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Development of a Dry Bone MDCT Scanning Protocol for Archaeological Crania

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Abstract

This poster discusses the development of a multi-detector computed tomography (MDCT) scanning protocol for dry bone skulls, using a Toshiba Aquilion 64-slice scanner at Quinnipiac University, in North Haven, Connecticut. Unfortunately, for individuals working in paleoimaging, the preset image manipulation factors have been developed for hydrated living tissues. Three likely preset protocols were selected as the initial starting place for the dry bone study in preparation for a potential large sample scanning session of skulls from Peabody Museum of Natural History at Yale University. Each protocol had specific raw data acquisition parameters and algorithm, mathematical manipulations of the raw data, intended to produce a particular effect on the resulting displayed images such as edge enhancement or beam hardening correction. The effects of these subtle data manipulations will be discussed and demonstrated. Finally, although the protocol was developed on a Toshiba unit, the manipulation factors presented can be employed as, at least a starting point for the optimization of image quality while reducing the magnitude of data collected from the scanners of other manufacturers.

Introduction

Multi-detector computed tomography (MDCT) has not only become one of the most frequently employed modalities in medical imaging, but also more commonly applied to paleoimaging studies. In order to increase the efficiency in the medical setting, equipment manufacturers provide preset protocols for all the examinations that might be performed on their units. Unfortunately, for individuals working in paleoimaging, the presets image manipulation factors have been developed for hydrated living tissues.

Before the finer points of image acquisition can be discussed, a brief review of the equipment operation must be considered. The x-ray tube and curve-linear detector array are separated by 180° within a donut-shaped structured termed a *gantry* (Figure 1).

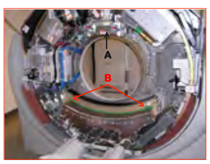

Figure 1. The cover of the gantry removed to reveal the x-ray tube (A) and the detector array (B).

The subject of the examination is placed on the table, more commonly termed the *couch*, that moves through the center of the gantry (Figure 2). As the x-ray tube and detectors spin within the gantry, a *slice* of data are collected. Prior to 1998, a single or dual detector system was employed to acquire the data. However, in that year a new generation of equipment was introduced that was equipped with multiple detectors, MDCT.[1] The principle features of the system included continuous movement of the couch through the opening in the gantry as the x-ray tubes and detector array constantly rotate. The result of the two movements generates a volume of data that can be sectioned in any desired plane or assembled into a three- dimensional rendering.

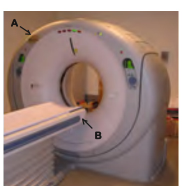

Figure 2. The basic components of the MDCT unit are the gantry (A) and the couch (B).

In MDCT, a protocol can be described as two general sets of parameters. The first is based on data acquisition and includes such factors as kV, mA, x-ray tube rotation time, channel selection, length of the scan along the z-axis (calibrated-field-of-view) and pitch. The second category focuses on the reconstruction of the raw data collected and includes, image thickness, reconstruction interval, and algorithms (or in Toshiba's terminology, filter convolutions). The latter is extremely important because it will control the detail of the resulting images.

Due to the limitations of a poster presentation, only three principle characteristics of the first set of parameters will be considered. Channel selection determines the minimum slice width that of data that can be reconstructed and the number and grouping of detectors that will be activated during the scan.[2] The Toshiba Aquilion unit is equipped with 64 detectors each 0.5 mm wide. If all the channels are selected, all 64 detectors will acquire 0.5 mm of data. Alternatively, two detectors can be coupled to collect 1.0 mm wide slice for, effectively, 32 detectors. The latter would require less radiation to produce a satisfactory image, but because the slice is twice as wide, the resulting image would lack detail in the z-axis. Therefore, selecting the smallest detector width is the first factor in optimization of data acquisition.

