Proceedings of the joint international event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES, Valencia (Spain). 26–28 April 2021

Received: 27/11/2020
Accepted: 26/02/2021

USE OF A NOVEL, LOW-COST 3D CT-SCAN VIEWER BY THE HOYO NEGRO PROJECT, QUINTANA ROO, MEXICO

James C. Chatters[a], William O. Adams Jr.[b], Diana Arano Recio[c], Dominique Rissolo[d,*], Helena Barba Meineke[e]

[a] Applied Paleoscience, Bothell, Washington, USA. paleosci@gmail.com

[b] MedVizi, LLC, Salt Lake City, Utah, USA. bill.adams@medvizi.com

[c] Delegación Campeche, Instituto Nacional de Antropología e Historia, Mexico. darano.camp@inah.gob.mx

[d] Center of Interdisciplinary Science for Art, Architecture, and Archaeology, University of California, San Diego, USA. drissolo@ucsd.edu

[e] Subdirección de Arqueología Subacuática, Instituto Nacional de Antropología e Historia, Mexico. helenabarbamei@gmail.com

Abstract:

Computed tomography (CT) scanning technology has become an invaluable tool for archaeological and paleontological research, particularly in the study of ancient human skeletons. Once CT scans have been obtained, however, viewing and analyzing the results typically has high entry-costs in terms of hardware and software. Here we report a new, low-cost app for exploring CT scans in 3D, called MedVizi™. We briefly discuss its application to the study of Naia, the late Pleistocene human skeleton from Hoyo Negro, Quintana Roo, Mexico.

Keywords: CT scanning, 3D visualization, bioarchaeology, Mexico

1. Introduction

Radiological imaging is an increasingly important tool for bioarchaeological, paleoanthropological, and paleontological research and conservation. In paleontology and paleoanthropology, X-rays and particularly computed tomography (CT) scans have been used to investigate matrix-enclosed fossils, aiding in extraction planning and 3D visualization of as-yet unexposed bones and giving access to internal structures, including brains (Müller, Ferreira, Pretto, Bronzati, & Kerber, 2020). It is almost impossible to publish findings on such skeletal features without accompanying radiographic evidence.

While CT scanning has become essential in paleo-osteological research, it is far from universally accessible. High entry costs create insurmountable barriers for many researchers, particularly faculty, students, and staff of smaller colleges and individuals at resource-challenged institutions. CT scan equipment used in hospitals, dental offices, and industrial settings costs ~$250,000 -> $1,000,000 USD. It is typically necessary to develop alliances with hospitals, medical schools, and colleagues with substantial grant funding to obtain the initial data. This can be the easy part. Once a specimen is scanned, software to investigate large 3D volumes can cost upwards of $15,000 USD and require a specialized workstation which is equally expensive. The new MedVizi™ mobile viewer allows specimens to be explored offline, without being connected to these expensive systems.

The MedVizi™ mobile viewer is developed by MedVizi, LLC of Salt Lake City, Utah. It can be used to explore and manipulate CT scans and 3D volumes of specimens on iPhone® and iPad®. Digital Imaging and Communications in Medicine (DICOM) files generated by the medical CT scanner and TIFF files produced by microCT systems are sent to MedVizi™ and for $150 USD are converted directly into 3D volumetric studies. Studies are configured to be rotated or peeled in the sagittal, coronal, or axial plane with density threshold manipulation. In addition, MedVizi™ can apply color to enhance density, simplifying illustration of skeletal features of interest. This represents functionality typically only found on expensive systems like those that accompany CT scanners (Christiansen, Shorti, Smith, Prows, & Bishoff, 2018). Once uploaded to the MedVizi™ website, these studies can be downloaded multiple times to numerous mobile devices and explored in real time in the office, laboratory, or even in the field without being connected to expensive, non-portable systems. Cost of the mobile viewer is $0.99 USD.

