technique for examining painted three-dimensional wooden artifacts with metal fasteners using wildfowl decoys from Shelburne Museum's collection as illustrations.

2. OVERVIEW OF COMPUTED TOMOGRAPHY

In CT, the x-ray source and detector rotate completely around the object to create a series of two-dimensional cross section images. These series can be taken along any one of three planes. The coronal plane divides the front from the back; the sagittal plane divides the body laterally down the middle; and the transverse or axial plane divides the top from the bottom as it rests on the table.

The images in any one plane can then combined to create a three-dimensional image (fig. 2) or reconstructed to create two-dimensional orthogonal multiplanar reconstructions (2DMPR). Using the data from a single series of images in a specific plane such as the coronal view, the computer reconstructs the images in the transverse and sagittal views at a specific point and places the two resulting 2D images side by side with the initial 2D view. This allows the researcher to look at any single point within the object in all three dimensions simultaneously, as shown in figure 3.

Initially developed in the 1970s for medical applications, high-resolution CT scanning has been used to image human remains, natural history specimens, archeological artifacts within soil blocks, and rolled papyrus scrolls (Payne 2013). Previously, with the help of radiological technologists at the UVMMCH, I've used CT to examine dolls in Shelburne Museum's collection (Ravenel 2004; Ravenel 2011).

Due to constraints posed by the design of CT scanners used in the medical field, most CT studies within cultural heritage have involved examination of objects no larger than a prone adult human. That said, a technique to perform CT on large-scale works of art, specifically an inlaid fall-front desk made by Pietro Piffetti (Italy, 1701–1777), has been developed using a prototype scanner (Re et al. 2014). The scanner was redesigned so that the object was placed on a turntable and the x-ray source and detector moved vertically in a synchronized fashion to acquire the images. While decoys are smaller than adult humans overall (fig. 4), they do not always fit within a medical scanner due to their height or width. This kind of redesigned scanner could be as applicable to larger decoys if it were available.

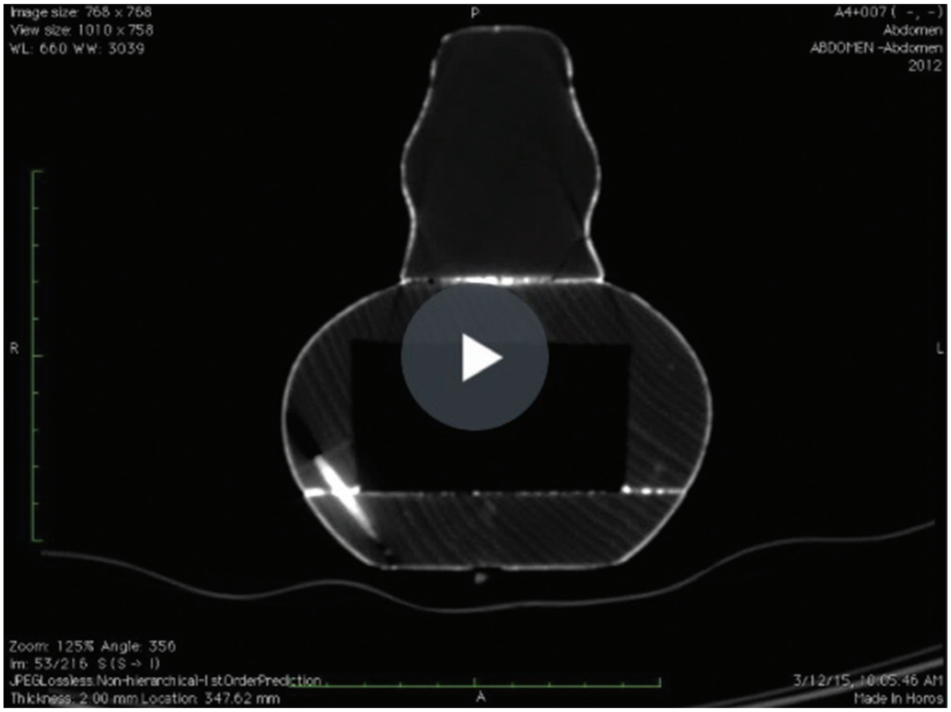

Fig. 1. Coronal view CT. Benjamin Holmes, *Black duck decoy*, ca. 1880, painted wood, iron, lead, leather, 16.2 x 16.2 x 41.9 cm, Shelburne Museum, 1952-192.57. Gift of J. Watson, Jr., Harry H., and Samuel B. Webb (Courtesy of Shelburne Museum and UVMMCH). Video available here: https://youtu.be/KlLPT44HhVg

Fig. 2. Three-dimensional reconstruction of CT of Holmes *Black duck decoy*, three-quarter view, from the coronal data (Courtesy of Shelburne Museum and UVMMCH)

