Intra- and Inter-Operator Variability in HR-pQCT Scan Positioning

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The role of the operator in HR-pQCT precision has not been evaluated, and may be critical for multicenter cross-sectional studies. At scan time, the operator acquires a 2D projection of the limb (scout image) and manually identifies an anatomic landmark, which determines the scan region. Variability in landmark identification impacts bone measurements, especially in the radius where morphological variations are greater. In this study, our goal was to quantify long-term and short-term intra-operator precision of landmark placement, variability among operators at multiple imaging centers, and the corresponding effect on bone measurements.

We reproduced the acquisition interface of the HR-pQCT system (XtremeCT, Scanco Medical AG) to simulate the process of identifying anatomic landmarks in the scout image. To evaluate intra-and inter-operator precision, 56 double stack scans (220 slices, centered on the standard scan region) and corresponding scout images were acquired at two imaging centers. We were thus able to virtually localize standard 110-slice sub-volumes for analysis, based on landmark positions retrospectively identified in the simulation environment. For both radius and tibia, we evaluated (1) long-term intra-operator variability for 2 operators (over 6-24 months); (2) short-term intra-operator precision for 7 operators in a subset of 15 images, positioned three times in a random order; (3) inter-operator precision for 5 operators. For each experiment, we calculated standard deviation of the landmark position (SD_{RMS}) and coefficient of variation (CV_{RMS}) of primary bone densitometric and structure parameters.

Precision results are in Table 1. Positioning for the tibia was highly reproducible, even across multiple operators (CV_{RMS}<1.8%). In contrast, errors for the radius were significantly greater ($p<0.05$), and particularly high across multiple operators (SD_{RMS}=0.56mm, CV_{RMS}=6.6% for Ct.Th). At both sites, Ct.Th was considerably more sensitive to position variability than density and structure measures.

In conclusion, we found that HR-pQCT scan positioning for the tibia is highly reproducible over time and across operators. Greater positioning variability is observed for the radius, leading to relatively high precision errors. Efforts to define more reproducible landmarks, establish more rigorous operator training procedures, and develop automated scan positioning methods should be pursued to minimize the effects of operator variability in the radius.

RADIUS	**Scout Positioning Precision**	**Impact on Bone Parameter Measurements**					
		BMD	Ct.BMD	Tb.BMD	Ct.Th	Tb.N	Tb.Sp.SD
	SD_{RMS} [mm]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]
Short-term intra-operator							
(n = 15 x 3 repetitions)	0.24 ± 0.05	0.89 ± 0.39	0.60 ± 0.24	0.35 ± 0.13	2.13 ± 0.86	0.36 ± 0.13	0.64 ± 0.26
Long-term intra-operator							
(n = 27)	0.31	1.21	0.97	0.58	3.22	0.69	1.56
Inter-operator							
(n = 53)	0.56	2.67	2.08	1.01	6.60	1.31	2.40

TIBIA	**Scout Positioning Precision**	**Impact on Bone Parameter Measurements**					
		BMD	Ct.BMD	Tb.BMD	Ct.Th	Tb.N	Tb.Sp.SD
	SD_{RMS} [mm]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]	CV_{RMS} [%]
Short-term intra-operator							
(n = 15 x 3 repetitions)	0.13 ± 0.07	0.18 ± 0.08	0.16 ± 0.08	0.21 ± 0.14	0.79 ± 0.38	0.26 ± 0.10	0.48 ± 0.22
Long-term intra-operator							
(n = 28)	0.35	0.63	0.49	0.77	2.54	0.78	1.30
Inter-operator							
(n = 56)	0.32	0.46	0.35	0.55	1.74	0.61	1.21

BMD = bone mineral density.
SD_{RMS} [mm] = Root mean square of standard deviations.
CV_{RMS} [%] = Root mean square of percentage coefficient of variations.
For short-term intra-operator precision and impact on bone parameter measurements, values refer to mean ± standard deviation.

Table 1. Long- and short-term intra- and inter-operator variability for HR-pQCT acquisitions of radius and tibia.