2. Hoyo Negro Case Study

Hoyo Negro is an immense collapse chamber located deep within the submerged Sac Actun cave system of eastern Quintana Roo state, Mexico (Chatters et al.,

* Corresponding Author: Dominique Rissolo, drissolo@ucsd.edu

2017). In that chamber, at depths between 39-50 m below sea level, our research team led by the Subdirección de Arqueología Subacuática of the Instituto Nacional de Antropología e Historia has documented the remains of over 50 mammals of 18 species, including a human. The human skeleton, an adolescent female known as Naia, has been dated by radiocarbon and uranium-thorium methods to between 13,000 and 12,000 cal BP (Chatters et al., 2014). Missing only a few ribs and vertebrae, along with most bones of the feet, Naia is the most complete of the earliest skeletons from the Western Hemisphere. As such, she provides an unequaled opportunity to explore the life of a young female among the earliest Americans.

To document and obtain a record of the bones, should they disintegrate upon contact with air, the remains were first CT scanned while in water-filled collection containers at the Hospital de Especialidades in Campeche, Mexico. Thereafter, numerous additional scans were conducted, including dental and microCT scanning at the Universidad Autónoma de Yucatán. MicroCT images were also obtained using Nikon Metrology X Ray CT XTH225ST at the Facultad de Odontología, Universidad Nacional Autónoma de México (UNAM), Mexico City and a Zeiss Xradia Versa 510 at the Geosciences Center, UNAM Querétaro. The problem we faced, despite this extensive, detailed record, was the lack of systems and expertise for viewing and manipulating these detailed datasets.

MedVizi™ contacted the senior author in summer, 2020, offering the viewer and service to the Hoyo Negro Project. We have since used it to explore Naia's skeleton, and for the first time are able to work through high resolution microCT and medical CT DICOMs to explore the endocranial cavity (Fig. 1), investigate anomalies in the teeth (Fig. 2), inspect detailed growth anomalies in the long bones (Fig. 3), and validate limb fractures (Fig. 4), among other studies.

Figure 1: An image from the MedVizi app, in the process of sagitally "peeling" the skull to expose the endocranial cavity of Naia from Hoyo Negro.

In the teeth, for the first time, we were able to work through microCT slices to determine tooth root number, investigate the extent and severity of caries, and map the extent and severity of diagenesis. With these findings, we were able to more selectively sample one of the teeth for radiocarbon dating while avoiding contaminated tissues in the diagenetically altered dentine.

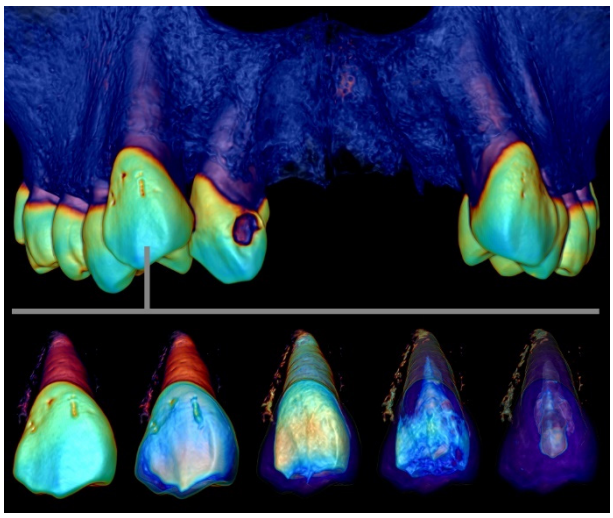

Figure 2: A composite of images produced by MedVizi, including a volumetric model of the maxilla (above) showing a large carious lesion in a second incisor, and a series of images of the right canine, extracted from the maxilla and highlighting high density tissues at left progressing to emphasis of low density on the right.