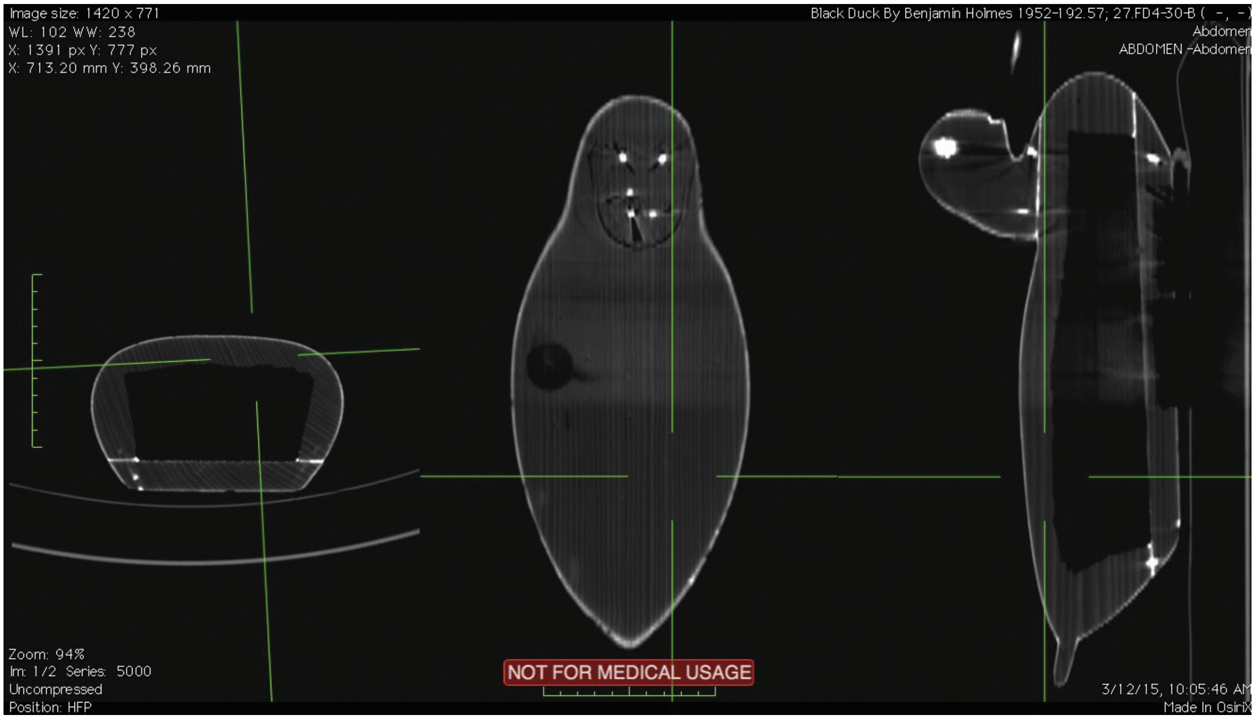

Fig. 3. An example of a two-dimensional orthogonal multiplanar reconstruction (2DMPR) view of Holmes *Black duck decoy*. Screen grab from OsiriX Lite DICOM viewing software. The coronal view is on the left, the transverse or axial view is in the center, and the sagittal view is on the right. Drill tip marks are circled in pink on the transverse view. Two marks made by a center drill bit are enclosed by a blue rectangle. The full circle surrounding the dot is a full turn by the bit, while the arc around the dot is a partial sweep created by the sharpened "tooth" on the outer edge of the bit. (Courtesy of Nancie Ravenel, Shelburne Museum, and UVMMCH)

Time on hospital CT scanners can be difficult to schedule as they are in high demand clinically. Of the 18 wildfowl decoys radiographed in the last two years, we've looked at two using CT, but commonly use VolumeRAD because of its convenience.

2.1 ISSUES CAUSED BY METAL COMPONENTS IN CT

Imaging objects containing metal fasteners or covered in lead-based paints using CT can be challenging. Medical radiographic literature documents efforts to improve digital x-ray CT images of bodies containing metal-based inclusions such as dental fillings, prosthetics, or ballistic damage by altering the conditions under which the CT is taken or the algorithm used to analyze the data that produces the images. While there have been examples of successful studies of pattern welding in medieval swords undertaken using medical and industrial x-ray CT (Stelzner et al. 2016), beam hardening resulting from metal content, whereby the x-ray photons are scattered by the dense material and create obscuring or distorting errors in the resulting images, limits their usefulness.

Distortions, flares, and voids are evident in the images around the metal weights on the underside of decoys, around the eyes due to metallic content in the glass, around the fasteners in necks, and the radiopaque fills in the back of the Albert Laing black duck decoy (fig. 5). The images show voids around these metallic parts where none exist, and in the cases of the lead weights, create light or dark flares that obscure features in other parts of the image.

In the coronal view CT images, the wood grain is clearly evident in Holmes *Black duck's* body (fig. 1), but artifacts from the metal fasteners, lead-containing adhesive, and eyes make it difficult to tell

