RECONSTRUCTING THE ANCESTRAL INHERITANCE OF COSTA RICA: MULTI-DISCIPLINARY METHODOLOGY UTILIZING 3D DIGITAL TECHNOLOGY

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ABSTRACT
This research is an archaeological investigation to identify Costa Rica's ancient people, placing a face on their history. The bones will be given a voice, reclaiming the identity of a country's lost human heritage as a bequest to the children who are the face of Costa Rica's future.

According to the radiocarbon date of 500 BC, burials at the archaeology site of La Regla, Gulf of Nicoya, Costa Rica contain some of the oldest human skeletal specimens in Central America. Excavations revealed multiple secondary bundled burials with associated material artifacts. The bundles were found entombed in a coastal swamp; heavy concretion limited traditional archaeological analysis and conservation and required new methodology. This undergraduate research project approaches the challenge with a multi-disciplinary strategy combining advanced digital techniques of non-destructive imaging and methods of non-invasive analysis to conserve, re-construct and duplicate selected bioarchaeological remains and burial artifacts from the Regla site.

Utilizing contactless CT scans, precise 3D models of the human skulls are printed and reviewed for accuracy by the 3D Systems VSP® (Virtual Surgical Planning) team of technical experts. These 3D models serve as the anatomical base for forensic facial clay reconstructions by a skilled forensic artist. These forensic reconstructions also incorporate 3D printed models of associated relics and adornments, such as a Spondylus shell collar, into the human depiction sculptures as the evidentiary material of the ancient people's rich artistic patrimony. These forensic sculptures will anchor the planned exhibit featuring the ancestral heritage of Costa Rica's indigenous people in The Museo Nacional de Costa Rica, San Jose. This methodology, combining innovative digital technologies with traditional archaeology and advanced forensic science and art techniques, enable us to thoroughly, and safely, explore these important burial bundles without incurring destruction or disturbance to the original artifacts.

Keywords: CT contactless scanning, 3D printing, digital imaging, non-invasive, reconstruction, archaeology, forensic.

INTRODUCTION

Between 1989 and 1991, archaeologists of the Museo Nacional de Costa Rica (MNCR), led by Juan V. Guerrero-Miranda, excavated the ancient cemetery site of La Regla. Located in the tidal zone of the Nicoya Gulf, Southwestern Pacific coast of the Puntarenas Province of Costa Rica,

the site produced dozens of secondary "bundled" burials as well as associated organic artifacts including wooden sticks, fishing nets, hammocks, wood beads, and a fashioned *Spondylus* shell collar adornment. Preservation of ancient organic materials, including bone, is extremely rare in many Costa Rican territories due to the high humidity and an annual rainfall average of over 3 meters. The Regla site discoveries are an exception in this environment. Currently, the cemetery lies in a tidal zone tilted toward the Gulf as a result of the subduction effect of a tectonic plate on the Nicoya Peninsula. The cemetery emerges above sea level only during very low tides. The location of La Regla is in a mangrove swamp where the mud bed provides an anaerobic environment. Archaeological evidence suggests that the bundles were originally deposited in an ancient coastal swamp. C 14 analysis from an associated wooden stick renders a date of 500 BC, marking these human bone samples as the earliest and best preserved in this area of the Central Americas, and now considered a national treasure of Costa Rica's human heritage. (Guerrero, Vázquez, & Solano 1992)

The same mud matrix that protected these materials over the past 2500 years also solidified around them as a rock-hard concretion, limiting traditional methods of study and analysis. The challenge posed to researchers is to develop a method of non-invasive, accurate, artifact evaluation and reconstruction, effectively peering into the concrete mass bundles while avoiding any alteration and destruction to the original state and integrity of these rare bioarchaeological items.