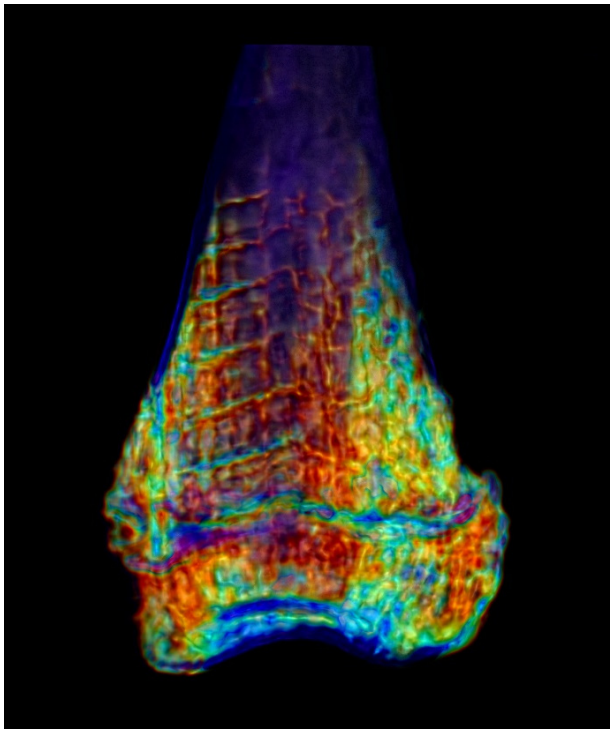

Figure 3: Naia's left femur, peeled to expose bright Harris lines transverse to the bone's long axis.

In the long bones, it was possible to scroll through the partially deteriorated trabecular bone to visualize, count, and quantify the severity of multiple episodes of growth interruption indicative of severe protein deficiency or abrupt surges in protein availability. This takes us a significant step toward understanding this young woman's mode of subsistence.

Manipulating density in the left radius, we could better visualize and confirm a healed spiral fracture, indicating a possible episode of abuse in her young life.

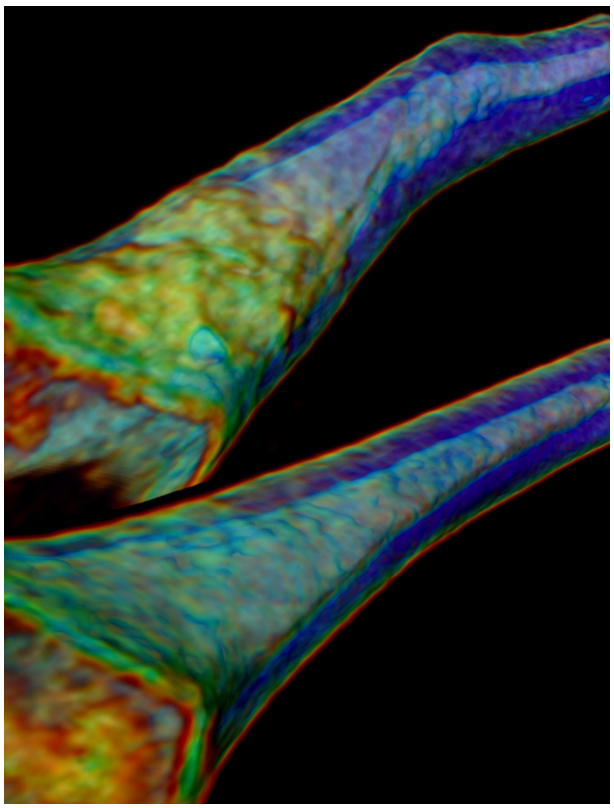

Figure 4: Sections of the diaphyses of Naia's radii, manipulating density to show the normal right (lower) and the healed spiral fracture in the left (above), which appears as a shaded green line.

3. Tools and Methods

In addition to the "hollow geometry surfaces" used in 3D printing, light scans and VR, it is desirable to explore both the interior and surface densities of a specimen CT scan using 3D pixels called "voxels." Two free tools helpful for viewing voxels and organizing CT scans are 3DSlicer and Horos™ desktop viewer for Mac. Both have 2D grayscale and basic 3D rendering. Horos™ also offers a mobile viewer with 2D grayscale and limited 3D rendering. 3DSlicer does not offer a mobile viewer. Unlike most other mobile viewers, neither the Horos™ nor MedVizi™ mobile viewer suffer from remote-render lag or 15 viewer per-server limitations. In addition to 2D grayscale, MedVizi™ Mobile renders cinematic 3D reconstructions in real time while rotating or changing density and peeling in axial, sagittal and coronal planes. Medical CT DICOM and microCT TIFF files sent to MedVizi are reconstructed into voxels in MedVizi™ Workstation. Voxel density changes are stored as opacity, color, surface and lighting in studies shared via the cloud. On iPhone® or iPad®, tapping a MedVizi™ link in text or email prompts "install" or "study download." Once downloaded, 2D and cinematic 3D reconstructions from multi-gigabyte CT scans open instantly and can be explored in real time, even in the field.