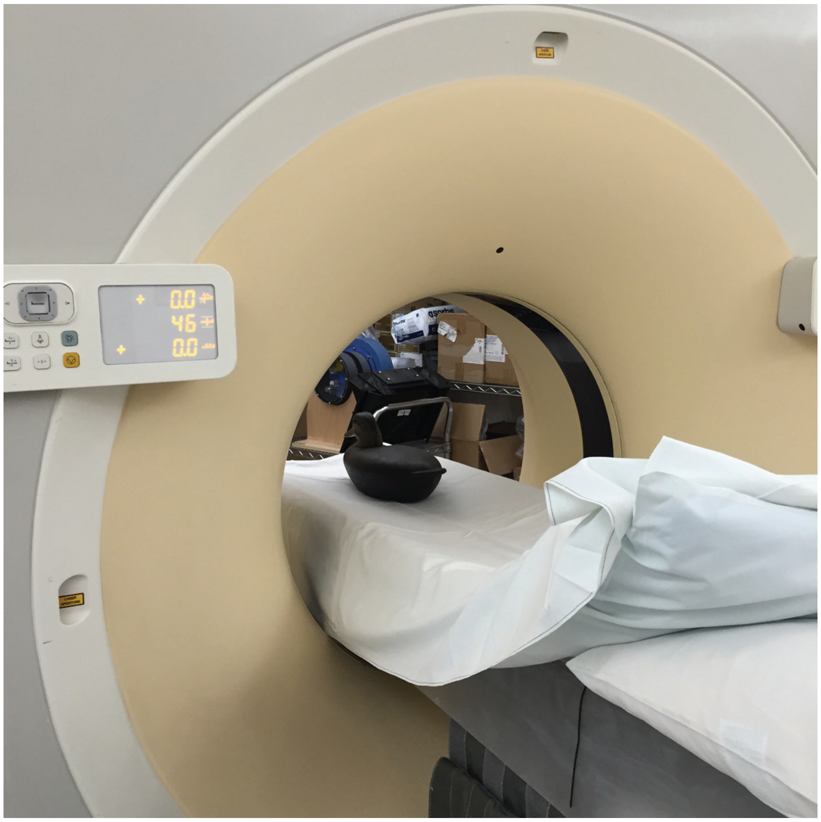

Fig. 4. Holmes *Black duck* in the Phillips Ingenuity CT scanner at UVMMCH (Courtesy of Nancie Ravenel, Shelburne Museum, and UVMMCH)

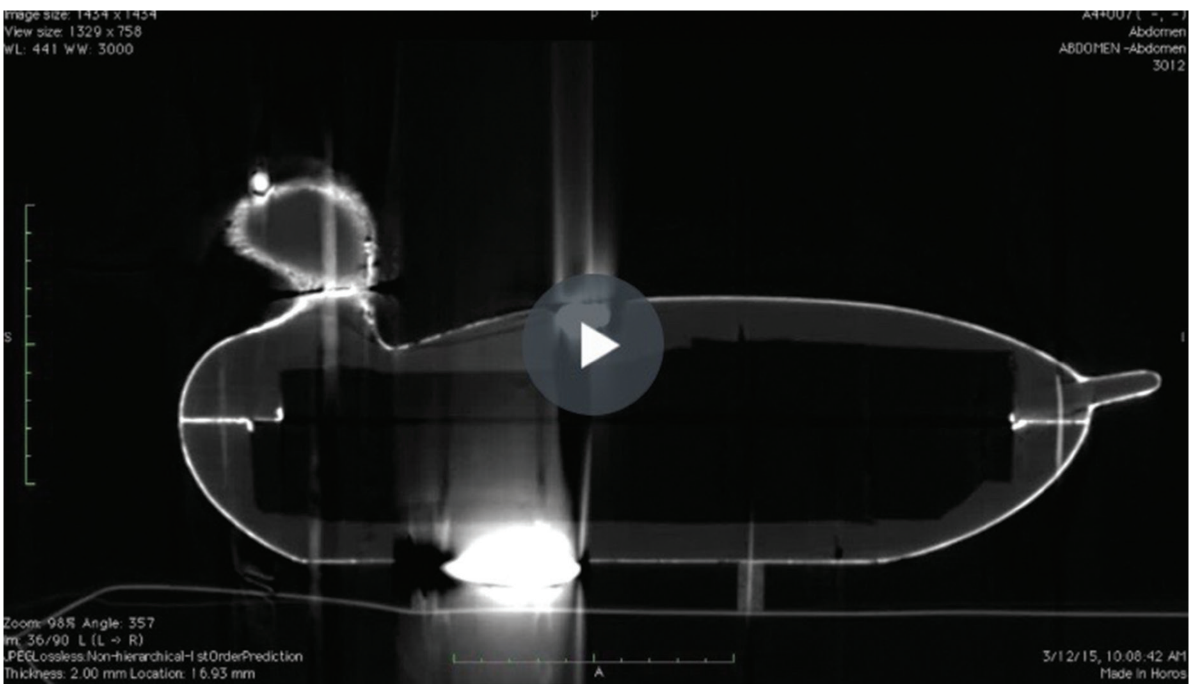

Fig. 5. Sagittal view CT. Albert Laing, *Black duck decoy*, date unknown, painted wood, iron, lead, leather, 17.8 x 16.2 x 40.6 cm, Shelburne Museum, 1952-192.46. Gift of J. Watson, Jr., Harry H., and Samuel B. Webb (Courtesy of Shelburne Museum and UVMMCH). Video available here: https://youtu.be/I2-cmE4PoIs

whether the lines through the head are wood grain or simply flares caused by the paint or other metallic features. However, by viewing the data as a 2DMPR (fig. 3), one can find areas within the structure that are not as affected by distortions, and features of the wood and clues about how it was shaped become more apparent. Especially notable in both the Holmes and Laing *Black ducks* are the marks of drill bits arranged in rows in the top of the hollow within the decoys' bodies as viewed in the axial plane. By moving up through that plane, the cylindrical shape formed by the bits terminate in points at the centers of the circles, and a single cutting point located at the outer perimeter of each mark. The form of these tool marks suggests that a center bit was used to hollow the bodies. This is notable in that the variety of drill bit used can be discerned by following the manner in which the tool bites into the wood by moving through the transverse plane in the 2DMPR.

