Design of CT Foot Phantom for Charcot Study

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DESIGN NEED

• Neurologic Charcot Arthropathy (NCA) is a potentially serious complication for the ~0.8 million Americans that suffer from diabetes mellitus.
• Diagnosis often coincides with a Charcot event, such as dislocation or fracture, which often leads to fixed foot deformity, ulceration, and amputation.
• It is hypothesized that bone mineral density (BMD) is an early indicator of Neurologic Charcot Arthropathy and that BMD predicts which patients will experience favorable treatment outcomes.
• Computed tomography (CT) may be used to measure foot BMD, but measurements are sensitive to both scanning and post-processing parameters and should be validated against surrogate with known standards.
• Existing BMD phantoms do not simulate cortical bone, nor do they represent the NCA foot. New phantoms that simulate foot morphology and attenuation characteristics are needed.

Objective: Design, construct, and test a solid CT phantom that is the best analogy to a Charcot foot to be used in the study of neurologic Charcot Arthropathy.

On Tuesday, November 19th, the phantoms were scanned in 14 configurations, varying height in the scanner, inclination angle in the scanner, phantom size, and scanning energy. The data, shown below, were analyzed and compared to a beam-hardening computer model.

- Three sizes of phantoms were made from Solid Water, with two of each size resulting in a total of six phantoms. Each phantom had a cross section of a rectangle terminated with a half circle on each end.
- In each phantom, there are four holes: a diameter of 0.375 inches and one with a diameter of 0.75 inches.
- The bone inserts were made from four different materials: ECTFE, PCTFE, HDPE, and Aluminum.
- The phantoms posed minimal safety concerns due to its limited contact with patients and users.

ANALYSIS USING COMPUTER CT MODELING

A MATLAB beam-hardening CT-projection program using polyenergetic modeling was used to analyze the three phantom shapes and the possible cross sections to see if there were any improvements or problems with the design.

In order to ensure that our selection of phantom geometry would yield successful reconstructions using the methods of back-projection, a profile was generated as a two-dimensional grey scaled density cross section. Then, using the data transmitted through a MATLAB's image processing toolbox, a set of simulated CT scans were generated on an entire series of irregular objects. An X-ray source generated the intensity profile of a phantom including the entrance and exit radiation, and the simulation included the projection of a single detector in a CT detector array. Then, radiused the intensity profiles from each orientation into a sinogram.

Finally, the reconstructed image was simulated using a CT reconstruction algorithm through the use of MATLAB's inverse radon.

Did we solve the problem?

- The three different phantom sizes simulate the various foot sizes and amounts of swelling.
- Each phantom is lightweight (less than a pound).
- The weight includes only count edges.
- The radiodensity of the Solid Water is very close to the ratio density of the muscle and fat tissues in the feet, and in the industry standard for representing fat and tissue in CT bone scans.
- The phantom accommodates two sizes of bone inserts: the 0.75 inch diameter hole represents the first metatarsal, and the four 0.375 inch diameter holes represent the 2nd-5th metatarsals. Up to five inserts may be used to simulate marrow in the bones by creating inserts with two concentric cylinders of different materials simulating cortical bone filled with bone marrow. We would also like to perform a more thorough analysis.

CONCLUSIONS

Future Directions

Based on scanning results, we may need to augment our design. Future directions could include a solid water or alternate material sleeve to represent feet with higher levels of swelling than the large phantom allows. Phantoms with other insert sizes or arrangements could be used instead of a foot with just one large metatarsal and four small metatarsals. Other possibilities for bone inserts include simulating marrow in the bones by creating inserts with two concentric cylinders of different materials representing cortical bone filled with bone marrow. We would also like to perform a more thorough analysis.

Acknowledgements

Thanks to Youn Fard and Paul Common (Electronics Radiology Lab), Dave Sinesio (Physical Therapy), and Tim Street (UCB) for their technical support and resources.

References

American College of Foot and Ankle Surgeons, "Foot Physician", http://www.acfacs.org/footclinicandfoot-foots.html
Blue Cross Blue Shield, "Care First", http://carefirst.bluecrossblueshield.com/Library/Encyclopedia/care-first

Implementation and Analysis

Analysis of Edge-Cupping Artifacts (in HU)

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Trajectory through Phantom Profile

CT Reconstruction Algorithm

Analysis of Material for Bone Inserts

- Teflon
- Aluminum
- HDPE
- PCTFE
- ECTFE

Inserts and Insert holes

- Insert size: 2 sizes of metatarsal bone (1 and 2 cm in diameter)
- Insert materials: emulates metatarsal bone densities (radio density of 500-2000 Hounsfield Units) for accurate representation and analysis.
- Phantom shape: rounded edges, no sharp corners

Model-reconstructed Trajectory through Phantom Profile

Implementation and Analysis

- The phantom accommodates two sizes of bone inserts: the 0.75 inch diameter hole represents the first metatarsal, and the four 0.375 inch diameter holes represent the 2nd-5th metatarsals. Up to five inserts may be used to simulate marrow in the bones by creating inserts with two concentric cylinders of different materials simulating cortical bone filled with bone marrow.

Three sizes of phantoms were made from Solid Water, with two of each size resulting in a total of six phantoms. Each phantom had a cross section of a rectangle terminated with a half circle on each end.

In each phantom, there are five holes: four with a diameter of 3/8 inches, and one with a diameter of 3/4 inches.

The bone inserts were made from four different materials: ECTFE, PCTFE, HDPE, and Aluminum.

- The phantoms posed minimal safety concerns due to its limited contact with patients and users.

Future Directions

Based on scanning results, we may need to augment our design. Future directions could include a solid water or alternate material sleeve to represent feet with higher levels of swelling than the large phantom allows. Phantoms with other insert sizes or arrangements could be used instead of a foot with just one large metatarsal and four small metatarsals. Other possibilities for bone inserts include simulating marrow in the bones by creating inserts with two concentric cylinders of different materials representing cortical bone filled with bone marrow. We would also like to perform a more thorough analysis.

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