The couch movement, along the z-axis, during the x-ray exposure can be termed the calibrated-field-of-view (C-FOV). The resulting image is displayed on a matrix composed of 512 vertical (y-axis) by 512 horizontal (x-axis) picture elements termed *pixels*. Each pixel is the two-dimensional representation of a volume of data or volume element termed the *voxel*, and is an important consideration in determining the resulting image detail. The size of the pixel is calculated by dividing the C-FOV by 512, the dimension of the matrix. Therefore, the smaller the C-FOV, the better the displayed detail. With the Toshiba system, a relationship exists between the half-millimeter slice thickness and the 240 mm C-FOV to produce what is termed *isotropic resolution*. Since the slice-thickness (0.5 mm) represents the dimension along the z-axis, and the 240 mm C-FOV (240mm/512) provides an x-y pixel size of 0.47 by 0.47mm, the resultant *voxel* is considered isotropic. Isotropic voxels provide equivalent resolution in the coronal, sagittal and axial slices and more accurate reconstructions in non-standard planes. Consequently, employing the smallest C-FOV will result in the most detailed and versatile images.

The third factor incorporates both the number of channels selected or the width of the x-ray beam and C-FOV and is termed *pitch*. Pitch can be calculated by dividing the couch movement during 360° rotation of the x-ray source and detectors by the width of x-ray beam. The lower the pitch value the more accurate the image reconstruction, but the greater the radiation dose to the subject. In clinical imaging the radiation dose to the patient is a concern, but it is not a significant factor in paleoimaging image. The lowest possible pitch should always be used in non-medical imaging situations.

Once the raw data have been collected, two primary data manipulations should be considered in order to insure high quality images and ease of management. The first is the algorithm used to process the raw information into data that will be displayed. Manufacturers may select different terms for these mathematical manipulations, for example, Toshiba terms them *filter convolutions* (FC), and the results determine the appearance of the images. Algorithms that incorporate edge enhancement will more clearly delineate the margin between bone and soft tissue, but will also increase the image noise. Conversely, smoothing will decrease the noise, but blur the bony demarcations.

The final factor that must be considered is the platform on which the study will eventually be viewed and images manipulated. Image acquisition generally requires less than a half-minute. The examination, manipulation and analysis of the resulting multi-planar reformatted (MPR) images, including axial, coronal and sagittal sections, may require a few hours. If more elaborate reconstructions procedures, such as three-dimensional renderings and animation are desired, many hours may be necessary. In most situations, the MDCT units are intended primarily for clinical data acquisition and not available for the extended period of time required for post-processing image manipulation. Therefore, the data will be downloaded as a *Digital Imaging and Communication in Medicine* (DICOM) file onto a *Picture Archiving Communication System* (PACS), and onto independent workstation within the imaging facility or to a DVD so the data can be removed to another location. Since the DICOM files represent translations of the raw data into a common computer code, the raw data no longer exists and manipulations are somewhat limited. For example, a slice cannot be generated that is thinner than the detector width that was used to acquire the data. Consequently, before the data is downloaded from the MDCT unit, all manipulations of the raw data must be completed.

Materials & Methods

A dry skull was placed in a supine position in the standard *head holder* of the Toshiba Aquilion MDCT unit and secured in place using pieces of foam (Figure 3). The laser localizer light was used to insure that the skull would be positioned in the center of the gantry opening and within the C-FOV for the study.

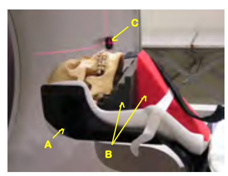

Figure 3. The dry skull was placed into the MDCT unit "head holder" (A) and maintained in position using foam sponges (B). Proper position of the skull was achieved using the laser localizer light (C).

Three different kilovoltage (kV) settings, 120, 100 and 80 were used for the study. It was suggested that the higher setting would be required to penetrate the thicker areas of the skull, such as the petrous portion of the temporal bone.[3] However, a decrease in kV would decrease the radiation dose required to produce a satisfactory study.

Three different filter convolutions (FC) were employed. Two of the algorithms were intended for bone studies: *Bone Sharp*, FC 31, was midway between *smoothing* and *edge enhancement*; and *Bone Hi Resolution*, FC 81, representing edge enhancement. The third algorithm, FC 25, would typically be employed for an examination of the patient's head and included not only edge enhancement, but also incorporated a beam-hardening-correction (BHC) in order to eliminate the x-ray beam hardening effect between the inner table of the skull and the brain surface. BHC reduces the effect of preferential filtering-out of lower energy X-rays by dense bone while higher energy X-rays trick the detectors into registering more transmission and lower material density.

A total of four protocols were established using the variation noted above, but maintaining all the other factors as constant including 64 x 0.5 mm detectors, a pitch factor of 0.641, C-FOV of 240 mm, and x-ray tube rotation time of 0.75 seconds. In addition, the milliamperage (mA) was automatically adjusted or *modulated* during the exposures.

