Photon-counting CT appears promising in quantifying bone microstructure in the knee

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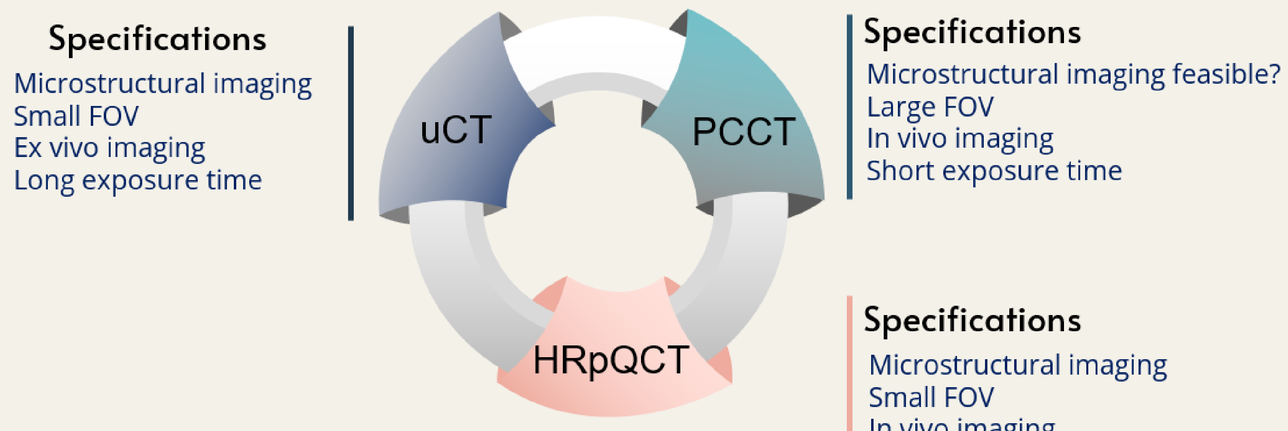
Introduction

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 (µCT). 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 uCT.



Methods

Specimen preparation and medical imaging

After obtaining ethical approval, one 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.

