PRECISION OF TWO HRPQCT SCANNERS FOR THE LONGITUDINAL EVALUATION OF HUMAN BONE MICROARCHITECTURE IN VIVO

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INTRODUCTION

High-resolution peripheral quantitative computed tomography (HRpQCT) is being used to quantify trabecular bone architecture in vivo. It is an accurate and precise technique to measure bone properties. Long-term follow-up provides excellent means to quantify micro-architectural changes over time. One challenge in long-term follow-up is the repeatability of a measure when changing apparatus. During the follow-up period of a large cohort of patients at the Mayo Clinic, the machine changed from a prototype of XtremeCT (Scanco Medical AG, Brutisellen, Switzerland) called 3DpQCT to the commercially available XtremeCT. The aim of this study was to quantify the differences between these apparatus. Specifically, we addressed the reproducibility of morphometric parameters and image-based estimates of bone strength.

METHODS

At Mayo Clinic (Rochester, Minnesota, USA), of 27 patients one of their distal radii was scanned on the same day with two different scanners, being the commercially available XtremeCT, and 3DpQCT (a prototype of the XtremeCT). The most remarkable difference between the machines is the resolution they provide. For the older 3DpQCT machine this is 0.090 * 0.090 * 0.089 mm. For XtremeCT the resolution is slightly better; 0.082 mm isotropic. 3DpQCT measures 116 slices, corresponding to a 10.79 mm thick cross-section. XtremeCT measurements included 110 slices, corresponding to a 9.02 mm thick cross-section.

Morphometry analyses were performed using the standard patient evaluation protocol provided by the scanner manufacturer. First, this protocol involved segmenting the periosteal surface of the radii using a semi-automated contouring scheme followed by a threshold-based algorithm to separate the cortical and trabecular regions [2]. Extraction of the mineralized phase occurs fully automatically, and uses a Laplace–Hamming filter followed by global thresholding. The indices determined by the analysis include measures of bone mineral density (vBMD) (mgHA/cm3), derived bone volume fraction (BV/TV), which is determined by dividing the apparent trabecular bone density by 1200 mg/cm3 HA, which represents mineralized bone. Trabecular number (Tb.N) was determined using 3D ridge extraction methods [3]. Trabecular thickness (Tb.Th) and separation (Tb.Sp) were derived from the measures of BV/TV and Tb.N using standard morphological relations [4]. Cortical thickness (Ct.Th) was calculated by dividing the mean cortical volume by the outer bone surface.

Strength was determined by μFE analyses. Linear models were built by a direct voxel-to-element conversion. All elements were given an E-modulus of 6.8 GPa and a Poisson's ratio of 0.3 [1]. An axial compression of 1% strain was applied and strength was determined by calculating the load required to cause 19% of tissue volume to be strained above 0.6% effective strain.

Three different comparisons were made for the morphological parameters. First, the parameters as derived from the original scans of both scanners were compared. The second comparison was similar to the first one, but this time after scaling down the resolution of the XtremeCT scans to match the resolution of the 3DpQCT scans. The third comparison complemented the second comparison by evaluating only the volume that was common to both scans. For the mechanical parameters, we did not perfom the analyses for the common volume, because these models were too small, and behaved too stiff.

To identify the common volume from two matching scans, a 3D image registration procedure was performed. It consists of an intensity-based least-squares algorithm [5,6]. B-Splines were chosen as interpolation method.

Precision was determined by quantifying the linear correlation of the indices as measured with the two different scanners, as well as by quantifying the standard error of the estimate. The standard error of the estimate was used as a measure of reproducibility.

RESULTS AND DISCUSSION

The correlation between the two scanners was high (Table 1, Fig. 1). For all indices R^2 values were higher than 0.9, except for Tb.Th and Ct.Th. When scans were registered first, and only the common volume was analyzed, correlation

improved for almost all parameters. Only for Tb.Th, the parameter with the lowest correlation in all comparisons, it slightly decreased. The standard error of the was good for all indices.