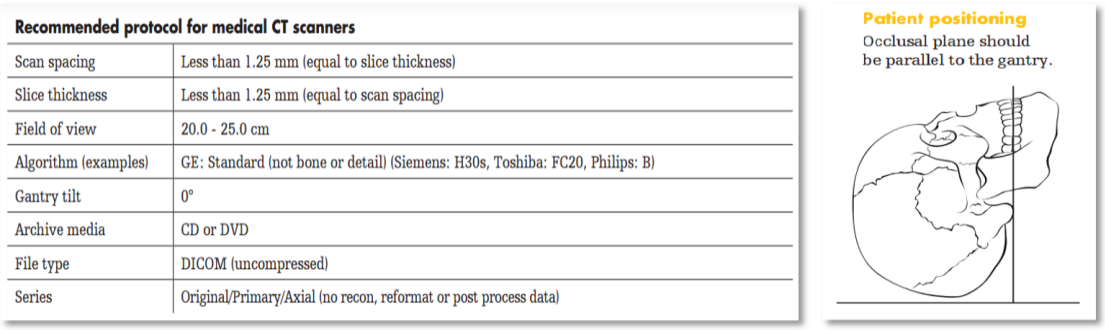
Figure 1: MNCR La Regla tidal zone excavation

Figure 2: Co-mingled bundled remains

Figure 3: Shell collar

THE MULTI-DISCIPLINARY APPROACH

MNCR archaeologist/anthropologist Dr. Ricardo Vázquez-Leiva selected a skull and an associated shell collar from the La Regla excavation collection as the first study specimen. Applying traditional biometric analysis techniques, Vázquez-Leiva concluded that this individual is an adult female. (Vázquez-Leiva 2012) The majority of the human remains found at La Regla consist of secondary burials of disarticulated bones and mixed bone bundles. Therefore, the crania and mandible of most specimens have co-mingled. This particular female's clavicle is impacted through the internal mandible, effectively locking together the cranium and mandible of the individual, making her an ideal study subject. The selected female skull and shell collar are x-ray computed tomography (CT) scanned by the digital specialists of the Dr. Chavarría Estrada Imágenes Médicas Centro in San Jose, Costa Rica. Using the facility's GE Medical Systems Discovery ST CT Scanner, the cranium and mandible datasets are acquired alongside the *Spondylus* shell collar using nearly the same methodologies. The staff of Imágenes Médicas scanned the cranial remains according to the cranio-maxillofacial CT Scanning Protocol provided by 3D Systems in the Colorado, USA facility. See figure 4 below for protocols.



Recommended protocol for medical CT scanners	
Scan spacing	Less than 1.25 mm (equal to slice thickness)
Slice thickness	Less than 1.25 mm (equal to scan spacing)
Field of view	20.0 - 25.0 cm
Algorithm (examples)	GE: Standard (not bone or detail) (Siemens: H30s, Toshiba: FC20, Philips: B)
Gantry tilt	0°
Archive media	CD or DVD
File type	DICOM (uncompressed)
Series	Original/Primary/Axial (no recon, reformat or post process data)

Figure 4: 3D Systems, cranio-maxillofacial CT Scanning Protocol

Salient metadata from each of the two resulting CT scans. See table 1 below.

Cranium		Concha Collar	
Acquisition Parameters	Specifications	Acquisition Parameters	Specifications
Pixel Matrix	512 x 512	Pixel Matrix	512 x 512
Thickness (mm)	0.488281012	Thickness (mm)	0.625
Voltage (KVP)	120	Voltage (KVP)	120
Raditation Intensity (mA)	106	Radiation Intensity (mA)	Mod.

Table 1: CT Scan Metadata of the archeological materials

The two completed CT scan datasets are shared with the staff at Metropolitan State University of Denver Colorado Center for Advanced Visualization and Experiential Analysis (CAVEA).