3. OVERVIEW OF DIGITAL X-RAY TOMOSYNTHESIS AND VOLUME RAD TOMOSYNTHESIS

Conventional medical x-ray tomography was developed in the first half of the 20th century to view consecutive sections of a body in order to separate an area of interest from competing structures. It was a precursor to CT (Littleton and Durizch Littleton 1996). In conventional medical x-ray tomography, the object of study remains stationary while the x-ray tube and film move simultaneously in opposite directions on opposite sides of the object. As a result, the fulcrum of that motion located within the object being studied is in focus in the radiographic image while the surrounding out-of-plane material appears blurry and thus less visible (Farlex Partner Medical Dictionary 2012). Digital x-ray tomography, a relatively recent refinement of conventional tomography, acquires multiple in-focus planes from a sequence of radiographic images taken in one sweep of the x-ray tube while the detector and the object of study remain in fixed positions. The raw data from the detector is then reconstructed and resliced to optimize the resulting images (Dobbins and Godfrey 2003). The individual images can then be viewed in sequence to get a sense of the object's volume.

VolumeRAD tomosynthesis is a digital x-ray tomosynthesis application produced by GE Healthcare. In the 10 years that VolumeRAD has been available to the medical community, it has been used to assess and monitor bone fractures and to detect nodules in the lungs (GE Healthcare 2016). Other companies including CanonUSA and Shimadzu either have produced or are producing competing devices (Iversen et al. 2015).

In VolumeRAD, the x-ray tube moves in a 40° arc over the object, taking as many as 60 images in a single sweep, depending on what protocol is applied (GE Healthcare 2016). The minimum thickness of an image is 1 mm. VolumeRAD typically uses a fraction of the radiation used to run a CT scan. Because the radiologists at UVMMCH use the GE Healthcare Discovery XR656, the machine that runs VolumeRAD, to create standard radiographic images of works of art and artifacts from Shelburne Museum, performing VolumeRAD sweeps is convenient; no separate scheduling is required. Because the design of the apparatus is more open than a CT machine, the size of the object is less of an issue (fig. 6). Larger objects can be repositioned for scanning. Since less radiation is required, metal fasteners and lead-containing coatings and adhesives do not create flares to the same degree they do in CT.

The resulting slices are linear with unfocused edges. Because the arc is not a complete 360°, the resulting slices cannot be reconstructed in three dimensions or reconfigured into other reconstructions in the same way CT slices can be. While the raw data volume can be resliced to further enhance the images, this cannot be undertaken after the images have been processed. Depending on the location of an internal feature, the object may need to be repositioned so that the desired feature will be in focus during a sweep.

Although metal or other high-contrast components within a structure may still cause unwanted ripples or blurs in VolumeRAD images, especially when the high-contrast element is oriented perpendicular to the sweep direction, the effect can be reduced by altering the angle of the object relative to the sweep or increasing the number of images acquired during a sweep (Machida et al. 2010).

Despite these drawbacks, VolumeRAD has proven its value for imaging internal marks that could not be imaged in CT either due to the size of the decoy or to the confounding influence of metal fasteners or lead weights. VolumeRAD also elucidates details of metal fasteners, such as the shape of a slot in a screw head, that might be obscured by other features within the object in a standard radiograph or would be indistinct in a medical CT.

3.1 VOLUME RAD TOMOSYNTHESIS IN PRACTICE: *SWAN DECOY* BY SAMUEL BARNES

Collector and author Joel Barber recounted the story of how he acquired the swan made ca. 1890 by Havre-de-Grace, Maryland carver Samuel Barnes (1857–1926) in his book *Wild fowl decoys* (1954), the first work to consider decoys as works of art. Despite Barber's account, in the 1980s, two decoy scholars questioned the attribution of the swan to Barnes, suggesting that it could be the work of another Havre-de-Grace carver, James Holly (1855–1935). A minimally repaired swan decoy unquestionably attributed to Samuel Barnes features a neck attached to the body with a dowel so that the head could be removed, and an incised Roman numeral "II" on the neck shelf, the join surface on the body with the neck (Johnsgard 1976). The scholars wanted to know if Shelburne's decoy had a similar mark.

Because of numerous metal fasteners added as repairs to secure the joins between the neck and head and in the join between the neck and body, the standard posterior-anterior view radiograph taken from above the neck shelf was fairly inconclusive as far as identifying a mark (fig. 8). The posterior-anterior view is created when the object is laid on the examination table such that the x-ray generator is located above and the digital x-ray detector, taking the place of film, is located within the table or directly under the object. The swan was too large to fit in the medical CT scanner at the UVMMCH, so VolumeRAD tomosynthesis was used to determine whether or not a maker's mark was present on the neck shelf.

By choosing appropriate starting and stopping points within the scan, an image of an incised mark was located. The technologist undertook a sweep of 24 projections around the join between the neck and body in the axial or transverse plane (fig. 7). Within the sweep, one projection provided a good view of the mark, a Roman numeral "III," on the neck shelf and a view of the top of the dowel that originally secured the neck to the body. This is more visible than it was in the 2D radiographic image (fig. 8). Another projection provides an image of the metal pin, which appears to be a headless rod that stops short of either side of the neck, that secures the neck through the dowel (fig. 9). Because the fastener is in plane with the x-ray source, there is no ripple or other distortion in the image.

