Quantitative assessment of bone microarchitecture in the human knee using photon-counting CT is feasible

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Introduction

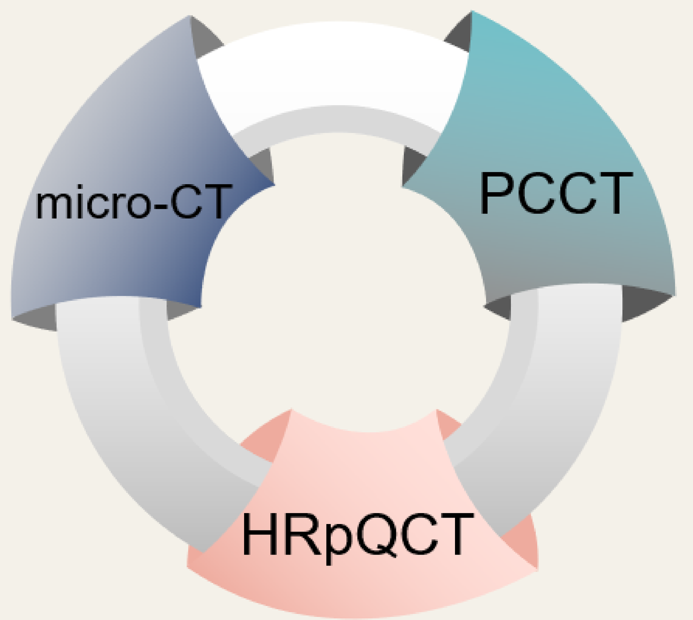
Visualization and quantification of bone microarchitecture are important in bone growth, aging, and disease studies. Bone microarchitecture can be assessed non-invasively using micro-computed tomography (micro-CT). While it is considered the gold standard for non-invasive imaging of bone, its applications have been limited due to the small field of view (FOV) [1, 2]; more importantly, usage is limited to *ex vivo* analyses, hence, it cannot be used to evaluate bone and bone adaptive responses in a patient. Clinical CT systems provide larger FOV and can be used *in vivo*, but do not provide bone microarchitecture. High-resolution peripheral quantitative CT (HR-pQCT) is considered the gold standard for *in vivo* imaging but is limited in use because of the rather small FOV and a relatively long acquisition time [1]. Photon-counting CT (PCCT) is a promising alternative with a larger FOV and much shorter scanning time. However, it is unknown whether bone microstructure can be quantified using PCCT.

Aim of the study

The aim of this study was to evaluate the accuracy of PCCT for the quantification of bone microstructural parameters in the human knee and compare it to HR-pQCT and micro-CT.

Specifications

Microstructural imaging
Small FOV
Ex vivo imaging
Long exposure time



Specifications

Microstructural imaging feasible?
Large FOV
In vivo imaging
Short exposure time

Specifications

Microstructural imaging
Small FOV
In vivo imaging
Moderate exposure time

Methods

Specimen preparation and medical imaging

After obtaining ethical approval, five human cadaveric knee was scanned with a PCCT scanner at an in-plane resolution of 0.14 mm and slice thickness of 0.10 mm. Next, the specimen was scanned with HR-pQCT scanner at an isotropic voxel size of 0.060 mm. Also, the tibial plateau of the specimen was dissected and scanned using TESCAN UniTOM XL system at an isotropic voxel size of 0.025 mm (Figure 1). Scanning parameters are given in Table 1.

