The Use of CT Numbers to Quantitatively Classify Cultural Heritage Materials

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BACKGROUND:

X-radiography and computed tomography (CT) scanning provide conservators with the ability to non-destructively generate images of otherwise inaccessible features of objects, such as internal cavities or armatures and enclosed components or hidden repairs.[1]

In both X-radiographs and CT scans, the image contrast (i.e. the areas of differing brightness) relates to the differences in linear X-ray attenuation of the regions through which the x-rays travel, and gives rise to differences in radiodensity. The superimposed nature of x-radiographic images makes quantitation of radiodensity impossible. However, CT scans can be directly related to the linear x-ray attenuation coefficient (μ) through the CT number (also called Hounsfield units, or HU):

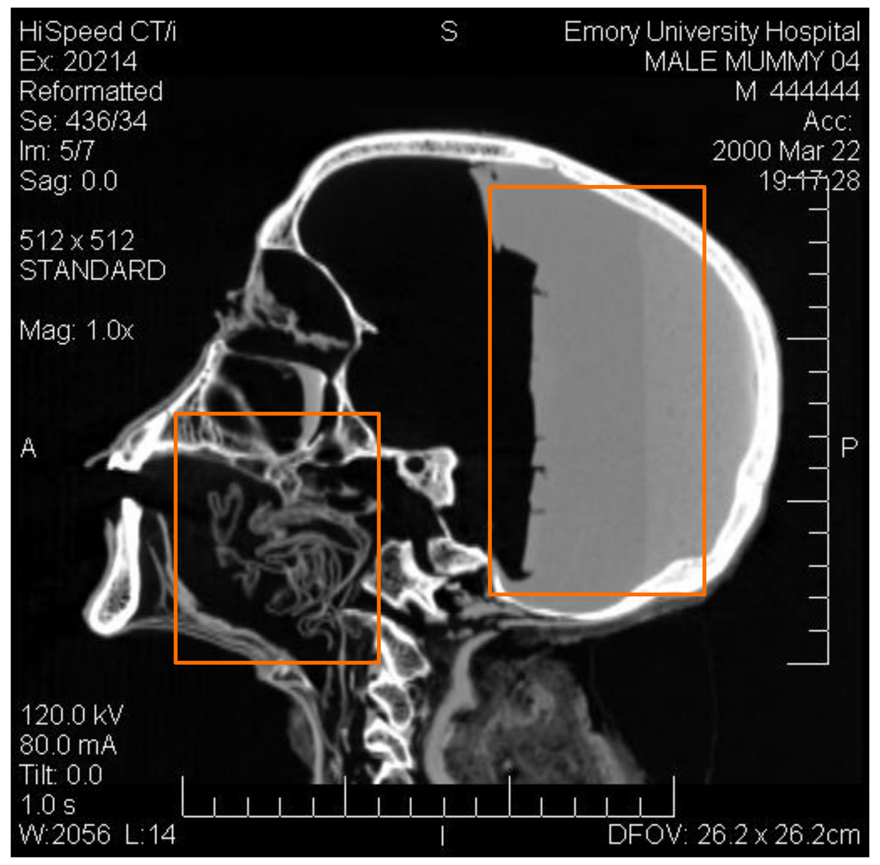
$$\textbf{CT Number} = 1000 \times \frac{\mu_s - \mu_w}{\mu_w}$$

where μ_s = the measured linear attenuation coefficient of the sample and μ_w = the measured linear attenuation coefficient of water.[1]

Medical diagnosticians reference CT Numbers for fat, blood, muscle, gray and white brain matter, different types of bone, and other organs and body fluids.[2] CT Numbers have been used to help comparatively characterize hidden objects and foreign materials present in corpses, especially metals or stone.[3,4] We suggest that the relationship between CT Number and material class given a constant tube voltage,[5] may also be significant for cultural heritage materials.

POTENTIAL APPLICATIONS:

In cases where it would be impossible or unethical to access hidden materials, the CT Number may be useful in characterizing concealed objects. Examples include African power objects enclosing potent materials, Egyptian mummies with hidden amulets, sealed Roman amphorae that still hold contents, and other similar objects.