3.2 VOLUME RAD TOMOSYNTHESIS IN PRACTICE: WHISTLER DRAKE DECOY BY THE MASON DECOY FACTORY

Using CT, it had been possible to capture tool marks in the hollows of the Holmes and Laing black ducks. We chose the hollow Mason Decoy Factory *Whistler drake decoy* (fig. 10) as a test subject to see if the same was possible with VolumeRAD, primarily because it had few complicating factors. The paint on the decoy was original and thinly applied but worn, exposing the wood grain on the surface of the body. The continuous nature of the wood grain across the seam in the decoy's body suggested that the body had been shaped before it was cut in half and hollowed. There was no indication of wood fasteners holding the neck to the body, and the ballast had had been removed from the underside. Thus, the only metal components expected within the decoy were nails securing the upper half of the body to the lower half, x-ray opaque adhesives, and the metal trace elements in the glass eyes.

Fig. 6. Swan decoy sitting on the GE Healthcare Discovery XR656 at the UVMMCH. Samuel Barnes, *Swan decoy*, ca. 1890, painted wood and iron, 48.6 x 24.1 x 97.2 cm, Shelburne Museum, 1952-192.4. Gift of J. Watson, Jr., Harry H., and Samuel B. Webb (Courtesy of Shelburne Museum and UVMMCH)

Fig. 7. VolumeRAD sweep, axial plane, of the neck shelf from the Barnes *Swan* (Courtesy of Shelburne Museum and UVMMCH). Video available here: https://youtu.be/I2-cmE4PoIs

Fig. 8. Projection 7/24 of the axial VolumeRAD sweep of the neck shelf on the Barnes Swan (left) and the posterior-anterior view two-dimensional radiograph of the same area. Pink rectangles indicate the location of the maker's mark on each image (Courtesy of Shelburne Museum and UVMMCH)

The standard radiograph in the lateral view (figure 11) indeed showed a drill mark in the upper back of the decoy, and the cone shape of the hollow suggested that the drill bit may have been rocked to create the hollow's slanted walls. One could also see that the head was attached to the body by means of a wooden dowel through the neck, secured with a metal pin. The posterior-anterior view radiograph also

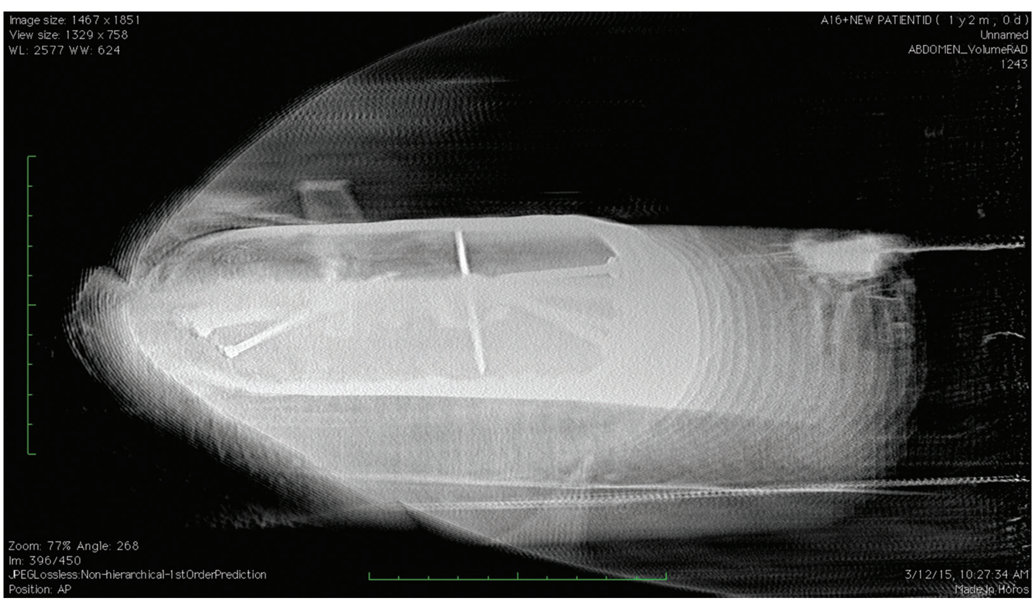

Fig. 9. Projection 13/24 of the axial VolumeRAD sweep of the neck shelf on the Barnes Swan. A pink rectangle indicates the area showing the metal pin securing a metal dowel (Courtesy of Shelburne Museum and UVMMCH

Fig. 10. Mason Decoy Factory, *Whistler drake decoy,* ca. 1900, painted wood, glass, and iron, 16.2 x 14 x 36.2 cm, Shelburne Museum, 1956-707.118. Museum purchase, acquired from Richard H. Moeller, 1956 (Courtesy of Shelburne Museum)

clearly showed the trace of the drill bit in the upper back and that the body had been split at the join line using a band saw, but was inconclusive as to how the bottom section was hollowed out.