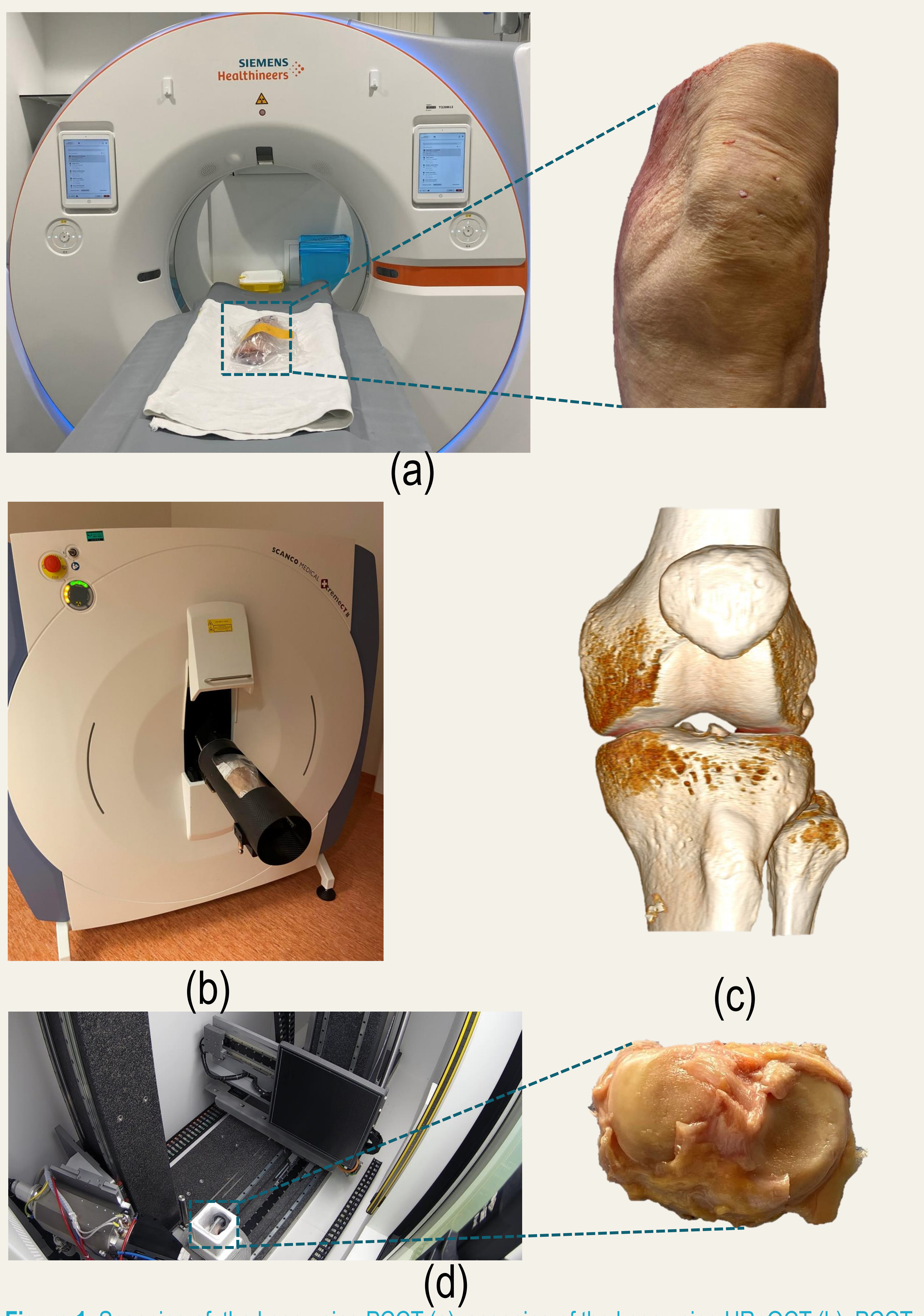


Figure 1. Scanning of the knee using PCCT (a), scanning of the knee using HRpQCT (b), PCCT-based 3D rendering of the knee (c), and scanning of the tibial plateau using TESCAN UniTOM XL system (d).

Table 1. Scanning Parameters of the PCCT Scanner (Siemens Healthineers), HR-pQCT Scanner, XTremeCT-II (Scanco Medical AG), and the UniTOM XL system (TESCAN).

	PCCT	XTremeCT-II	Micro-CT
Energy (Kv)	120	68	150
Current (µA)	2350	1470	182.92
FOV (cm × cm × cm)	wide	14 x 14 x 1.0	5.6 x 5.2 x 6
Projections	1675	1611	3000
voxel size (µm)	146.47	60.07	0.025
Time(one-stack)(seconds)	8	180	2010
Total time (seconds)	8	360-540	4020

VOIs definition

Volumes of interests (VOIs) were defined in the load-bearing regions of the tibial and femoral condyles. Three cylindrical volumes (anterior, central, and posterior) with a diameter of 12 mm and overlap of 2 mm were indicated in the medial and lateral condyle, each subdivided in three volumes of 2.5 mm height [2] (Figure 2), resulting in 36 VOIs per knee.