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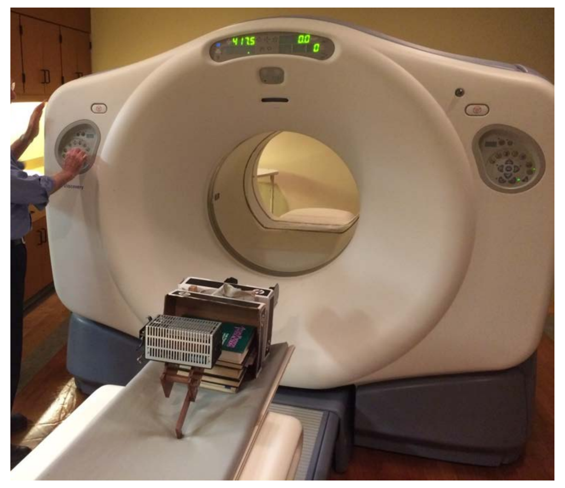
The above CT image of an ancient Egyptian mummy reveals unknown materials partially filling the skull as well as packed into the mouth and throat. Beyond the visual comparison of brightness as a relative indication of density, CT Numbers could be used to compare these unidentified materials with known references.

EXPERIMENTAL PROCEDURE:

A range of sample materials frequently found in cultural heritage objects was selected for study. Loose disparate materials like sand or leaves were packed into plastic bags or containers. Flat sheet materials like leather or textiles were tightly rolled or compressed.



GE 4-Slice PET/CT Scanner at Grady Memorial Hospital.

Oak, poplar, pine, dried clay, and terracotta blocks.

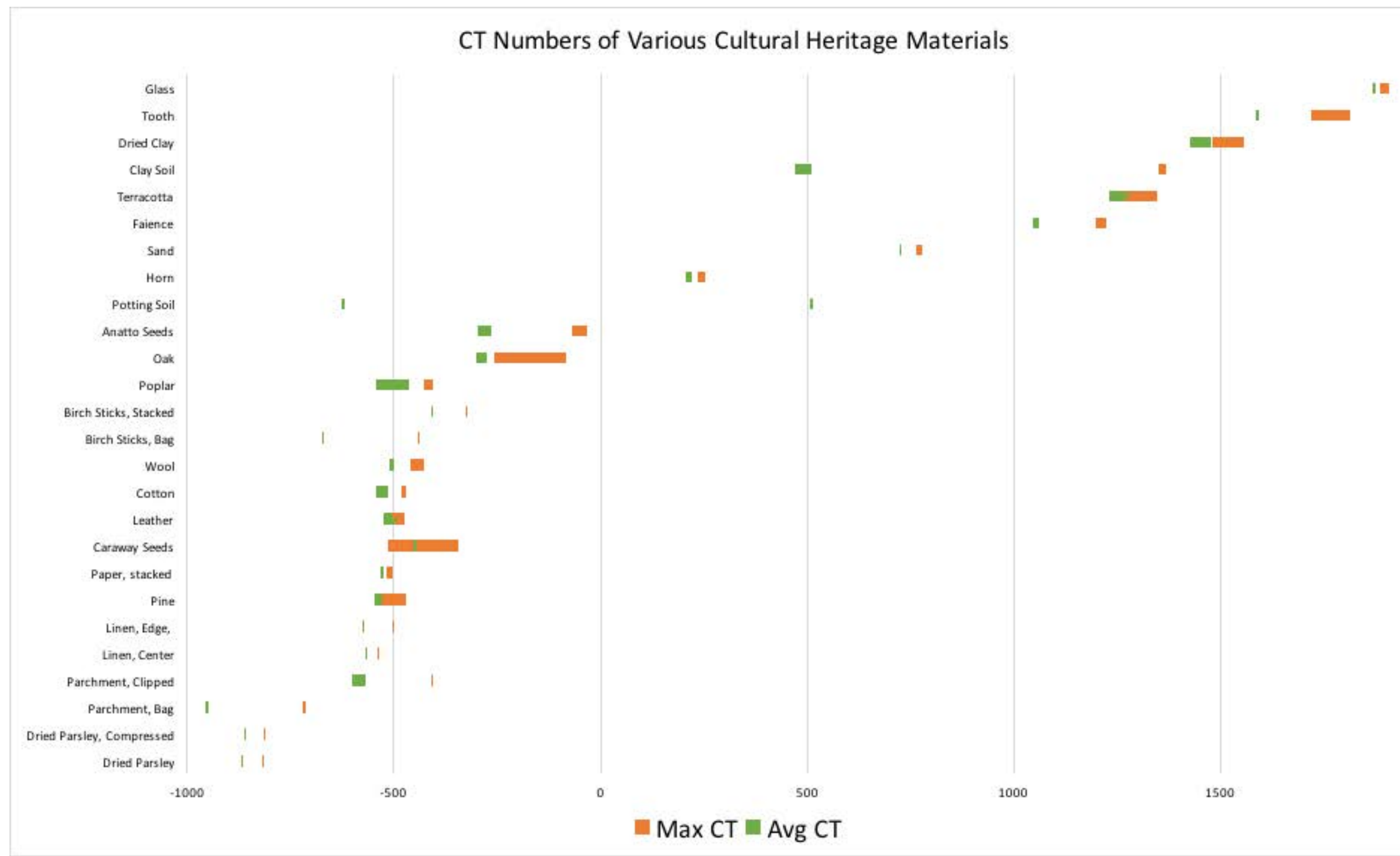
Oak block, glass muller, rolled pieces of leather, wool, and cotton.