4. Concluding Statement

MedVizi™ is an inexpensive alternative to high-priced 3D systems for CT that effectively makes this important analysis, visualization, and documentation technique much more readily available to archaeological, paleontological, and paleoanthropological practitioners. Needing only an iPhone® and access to the Internet during download, it will be particularly valuable for researchers who do not have access to more costly software solutions.

Acknowledgements

This research is a project of the Subdirección de Arqueología Subacuática of the Instituto Nacional de Antropología e Historia (INAH), Mexico, directed by Roberto Junco. Field research was conducted under the supervision Adriana Velázquez Morlet and Margarito Molina of Centro INAH Quintana Roo. Funding for the recovery of human skeletal remains was provided by the National Geographic Society, with field activities facilitated by CINDAQ. Specific to the research presented here, we thank Leopoldo Ruiz, Dante Arteaga, and Norman H. Gellada. The following individuals have been integral to the success of the Hoyo Negro Project: Alejandro Alvarez, Joaquín Arroyo-Cabrales, Franco Attolini, José Balam, Patricia Beddows, Susan Bird, Roberto Chávez Arce, Andrea Cucina, Danylo Drohobytsky, Falko Kuester, Eric Lo, Robert Lourie, Sam Meacham, Alberto Nava Blank, Vid Petrovic, Eduard Reinhardt, Blaine Schubert, Brian Strauss, Vera Tiesler, and always Pilar Luna Erreguerena.

References

Chatters, J. C., Kennett, D. J., Asmerom, Y., Kemp, B. M., Polyak, V., Nava Blank, A., Beddows, P. A., Reinhardt, E., Arroyo-Cabrales, J., Bolnick, D. A., Malhi, R. S., Culleton, B. J., Luna Erreguerena, P., Rissolo, D., Morell-Hart, S., & Stafford, T.W., Jr. (2014). Late Pleistocene Human Skeleton and mtDNA Link Paleoamericans and Modern Native Americans. *Science, 334*(6185), 750-754. https://doi.org/10.1126/science.1252619

Chatters, J. C., Rissolo, D., Arroyo-Cabrales, J., Stafford, T. W., Jr., Kemp, B. M., Alvarez, A., Nava Blank, A., Attolini, F., Beddows, P. A., Reinhardt, E., Kovacs, S., Collins, S., Morell-Hart, S., Chávez-Arce, R., Bird, S., & Luna Erreguerena, P., (2017). Hoyo Negro: Tapping the Paleoanthropological and Paleoecological Potential of a Deeply Submerged, Underground Chamber on the Yucatan Peninsula, Mexico. In P.B. Campbell (Ed.), *The Archaeology of Underwater Caves* (pp. 119-129). Southampton: Highfield Press.

Christiansen, A. R, Shorti, R. M., Smith, C. D., Prows, W. C., & Bishoff, J. T., (2018). Intraoperative utilization of advanced imaging modalities in a complex kidney stone case: a pilot case study. *World Journal of Urology, 36*(5), 733-743. https://doi.org/10.1007/s00345-018-2260-4

Müller, R. T., Ferreira, J. D., Pretto, F. A., Bronzati, M., & Kerber, L., (2020). The endocranial anatomy of Buriolestes

schultzi (Dinosauria: Saurischia) and the early evolution of brain tissues in sauropodomorph dinosaurs. *Journal of Anatomy, 238*, 809-827. https://doi.org/10.1111/joa.13350