Using a variant on a wrist protocol, the technologist performed a VolumeRAD scan with 33 projections in the sagittal or lateral view, with each projection measuring approximately 2 mm in thickness. In the 24th projection of the scan, one can see a more defined mark in the top of the back, but the centers of the drill tips were also clearly visible in the bottom of the hollow, a feature that could not

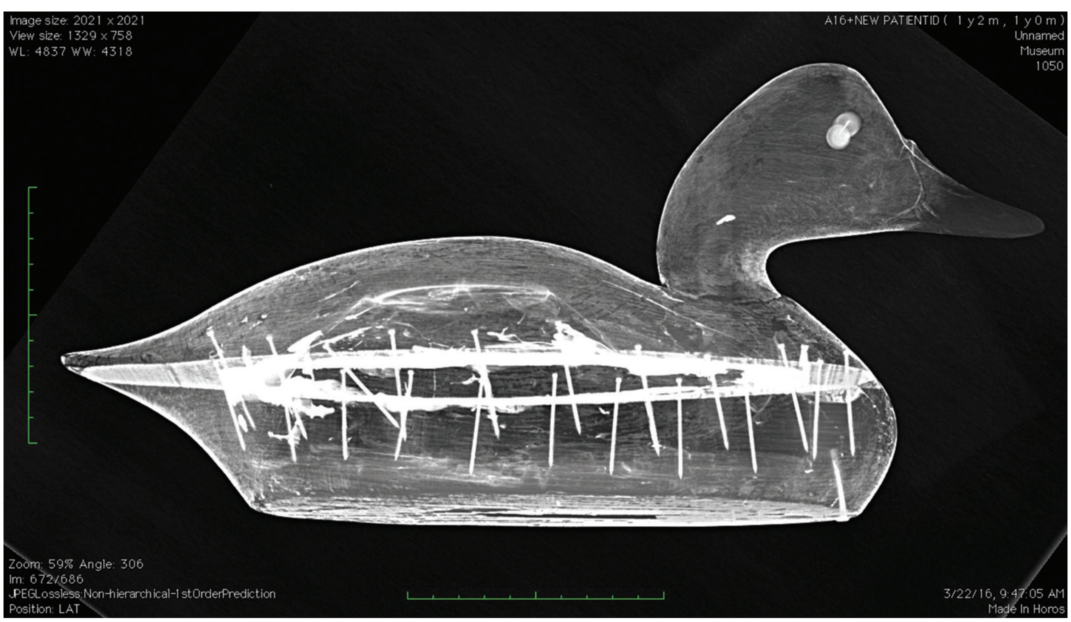

Fig. 11. Lateral view radiograph of the Mason Decoy Factory *Whistler drake decoy* (Courtesy of Shelburne Museum and UVMMCH)

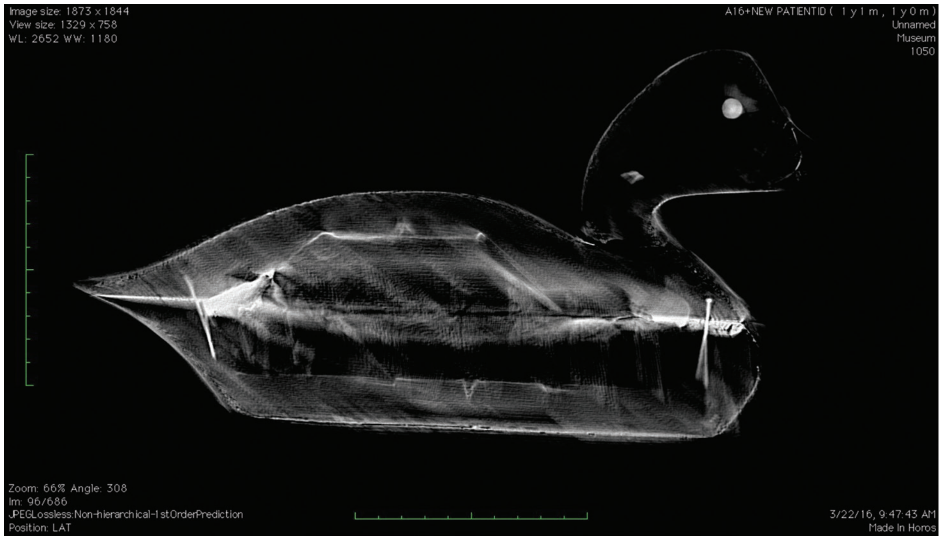

Fig. 12. Projection 24/33 sagittal view VolumeRAD scan of Mason Decoy Factory *Whistler drake decoy* (Courtesy of Shelburne Museum and UVMMCH)

be seen in the two-dimensional lateral view (fig. 12). For the axial or transverse view, using the same variant on the wrist protocol, the technologist performed a sweep with 23 projections, each measuring about 2 mm in thickness. In projection number 9 of the scan, approximately 18 mm from the underside of the decoy, one can see five rotations of what appear to be marks from Forstner bits (fig. 13). The centers of the marks are different sizes, which could suggest that the drill bits were run at various angles at each location as the hollow was being cleared.

