Geometric Accuracy of Low Dose CT Scans for Shoulder Musculoskeletal Modeling

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INTRODUCTION: Computed tomography (CT) imaging is commonly used in a variety of clinical and research applications including surgical planning [1], kinematic tracking using biplane videoradiography [2], and musculoskeletal modeling [2-4]. For the shoulder, CT scanning protocols are typically based on a standard clinical scan which seeks to achieve good contrast for both soft tissue and bone [2]. Within musculoskeletal research applications, bony anatomy is often the only tissue of interest, which typically exhibits high natural contrast. Therefore, it is likely possible to substantially reduce the dose associated with CT protocols within musculoskeletal research in accordance with the ALARA (as low as reasonable achievable) principle of radiation safety. This is especially important for shoulder imaging since it exposes radiosensitive organs within the thorax (e.g., lungs). However, little data exists regarding the extent to which lower dose CT protocols impacts the geometric accuracy of reconstructed 3D bones models. Therefore, the purpose of this study was to determine the dose-accuracy trade-off between incrementally lower-dose CT scans and geometric accuracy of the humerus, clavicle, and scapula.

METHODS: Three fresh-frozen cadavers consisting of the torso and bilateral shoulders (6 total shoulders) were acquired from the University's Body Donor Program. Specimens were scanned on a Siemens Biograph CT scanner using 5 different helical protocols which varied the x-ray tube voltage (kVp) and current (mA) to influence dose: 1) 120 kVp, 450 mA (full dose scan); 2) 120 kVp, 120 mA; 3) 120 kVp, 100 mA; 4) 100 kVp, 100 mA; 5) 80 kVp, 80 mA. Scans were acquired using a pitch of 1.0, voxel size of 0.664×0.664×0.6 mm, and the manufacturer's CarePlus option, which is a dose reduction setting that modulates tube current up to a pre-specified maximum while maintaining image quality. Scans were subsequently reconstructed using a Br60 bone convolution kernel. Mimics software was used to segment the humerus, clavicle, and scapula from the CT images. Segmented volumes were then reconstructed into surface meshes, smoothed using a Taubin smoothing algorithm (λ=0.5, μ=0.53, iterations=10), and transformed into a common reference frame using a voxel-based registration method. Geometric error was assessed by comparing the distance between each point on the experimental low dose mesh and the nearest surface of the full dose mesh and were described using mean absolute error and bias (mean) error. Effective doses were estimated using the dose length product reported by the scanner and the conversion factor recommended by the American Association of Physicists in Medicine [5].

RESULTS: All experimental protocols resulted in a substantial (>70%) reduction in the estimated effective dose relative to the standard clinical scan (protocol 1: 11.59 mSv; protocol #2: 3.07 mSv; protocol #3: 2.55 mSv; protocol #4: 1.50 mSv; protocol #5: 0.82 mSv). As expected, reducing the applied dose by modulating the tube voltage and current resulted in higher geometric errors (Figure 1). However, with the exception of the lowest dose scan (80 kVp, 80 mA), mean absolute errors were generally less than 0.35 mm across all bones. The lower dose scans resulted in higher bias error (i.e., larger 3D bone models), which was likely due to the loss of contrast between the bone edge and the surrounding tissue.

DISCUSSION: These data suggest that the effective dose associated with CT imaging can be substantially reduced in applications where bone is the only structure of interest. However, the protocol selected may depend on the research application. For example, statistical shape modeling may be less sensitive to surface errors than joint contact pattern calculations.

SIGNIFICANCE/CLINICAL RELEVANCE: The >70% dose reduction complements the ALARA principle of radiation exposure. Future work will investigate the dose-accuracy trade-off between these low dose CT scans and kinematic tracking using biplane videoradiography, as reducing CT dose would allow for more motion trials and data collection visits while maintaining patient safety. Future work will also seek to translate these findings into clinical pipelines where CT is often utilized (e.g., surgical planning).

REFERENCES: [1] Lorenzana et al. *J Bone Joint Surg Am*, 2022. [2] Lawrence et al. *J Vis Exp*, 2021. [3] Peltz et al. *J Biomech*, 2015. [4] Lee et al. *Clin Biomech*, 2020. [5] Report of AAPM Task Group 23 of the Diagnostic Imaging Council CT Committee. 2008.

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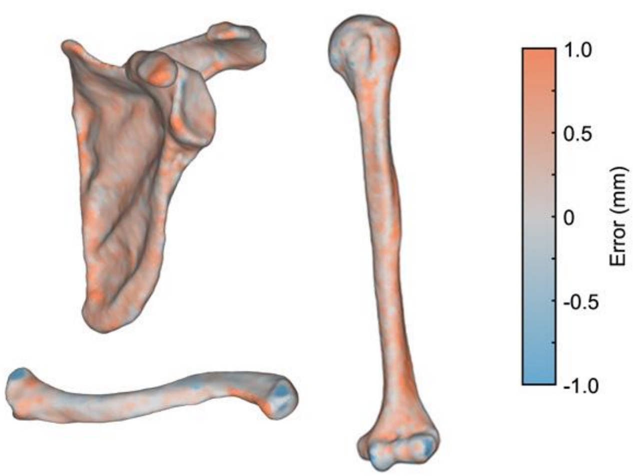

Figure 1: Geometric errors on a representative subject for the lowest dose protocol (80 kVp, 80 mA). Positive errors indicate the 3D model resulting from low dose protocol were larger than that made with the full dose protocol (120 kVp, 450 mA), while negative errors indicate the model was smaller.

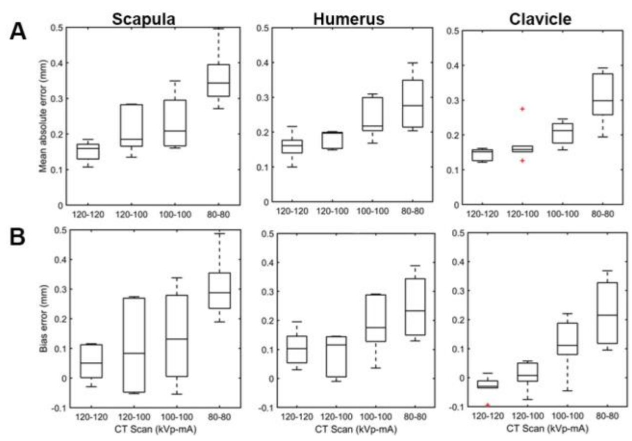

Figure 2: Geometric errors of the experimental low dose protocols compared to the full dose protocol (120 kVp, 450 mA): A) mean absolute error, B) bias (mean) error. Within each boxplot, the midline represent the median, the box edges indicate the 25th and 75th percentiles, and the whiskers extend to the most extreme data points not considered outliers. Outliers are defined as a value that is >1.5 times the interquartile range away from the bottom or top of the box and are indicated by red "+".