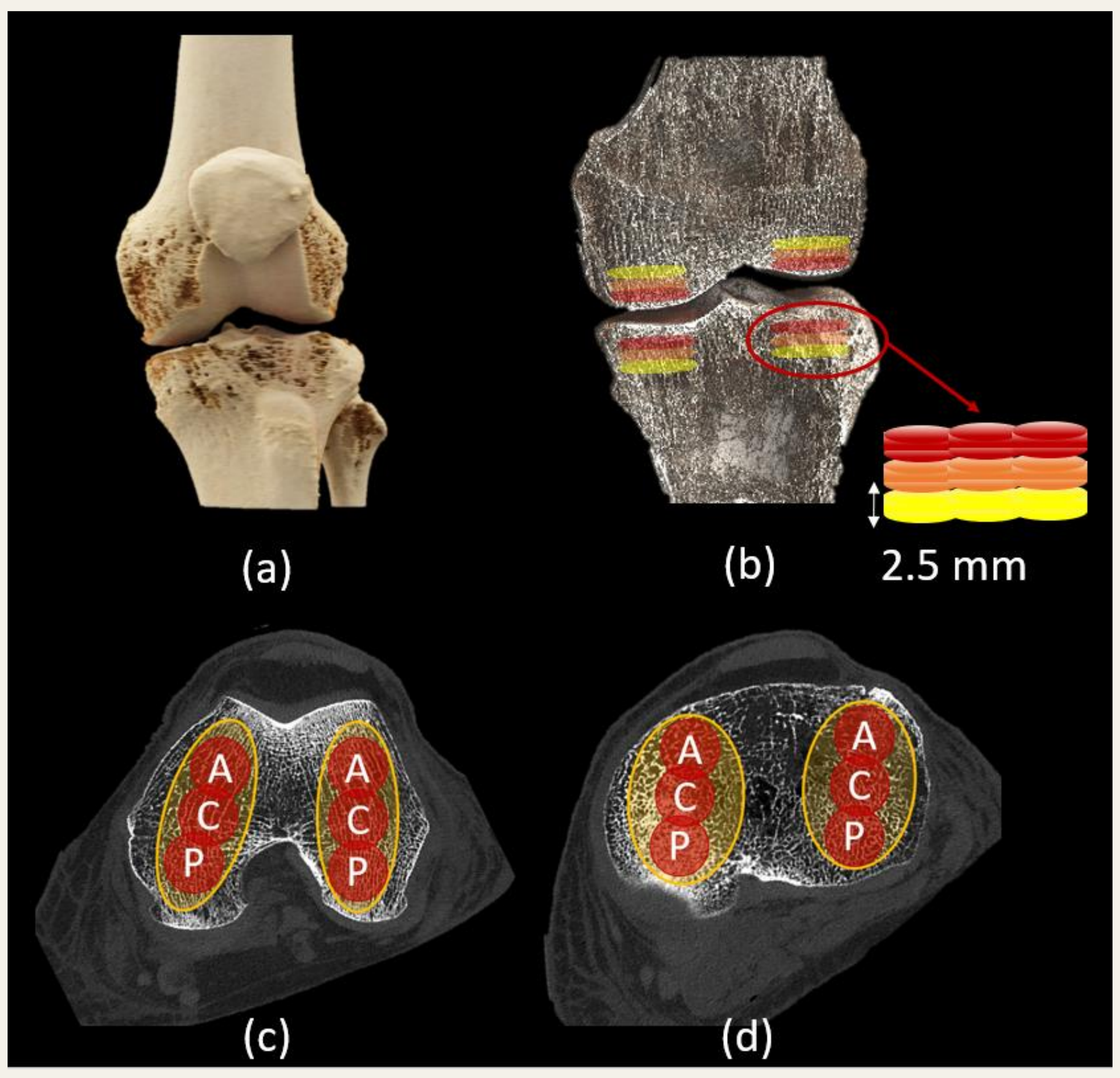


Figure 2. PCCT-based rendering of the knee (a); location of the VOIs in the coronal view (b), in the femoral condyle (c), and in the tibial condyle (d).