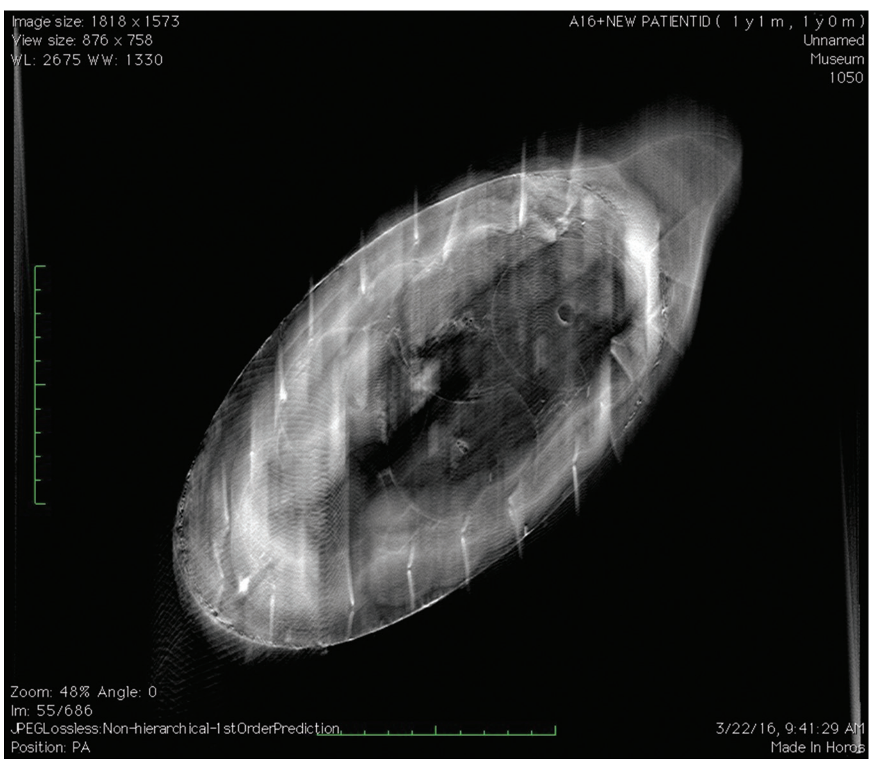

Fig. 13. Projection 9/23 axial view VolumeRAD scan of Mason Decoy Factory *Whistler drake decoy* (Courtesy of Shelburne Museum and UVMMCH)

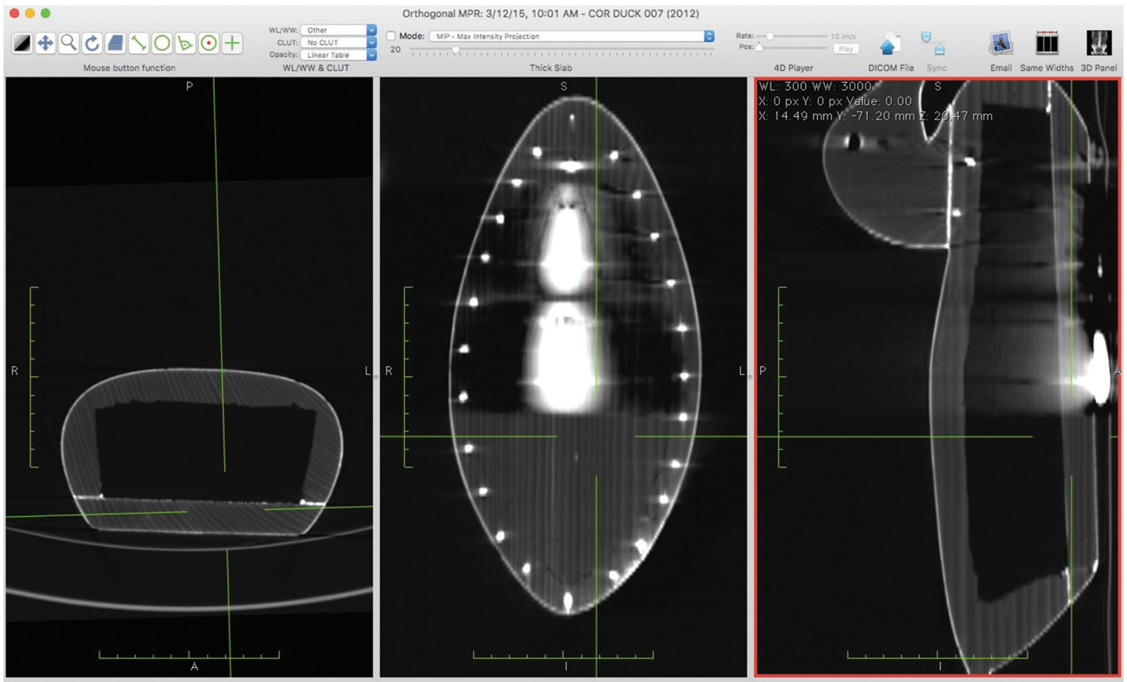

Fig. 14. 2DMPR from coronal view CT series from *Black duck decoy* by Benjamin Holmes (Courtesy of Nancie Ravenel, Shelburne Museum and UVMMCH)

4. CT AND VOLUME RAD HEAD TO HEAD: *BLACK DUCK DECOY* BY BENJAMIN HOLMES

In the interest of clarifying the relative utility of CT and VolumeRAD, let's return to the Holmes *Black duck decoy*. Looking at the individual 2D slices within the CT in figure 1 and in the 2D MPR of the CT data in figure 14, not only is the wood grain apparent in the CT slices, but we can also see that the wood grain in the bottom board is continuous with the rest of the body, indicating that maker, Benjamin Holmes, produced the body from a single block of wood, slicing a piece off the bottom to make the bottom board before hollowing out the upper part. This may place the decoy earlier in Holmes's career (Chitwood 1997). The wood grain structure is not evident in the standard radiograph or VolumeRAD images, possibly obscured by the priming layer of paint. However, the texture of the painted surfaces on the bottom board are clearly evident and discernible from one another in the VolumeRAD projections (fig. 15) while that interior painted surface is not easily identified within the CT images. Figure 15 also shows the position of the screw holding the rigging loop to the underside of the decoy relative to the lead weights, a feature obscured by the head in the standard radiograph.