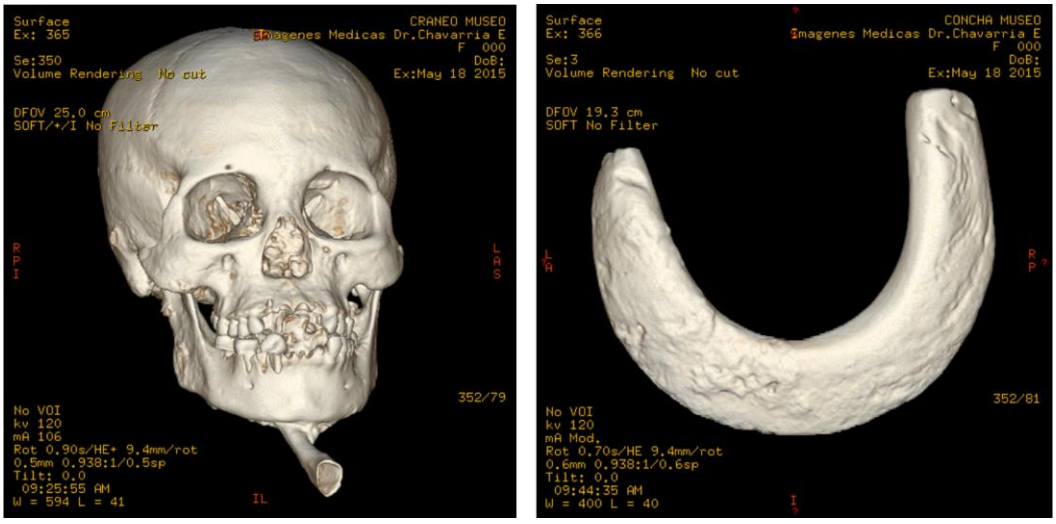


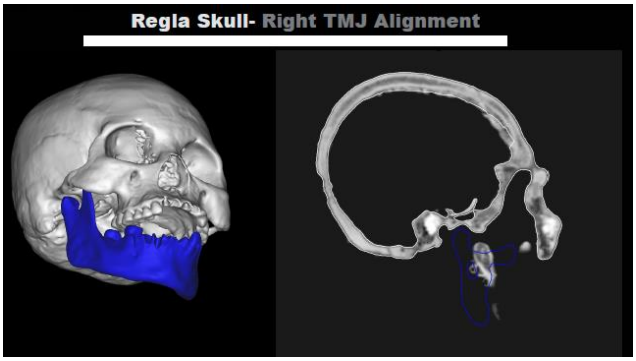
Figure 5: Visualizations of the DICOM CT scan data from the archeological materials

Mango, an open-source medical imaging software, was used to visualize and process the DICOM data. A preliminary examination of the archeological materials is completed using data visualizations like those found in figure 5 above. The concha collar data is processed into a STL file type and reproduced as a sandstone substrate 3D print by the 3D Print Store in Boulder,

Colorado. After examining the digital visualizations, it is determined that the cranium would require the attention of medical modeling technical experts to eliminate the various concretions existing on the bone material, and to ensure the correct anatomical repositioning of the mandible. Partners with 3D Systems are identified and the cranium and mandible datasets are passed to them for further processing.

FORENSIC DIGITAL RECONSTRUCTION

The forensic digital restoration of the bioarchaeological materials in a medical-legal context sets this research apart from other facial reconstruction projects. Our partnership with 3D Systems incorporates the skills of a Metropolitan State University of Denver graduate as a specialized digital engineer who utilizes advanced proprietary perceptual scan and design tools to produce detailed and forensically accurate 3D reconstructions. Digital engineers color code the scan files to isolate the bone material from the mud matrix and all other concretions, working through the scan slices, the technician virtually "cleans" the bone material. All the work performed by the digital engineers and the final 3D prints are reviewed for approval by a panel of technical, medical experts.



METHOD

The acquired CT data was brought into image processing software Mimics® (Materialise, Leuven, Belgium). Using both manual and automatic segmentation techniques, a highly accurate 1:1 scale digital 3D model was created from CT scanned anatomy. During the segmentation process, marine life and calcification on the remains were removed, the improperly aligned maxilla and mandible were separated, and the clavicle that was fused to the skull due to calcification was also removed. The 3D digital files of the maxilla and mandibular anatomy were exported into the STL file type. Once STL files were created, it was possible to independently move and align the maxilla and the mandible into the natural bite alignment. This is done by referencing the condyle fossa relationship that makes up the temporomandibular joint (TMJ) and also the relationship of the maxilla to mandibular occlusion. Once a proper bite alignment was achieved, the 3D STLs were prepared for print in Geomagic® FreeForm® software (3D Systems, Inc. Cary, NC). FreeForm® is a force feedback haptic enabled 3D sculpting software. The aligned individual anatomy files were perfected and smoothed where the marine life and calcification had manipulated the surface of the model. In preparation for 3D printing, struts were added for model stability in the teeth and the TMJ to preserve the alignment.

