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The 2nd generation of HR-pQCT: progresses in bone microstructure assessment with 61 µm voxel size *in vivo* scans

Nicolas Vilayphiou, Stefan Hämmerle and Bruno Koller [1]

[1] Scanco Medical AG, Fabrikweg 2, CH-8306 Brüttisellen, Switzerland

Introduction

We developed in 2004 a novel high resolution peripheral quantitative tomography (HR-pQCT) scanner dedicated to bone microstructure assessment at the ultradistal radius and tibia. This 1st generation of HR-pQCT, XtremeCT (XT-I, Scanco Medical AG, Bruttisellen, Switzerland), proposes a 2.8min scan over a 9.02 mm region, with 82 µm voxel size for radiation 3 µSv dose [*Laib et. al – Bone 1999*].

Its accuracy, variability and interest mainly in the field of osteoporosis research has been widely reported, as the XT-I has been subject of about 200 original scientific papers published in peer reviewed journals since 2004 [*Cheung et. al – Curr. Ost. Reports 2013*].

Experience has shown that movement artifacts affect tremendously XT-I scans, at the ultraradius particularly. They impact dramatically the reproducibility of the measurements, and reduce the number of valid scans in longitudinal studies on bone fragility or osteoporosis treatment efficacy [*Pialat et. al – Bone 2011*].

Figure 1: XtremeCT

XtremeCT II

The movement artifact issue has motivated the design of a new HR-pQCT scanner: XtremeCT II (XT-II).

The primary goal for this project was to modify the hardware to reduce the scan time by a factor of 2, and to maintain the image quality and radiation dose.

2 prototypes have been built, using a complete new set of:

- High-voltage generator
- X-ray tube
- CCD Detector

Also, a new forearm cast has been designed to minimize the patient movements

The new detector also allows for higher resolution scans *in vivo*: **61 µm voxel size** be achieved, for a 2 minutes scan irradiating less than 5 µSv.

Scanner Specifications Summary

	XtremeCT I	XtremeCT II	
	XT-I	Low resolution "XT-I mimic"	High resolution
X-ray Tube			
Voltage [kV]	60	68	68
Intensity [µA]	900	1460	1460
Scan protocol			
Integration Time [ms]	100	36	43
Projections [#]	750	750	900
Radiation [µSv]	< 3	< 3	< 5
Scan time [min]	2.8	1.4	2
Resolution			
Voxel size [µm]	82	91	61
MTF @ 10% [µm]	130	120	95
Field of View			
Diameter [mm]	126	140	140
Stack height [mm]	9	10	10
Number of slices [#]	110	110	164
Max scan length [mm]	150	200	200

Material & Methods

A forearm phantom (Radiology Support Devices, Long Beach, CA) was scanned to compare results across the different scanners and scan protocols.

XT-I scan was the reference to address compatibility between the two scanners, whereas XT-II scan at native 30 µm voxel size served as a gold standard to address the accuracy of all measurements.

Lower resolution scans (82 and 91 µm) were analyzed with the standard evaluation already used in XT-I.

High resolution scans (61 and 30 µm) were completely analyzed using direct threshold segmentation, without using plate model assumptions (to assess trabecular thickness for example).

Results are presented for Trabecular density (Tb.vBMD), number (Tb.N), thickness (Tb.Th) and bone volume fraction (BV/TV).
Cortical parameters presented are the Cortical density (Ct.vBMD), thickness (Ct.Th) and porosity (Ct.Po).

Figure 2: Forearm phantom and the new forearm cast

Results

As expected from the original specifications, the lower resolution XT-II scan gave comparable results to XT-I, excepted for Tb.N where it was lower.
Compared to the 30 µm scan, both low resolution scans overestimated Tb.N, whereas Tb.Th and Ct.Po were underestimated.

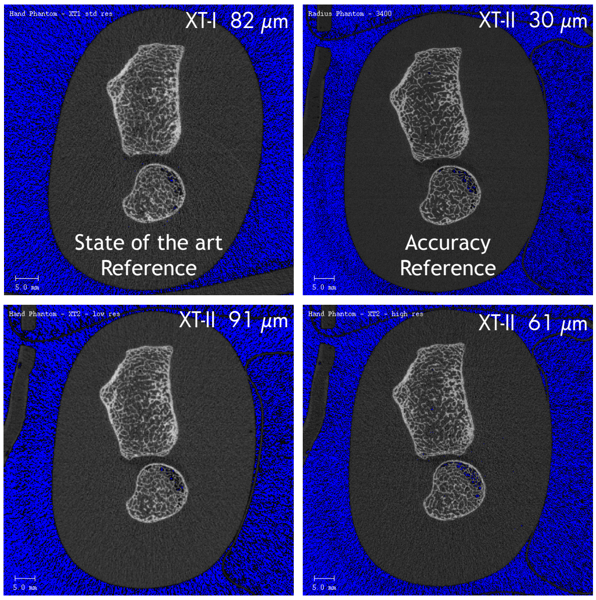
The 61 µm scan was more accurate with Tb.N=1.11 and Tb.Th=241, compared to 1.05 and 239 obtained at 30 µm. Ct.Po was also more accurate compared to lower resolution scans.

Microarchitecture results

	Scan protocol			Trabecular bone				Cortical Bone		
Scanner	Voxel size [µm]	Dose [µSv]	Scan Time [min]	Tb.vBMD [mgHA/ccm]	BV/TV [%]	Tb.N [1/mm]	Tb.Th [µm]	Ct.vBMD [mgHA/ccm]	Ct.Th [mm]	Ct.Po [%]
XT-I	82	3	2.8	239	19.9*	1.58	126*	904	0.93	4.2
XT-II	91	3	1.4	232	19.4*	1.21	155*	936	1.02	3.1
XT-II	61	5	2.0	235	20.9	1.11	241	1013	1.07	5.9
XT-II	30	84	16.5	252	18.6	1.05	239	965	0.91	10.4

**derived from Tb.vBMD and Tb.N*

Scan Previews



Discussion and Conclusion

Based on those preliminary data, we expect our prototypes to fulfill more than their primary goal:

- We managed to keep the same image quality and radiation dose, and **reduce by half** the scan time compared to XT-I standard in vivo scan (1.4 vs 2.8 min).
- The new detector allows for higher resolution scans in clinical setup. **A 61 µm scan can be done *in vivo* for less than 5 µSv radiation in 2 min**, which is still quicker than the XT-I scan (2.8 min).
- For large bone specimens, ***ex vivo* scans could reach 30 µm voxel size**.

We expect the reduced scan time will help to minimize motion artifacts. From this the scans quality should increase, hence diminishing the patient-specific variability on the data. This scanner should provide better data for longitudinal clinical studies.
We are currently conducting a more exhaustive comparison with XT-I to confirm those first results, based on a cross calibration microarchitecture phantom set [*Burghardt et.al – JBMR 2013*].

However, *in vivo* cross calibration is still needed to validate the compatibility with XT-I.
And particularly, the efficacy of the new hand cast needs to be addressed.

Overall, studies on bone deterioration or on osteoporosis treatment efficacy should all benefit from this new HR-pQCT scanner.
Especially as XtremeCT II will make possible 61 µm scans for the 1st time in clinical research.

Scanco Medical AG
Fabrikweg 2, CH-8306 Brüttisellen, Switzerland
www.scanco.ch, info@scanco.ch