Registration

Identical VOIs were mapped in PCCT, HR-pQCT, and micro-CT images using a multiresolution mutual information image registration (Figure 3). Specifically, a rough initial alignment was conducted using SimpleITK library in python. That was done by first aligning the centers of geometry, and secondly by determining the rigid transformation of full bone masks based on the calculation of principal axes of inertia. The final multiresolution registration was done in Elastix using the initial transformation matrix achieved by SimpleITK.

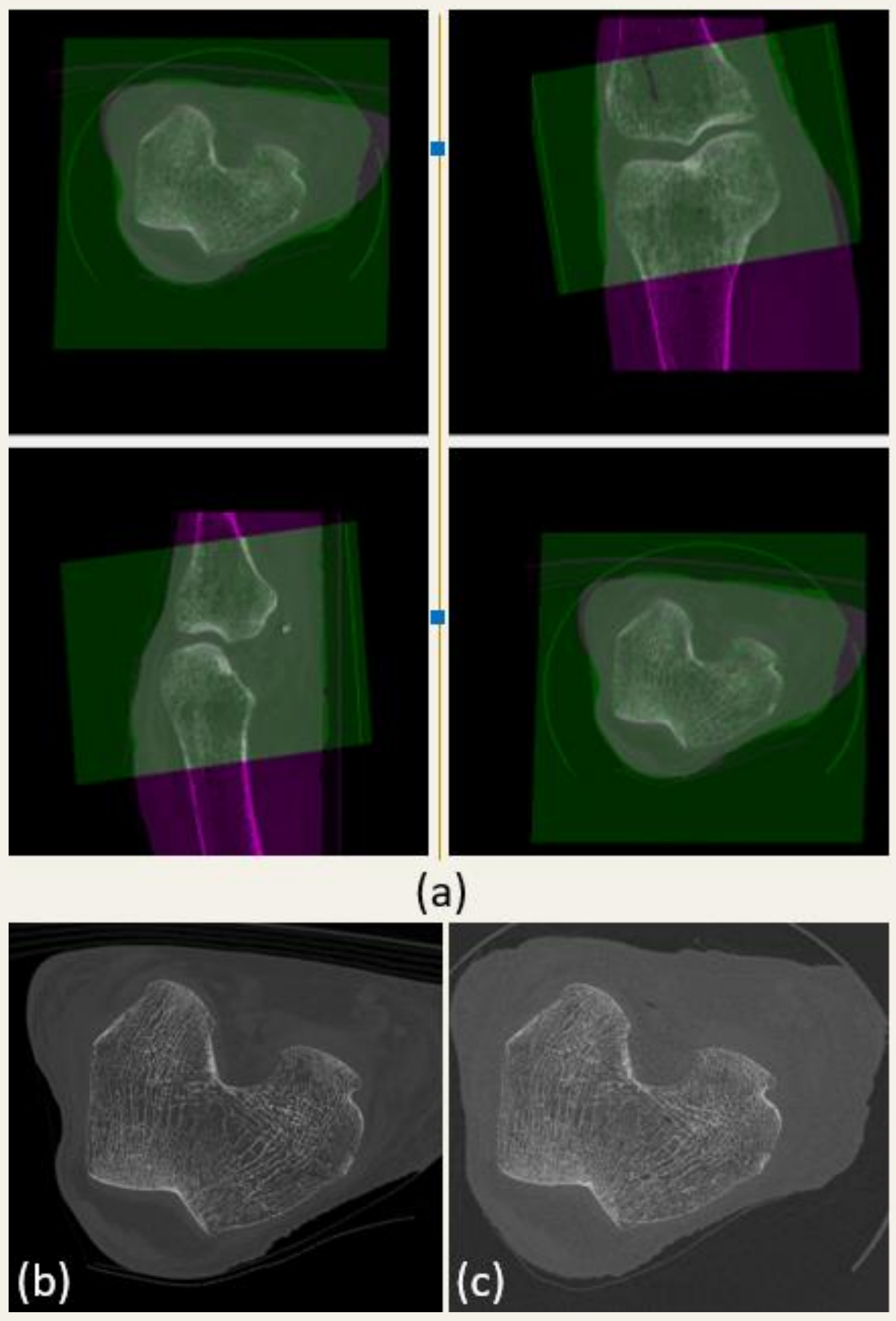


Figure 3. PCCT overlaid on registered HR-pQCT (a). One slice of the PCCT scan (b) and registered HRpQCT image (c)