A GE 4-slice CT scanner was used in helical mode with a tube voltage of 140kv. Tube current x time was 30 maS, and slice thickness was 5 mm. The scanner is part of a PET/CT scanner configuration.

The center-most axial slice was generally selected for quantitation (e.g. slice 4 or 5 out of 8 relevant slices; slice 6 out of 11). In order to achieve the most representative radiodensity, an elliptical region of interest (ROI within X and Y dimensions) was selected within the axial slice. The Maximum and Average CT Number for each ROI was calculated and displayed by the scanner software.

RESULTS:

The range of values obtained for Maximum and Average CT Numbers were recorded and graphed below. Many materials were scanned multiple times.



MaxCT = Maximum CT Number is the largest CT value within a ROI.

AvgCT = Average CT Number is the weighted mathematical mean of the CT values for each voxel within a ROI.

PVE = Partial Volume Effects is the phenomenon whereby a material's microstructure, including voids, is characterized by various linear attenuations within a single voxel, thus proportionally weighting the calculation of the AvgCT. PVE can be minimized with a higher resolution, i.e. smaller slice thickness.

DISCUSSION:

As shown in the table, inorganic and organic materials were clearly differentiated by CT Number. Regardless of whether MaxCT or AvgCT is considered, organic materials were represented by CT Numbers less than approximately 500.

The exception was mixtures, for which the AvgCT depends upon the variable ratio of organic to inorganic components. For example, the MaxCT of clay soil was similar to dried clay, while the AvgCT is lowered by the organic components. Interestingly, the clay soil was damp, suggesting that the presence of moisture may not significantly impact MaxCT.

AvgCT seems to be useful for single materials (not mixtures) that do not have variable microstructures or significant voids. However, AvgCT could be useful for comparison of materials with variable microstructures, provided that the ROI is selected to be representative (depending upon size, location, and thickness).

The MaxCT seems to provide a more meaningful quantitative value for a given ROI in substances with many voids. The MaxCT generally coincides with that of the given material and not the voids present, as demonstrated by the results from rolled, packed, or stacked samples compared with data from the same materials unrolled or loose.

CONCLUSIONS:

The findings of this preliminary study warrant further testing for reproducibility with more scans of each material on a single scanner and with different settings (e.g. slice thickness and filtration), as well as on different scanners. If validity is not reduced by inter-instrumental variation, it is conceivable that a table of reference values or ranges could be developed for cultural heritage materials.

Short of a universal reference table, however, our work suggests that the CT Number of reference materials measured on a single scanner could help characterize objects scanned with the same instrument.

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