Thus, both techniques, CT and VolumeRAD have the potential to reveal aspects of the manner in which decoys are constructed that the other one might not.

5. CONCLUSIONS

Three-dimensional radiographic techniques allow the conservator to view features within polychrome objects that may be obscured or hidden in two-dimensional radiographic images. Computed tomography provides full 360-degree data which can be reconstructed in a number of ways. However, the amount of radiation involved in scanning an object with CT can result in beam hardening when the radiation

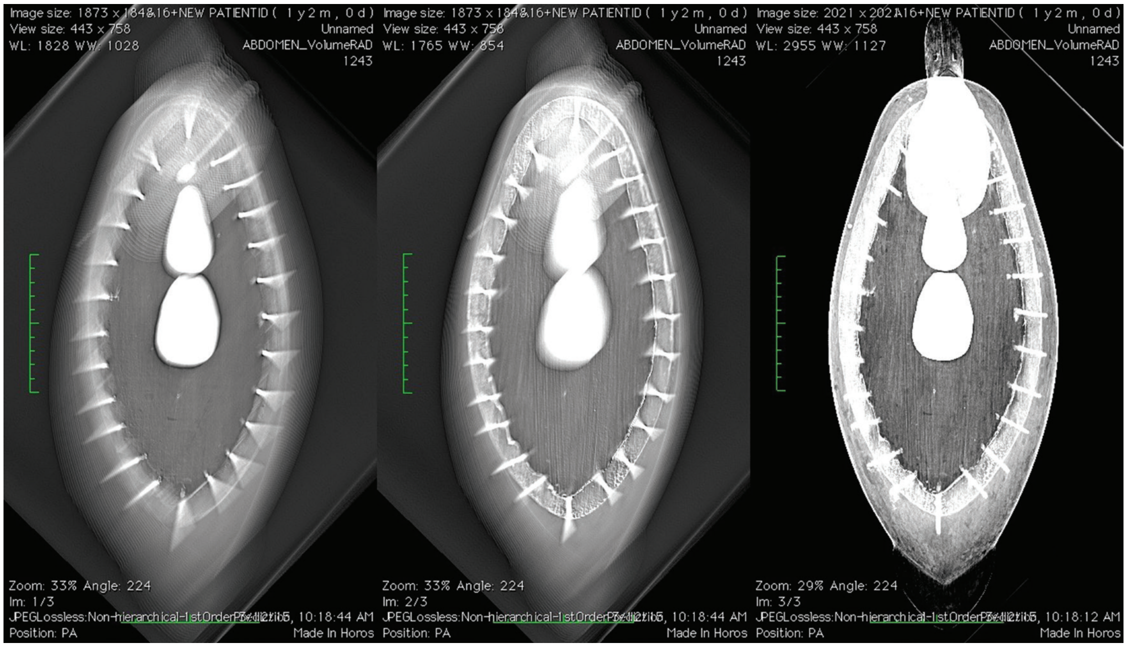

Fig. 15. VolumeRAD projection 5/23, axial view, from the bottom of the Holmes *Black duck decoy* (left), VolumeRAD projection 15/23, axial view, from the bottom of the Holmes *Black duck decoy* (center), and posterior-anterior view radiograph of the Holmes *Black duck decoy* (right) (Courtesy of Nancie Ravenel, Shelburne Museum, and UVMMCH Diagnostic Radiology Department)

encounters radiopaque materials such as paint, metal fasteners, or glass-containing parts. The resulting image artifacts may obscure, obliterate, or distort features of interest within the image.

While figures 1-3 reveal some of the value of looking at painted wooden objects with CT, they also touch on some of the challenges. Chief among these is the manner in which radiation bounces off of metal fasteners and lead-containing fills, adhesives, and paint. Metal objects within the decoys are distorted in appearance. The resulting flares can obscure or even obliterate structural features. For instance, the nails holding the bottom board to the body are indistinct; from the CT image we can't see if they are cut nails or finishing nails, and the lead weights appear pulled out of shape.

VolumeRAD tomosynthesis uses less radiation to complete a scan, but the data represents only a fraction of that which is collected in a CT. Although there are currently fewer options to reconstruct the resulting data for viewing, metal fasteners will be clearly visible and minimally distorted if they are in plane with the scan because less radiation is required for the scan. Because the scan is an arc rather than a full 360-degree sweep, patience is required in making the scan, and the object may need to be repositioned relative to the detector so that features of interest are in the proper plane. VolumeRAD projections are thicker than CT slices, so there is a chance that details such as interior tool marks could be missed in reviewing images.

Depending on the location of metal fasteners and components and the thickness of paint coatings, medical CT and VolumeRAD are capable of revealing marks and other aspects of construction that are not visible in standard two dimensional radiographs.

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