The skull was printed on the 3D Systems iPro8000 (3D Systems, Inc. Rockhill, SC) production series 3D printer out of ABS like plastic. The iPro8000 is a stereolithography (SLA) 3D printing machine which uses a computer-controlled moving laser beam to build up the required structure,

layer by layer, from a liquid polymer that hardens on contact with laser light. SLA produces highly accurate plastic parts without the restrictions of CNC, injection molding or other traditional manufacturing techniques. The print took approximately 11 hours to complete and 3 hours to post process. Post processing of the model requires support removal, washing and post curing. The final model was delivered within 2 weeks of receipt of the original CT data.

RESULTS

The finished 3D product is an exact, restored, copy of the original individual, figure 7, as she was interned as a secondary burial in the Regla cemetery site over 2500 years ago.

Figure 6: Original excavated skull

Figure 7: Restored 3D print

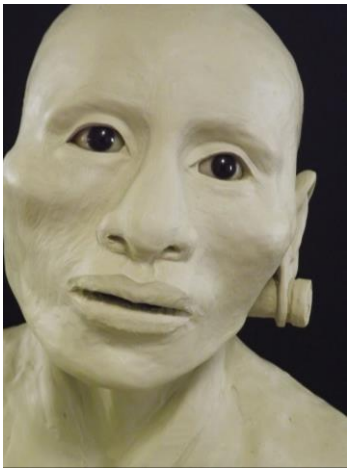


Figure 8: Preliminary facial reconstruction

NEXT STEPS

Many anthropologists posit that these ancient people are included in the linage of the Chibchan language group. Linguists acknowledge the intimate relationship between southern Central America and northern Colombia as an area occupied mostly by speakers of Chibchan languages. Therefore, the forensic artist is applying tissue depth marker data from current Colombian populations to establish the preliminary facial architecture of the forensic sculpture on the 3D model, figure 8. Because the Amerindians of the Isthmo-Colombian Area left no known written history, the only forensic evidence supporting individual features such as coiffures, body decoration, and adornment is found in the excavated artifacts. Ceramic specialists and archaeologists are currently researching the archives and the collections of the Museo Nacional de Costa Rica in San Jose, CR, and the Frederick and Jan Mayer Center for Pre-Columbian Art at the Denver Art Museum, gathering this evidentiary material from the Greater Nicoya, Period IV artifacts. Final sculpting decisions will be based on reflecting the documented portrayals of such items as hairstyle, ear spools, body painting, and adornment from these artifacts.

Additional research is directed to the collection of bioarchaeology resources from the Regla specimens. Specific CT scan slices featuring the dentition of the female's maxilla and mandible are isolated. These visualizations are sent to the coroner for an evaluation concerning the possibility of harvesting viable DNA from the dentin and pulp chambers in the original skull. Targeting a DNA extraction location with pinpoint accuracy will minimize damage to the original specimen.

The research team recently completed the forensic CT scans and 3D prints of an adult male and a sub-adult (child) from the Regla site collection.

CONCLUSION

This multi-disciplinary approach, combining innovative non-invasive digital technologies with methods of traditional archaeology and forensic science, achieve accurate anatomical duplicates of the bioarchaeological artifacts from the Regla excavations without incurring destruction on the valued specimens. The resulting 3D skull prints of the individuals will serve as the anatomical base for the forensic facial reconstruction sculptures. These facial portraits of the ancient people of the Nicoya area will anchor a planned exhibit of the humanities in the Museo Nacional de Costa Rica, San Jose.

"To find oneself is to find our humanity".
Deredia y Amoretti, 2013 UNESCO World Heritage Nomination, Costa Rica

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