Results and Discussion

In five knees, 180 VOIs were evaluated to quantify bone microstructure using three different image modalities of micro-CT, HRpQCT, and PCCT. BV/TV as measured with PCCT correlated well with BV/TV as measured with micro-CT and HRpQCT ($R^2 \geq 0.87$, Figure 4). The overestimation of trabeculae and the loss of thin trabeculae in PCCT resulted in larger values of BV/TV compared to micro-CT and HRpQCT. The most association between PCCT and both micro-CT and HRpQCT was found for BV/TV ($R^2 \geq 0.87$, Table 2). Correlations between PCCT and micro-CT ($R^2 \geq 0.69$, Table 2) were lower than PCCT and HRpQCT ($R^2 \geq 0.80$, Table 2).

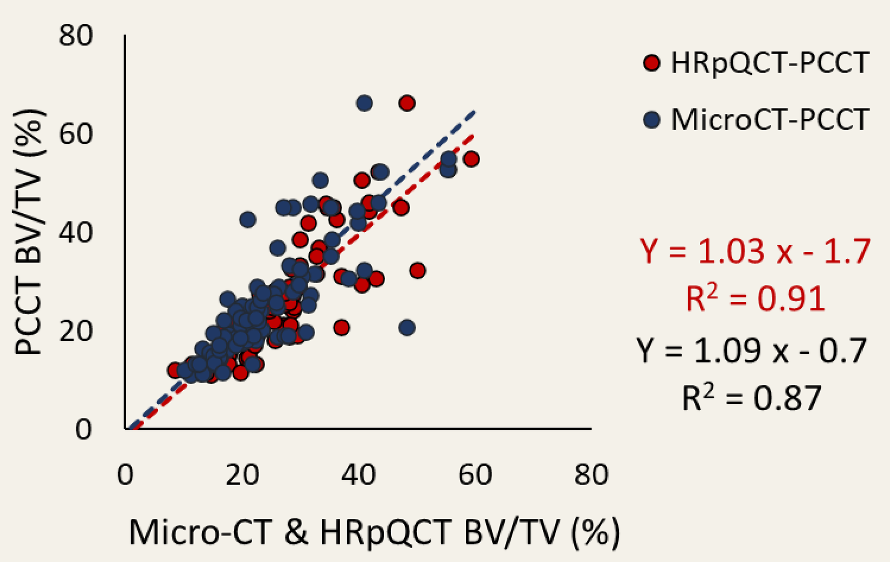


Figure 4. Micro-CT- and HR-pQCT- based BV/TV correlated to PCCT- based BV/TV (36 VOIs).

Table 2. Correlation between PCCT, HR-pQCT, and micro-CT- based parameters in 36 VOIs.

	R^2, *p (PCCT-HRpQCT)*	R^2, *p (PCCT-Micro-CT)*
BV/TV	0.91, < 0.001	0.87, < 0.001
Tb.Th	0.83, < 0.001	0.79, < 0.05
Tb.Sp	0.80, < 0.001	0.81, < 0.001
Tb.N	0.85, < 0.001	0.69, < 0.05
SMI	0.88, < 0.001	0.84, < 0.001
SBP.Th	0.88, < 0.001	0.76, < 0.05
SBP.Po	0.81, < 0.05	0.84, < 0.001

Conclusion

The good agreement observed between PCCT and micro-CT, the gold standard for ex vivo scanning, as well as between PCCT and HRpQCT, considered as the gold standard for in vivo scanning, supporting the potential of PCCT as a promising technique for visualizing and quantifying bone microstructure. Although the trabecular geometry of the knee bones was distinguishable, but the resolution of the PCCT was found to be a limitation in accurately determining bone parameters. Specifically, the correlation between PCCT and micro-CT is not as strong for the trabecular number (Tb.N) and trabecular thickness (Tb.Th) parameters compared to the correlation between PCCT and micro-CT for the BV/TV parameter. Further investigations will be conducted to expand the sample size and include a larger number of knees with a broader range in BV/TV, in order to corroborate and extend the findings of this study.

References

[1] Mys *et al*., JBMR 34:867-874, 2019.
[2] Kroker *et al*., Bone 97:43–48, 2017.

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