Evaluation of the Effects CT Scanner Model and Reconstruction Kernel on the CT Number Calibration

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INTRODUCTION: Scanning a densitometry phantom provides critical information to derive CT number [HU] as a function of physical density [mg/cc], relevant to quantifying the density of patient musculoskeletal tissues. Current research suggests different models of clinical CT scanners produce variation in the calibration slope [1]. However, the difference of slope produced by scanners from the same manufacturer is small, 1.3% for GE CT scanners[2]. The calibration slope geometrically maps to the segmentation and therefore influences the results of clinically relevant finite element analysis (FEA), such as Biomechanical Computed Tomography[3]. As the impact of these differences has not been assessed at the segmentation level, the aim of this study was to examine the effects of two CT scanner models and two reconstruction kernels on CT number over a digital volume (D.V).

METHODS: CT scans were taken of phantoms including custom (CIRS, Inc.) $Ca_5(PO_4)_3$ plugs of densities 100 mg/cc (part: RDH 357 Y-23) and 400 mg/cc (part: RDH 362 Y-24) and stock plugs 1000 mg/cc (part: 06217) and 1750 mg/cc (part: 06221). Data were collected on CT scanner models Discovery CT 1750 HD (Disc.) and Optima 660 (Opt.) (GE Healthcare) using BonePlus kernel (BPK) and Standard kernel (SK) with a varying slice spacing (0.325mm, 2.5mm) and slice thickness (0.625mm, 5mm). Pixel spacing was 0.23mmx0.23mm. Manual segmentation of all analyzed CT data was completed in Mimics v. 23 (Materialise) by one operator (EGC). The D.V. were inspected to ensure that the segments were at least 100 voxels (ASTM E1935 2019). Volume in the segment was maximized with steps taken to reduce edge effects by eroding the segment three voxels and growing by two voxels. The D.V, standard deviation, and average value for each segment were recorded. Normality was checked using a Shapiro-Wilk test and histograms. For non-normal data, skew was evaluated to determine shape distribution. The differences between mean CT Number measured by each CT scanner model for SK and BPK and the differences between mean density measured with each kernel for the Disc. and Opt. were analyzed through paired t-tests (α=0.010) respectively. A 1.0% significance level was used because CT scanners produce highly repeatable measurements. The correlation slope between CT scanners for both kernels and between kernels for both CT scanners were compared to orthogonal slopes and were t-tested (H_0: m=1). Bias, the difference between zero and the calculated mean difference, was examined in CT number between scanner models through Bland-Altman plots. Statistical analyses were completed in RStudio Desktop 1.3.1073.

RESULTS: Scanner model did not affect CT number, but reconstruction kernel did (Fig. 1). The difference between CT number from scans taken on Disc. and Opt. was not statistically significant for BPK (p=0.012) or SK (p=0.316). However, the difference in CT number between scans taken with both kernels was significantly different for Disc. (p=0.009) and Opt. (p=0.006). Measurements between scanners were highly orthogonal, with m=0.997 for BPK and m=1.000 for SK. Slopes were not statistically different than one for BPK (p=0.386) and SK (p=0.991) (Fig. 1A,1B) Correlation slopes for Disc. (m=0.980) and Opt. (m=0.977) were significantly different from one (p=0.004 and p=0.001, respectively). Higher density plugs showed greater differences than lower density plugs for both kernels (Fig. 1C, 1D). The overall bias was positive for SK (3.491 [HU]) and BPK (4.912 [HU]) (Table 1). Data which failed the Shapiro-Wilk test for normality were found to be symmetric and t-tests could be applied.

DISCUSSION: The lack of statistically significant differences between CT scanner models is consistent with the literature, specifically the previously noted small difference in calibration slope between GE scanners[1]. Furthermore, this suggests that statistical measurements of the CT number of the segments produced from scans taken on either CT scanner model are comparable. However, when examining the relationship between kernel and CT number, the volumes produced by different kernels cannot be interchanged. The biases shown in the Bland-Altman plots (Fig. 1 C,D) demonstrate that the CT number measurements on Disc. were generally higher than those on Opt. When bias was plotted against density (Fig. 1 E), there was a strong non-linear relationship. These phantom scans were taken with air as the background medium instead of water. As other studies have found[4], this nonlinearity may be related to the scanning medium. The effect of scanning medium should be considered in future studies.

CLINICAL RELEVANCE: CT scanner model did not influence mean CT number over a D.V. When controlling for kernel, the CT numbers were not significantly different between scanner models. The evidence that CT scanner model does not have a significant effect on the CT number suggests image data produced by either scanner model will not produce a significantly different result in clinically available patient-specific FEA.

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IMAGES AND TABLES:

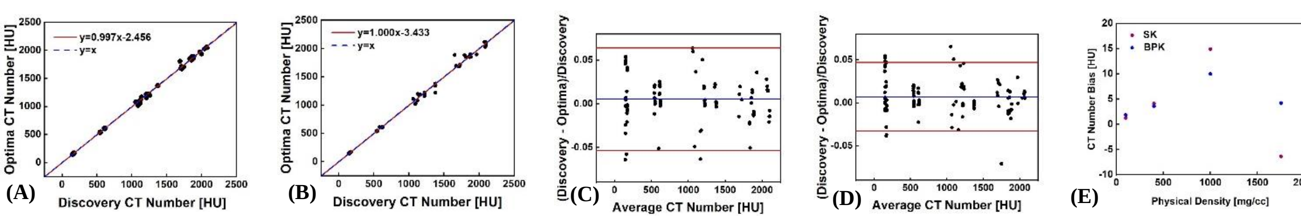

Figure 1: Density measured by Optima vs. Discovery for both SK (**A**) and BPK (**B**) demonstrate a strong linear correlation between the measured values of both CT scanner models. These correlations are not significantly different than m=1 for SK (p=0.991) and BPK (p=0. 386). The mean difference in CT number between CT scanner models was small and comparable for SK (**C**) and BPK (**D**). Bias between machines (Discovery – Optima) was greatest for both kernels for the 1000 mg/cc plug. (**E**).

Table 1: Bias between machines (Discovery–Optima) calculated for each plug density used in this study. The overall bias reflects the bias calculated using the Bland-Altman Plot (**Fig. 1 C, D**).

Physical Density [mg/cc]	100	400	1000	1750	Overall
Standard Bias [HU]	1.278	4.100	14.94	-6.350	3.491
BonePlus Bias [HU]	1.867	3.575	9.990	4.214	4.912