Results

In order to visualize the effects of protocol manipulation, an arbitrary axial section was selected that demonstrated various anatomic structures (Figure 4). Because of their small size and complex shape, particularly interest focused on the semicircular canals.

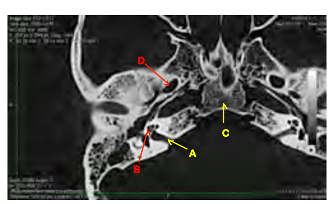

Figure 4. Axial section 253 of a series of 439 images demonstrating the internal auditory canal (A), cochlea (B), clivus (C), and foramen ovale (D) magnified 330%.

Changes in kV did not affect the image detail (Figure 5). However, as expected, increasing the kV did increase the dose: the 80 kV dose (1050 mGycm) was 37% less than at 120 kV (2816 mGycm).

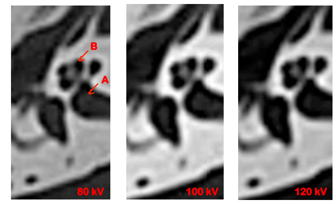

Figure 4. Axial section 253 of a series of 439 images demonstrating the internal auditory canal (A), cochlea (B), clivus (C), and foramen ovale (D) magnified 330%.

The high-resolution bone algorithm (FC81) resulted in the sharpest image, with some beam hardening artifacts in the surrounding air (Figure 6). Use of the bone sharp algorithm (FC31) resulted in an image nearly as sharp as FC81, again with beam hardening artifacts in the air. The algorithm (FC25) including the beam-hardening correction produced a less detailed image than the FC81 protocol specifically designed to maximize edge enhancement. However, it is important to emphasize that the former was developed to demonstrate brain tissue adjacent to the inner table of the skull. Beam hardening artifacts are reduced substantially in the surrounding air (brain), but this is not the volume of interest in the examination of dry bone.

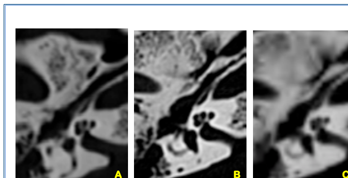

Figure 6. A comparison of the three algorithms: A. FC 30, Bone Sharp; B. FC 81, High Resolution Bone; and FC 25, Head with BHC.

Conclusions

Since radiation dose is not a significant factor in paleoimaging, the smallest detector width, calibrated field-of-view, and lowest pitch value should be employed when acquiring a volume of data with multi-detector computed tomography. Lower dose does become a consideration if a large number of specimens are going to be examined. X-ray tube life can be extended by employing factors that result in lower heat production, for example lower kV and mA settings. Generally when live patient examinations are performed, it takes at least 15 minutes to get the patient into the room, onto the CT couch, position the patient, and set the protocol before the exposure is taken. During this period the CT unit would have an opportunity to cool from the previous examination. If the study consists of a group of skulls, all the skulls may be in the CT room and perhaps only five minutes may separate the exposures. The x-ray tube would have less time to cool. Therefore lower kV settings would result in lowering the total heat produced. In addition, by employing mA modulation, the unit will only generate the quantity of x-ray necessary to produce a satisfactory imaging and also contribute to lower heat production.

Although the kV should not affect the resulting detail, it has been employed to control the beam penetration. In the case where the skull is surrounded by hydrated tissue, as in a live patient, the higher kV is required to provide adequate penetration. In this study, it was demonstrated that the lower setting provided satisfactory results.

Using the "Bone Hi Resolution" filter convolution resulted in images with the highest degree of edge-sharpness. In a live patient, this algorithm would primarily be employed in examinations of the petrous portion of the temporal bone. Therefore, only preset protocols designed for such studies would include this algorithm. The algorithms used for general examinations of the skull did not produce the high degree of detail.

Beam hardening correct, BHC, would commonly be incorporated with protocols employed with skull examinations of live individuals. Unfortunately, the BHC, resulted in a loss of detail on the dried skulls

Therefore, if the examination of dry skulls are the objective of the MDCT examination, a special protocol should be developed that incorporates, lower kV, modulated mA, the smallest pitch, small C-FOV, a high resolution bone filter, and a disengaged the beam hardening correction filter.

References

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