For strength, the R^2 is equally high when comparing the original scans and when using the downscaled version of the XtremeCT scans. However, as the slope gets closer to one, and the intercept closer to zero, downscaling to the same resolution is recommended when a μFE based comparison for strength is made for scans of a different scanner. By using a slightly higher bone tissue modulus for the models with the reduced resolution (i.e., 6.9 instead of 6.8 GPa) the average strength data exactly matched the strength data of the models with higher resolution..

Excellent agreement was shown, especially considering that the measurements were done in vivo, hence, included all experimental errors in positioning inaccuracies and patient movement.

CONCLUSIONS

The precision of HRpQCT measurements of the distal radius is high. For morphometry analyses optimal repeatability was achieved when the common volume only was analyzed. For mechanical parameters we recommend to compare scans at the same resolution.

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Table 1. Slope, intercept, linear correlation coefficient and standard error of the estimate, 3DpQCT vs. XtremeCT

	Parameter	slope	intercept	R^2	SEE	SEE (%)
3DpQCT vs. XtremeCT	**vBMD (mgHA/cm^3)**	1.09	14.45	0.90	24.06	7.3
	BV/TV (%)	1.06	-0.02	0.98	0.005	4.3
	Tb.N (mm^{-1})	1.00	-0.03	0.95	0.100	6.1
	Tb.Th (mm)	0.94	0.00	0.66	0.006	7.1
	Tb.Sp (mm)	1.08	-0.02	0.98	0.035	5.9
	Ct.Th (mm)	0.93	0.26	0.83	0.083	9.9
	Strength (N)	0.96	138	0.99	83.61	2.8
3DpQCT vs. XtremeCT scaled down	**vBMD (mgHA/cm^3)**	1.09	11.6	0.90	23.95	7.3
	BV/TV (%)	1.06	-0.02	0.98	0.005	4.1
	Tb.N (mm^{-1})	0.90	-0.14	0.94	0.093	6.2
	Tb.Th (mm)	1.04	0.01	0.68	0.006	6.9
	Tb.Sp (mm)	1.43	-0.08	0.92	0.096	14.6
	Ct.Th (mm)	0.95	0.23	0.83	0.084	10.2
	Strength (N)	0.97	-32.2	0.99	96.22	3.3
<u>Common volume</u>	**vBMD (mgHA/cm^3)**	1.00	-8.36	0.99	8.313	2.4
3DpQCT vs. XtremeCT scaled down	**BV/TV (%)**	1.02	-0.01	0.99	0.004	3.9
	Tb.N (mm^{-1})	0.84	0.05	0.95	0.087	6.0
	Tb.Th (mm)	0.72	0.03	0.53	0.007	8.3
	Tb.Sp (mm)	1.06	0.05	0.95	0.074	10.8
	Ct.Th (mm)	1.01	0.00	0.96	0.041	4.5

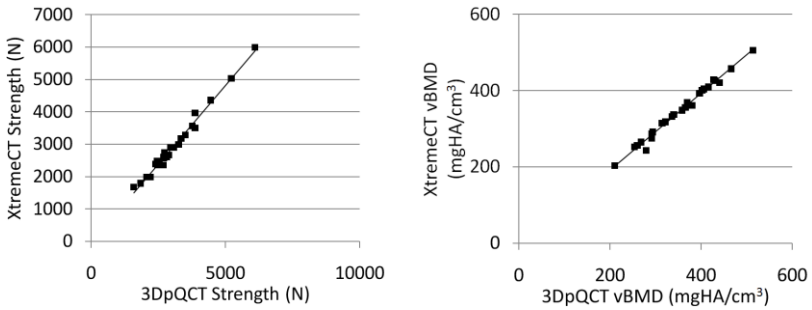

Figure 1. Scatter plot of strength for scans at the same resolution on the left and vBMD for the common volume only on the right