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

	PCCT	XTremeCT-II	uCT
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

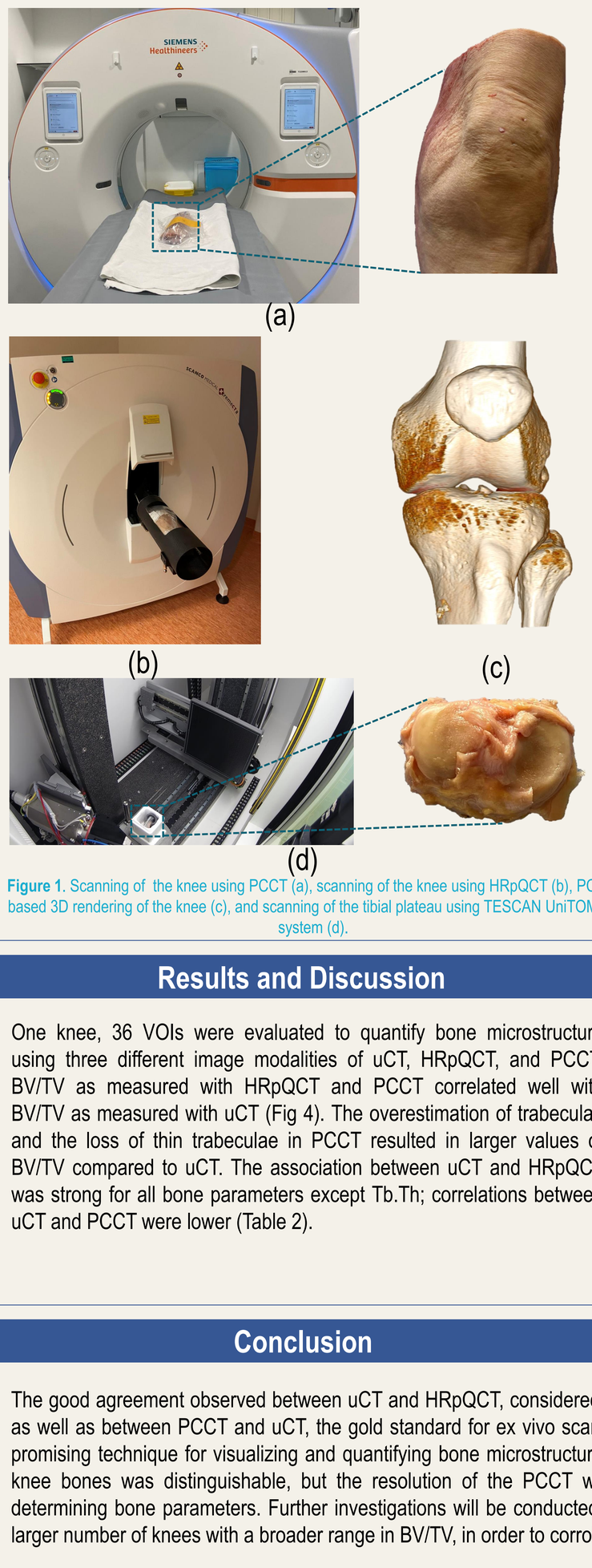


Figure 1. Scanning of the knee using PCCT (a), scanning of the knee using HRpQCT (b), PCCT-based 3D rendering of the knee (c), and scanning of the tibial plateau using TESCAN UniTOM XL system (d).

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] (Fig. 2), resulting in 36 VOIs.

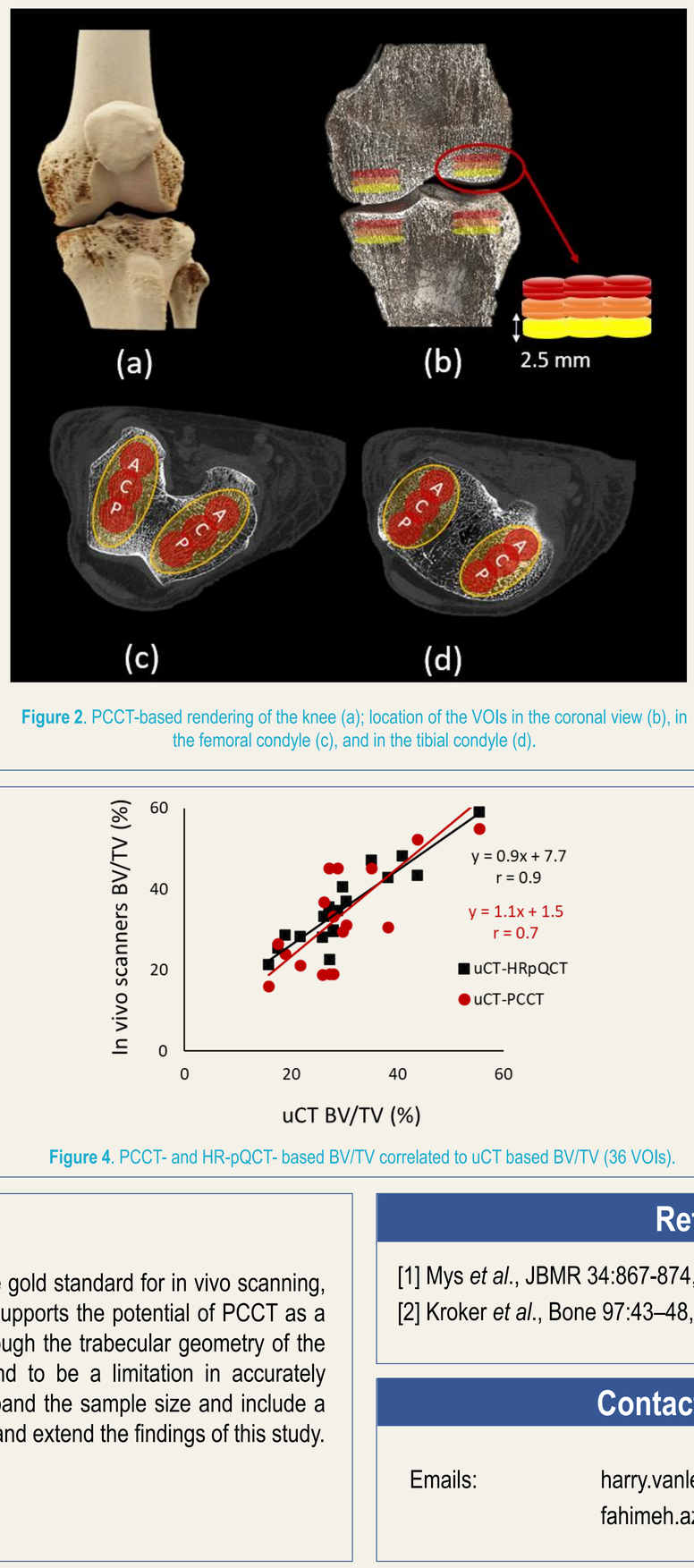


Figure 2. PCCT-based rendering of the knee (a); location of the VOIs in the coronal view (b), in the femoral condyle (c), and in the tibial condyle (d).

Registration

Identical VOIs were mapped in PCCT, HR-pQCT, and uCT images using a multiresolution mutual information image registration (Fig. 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.

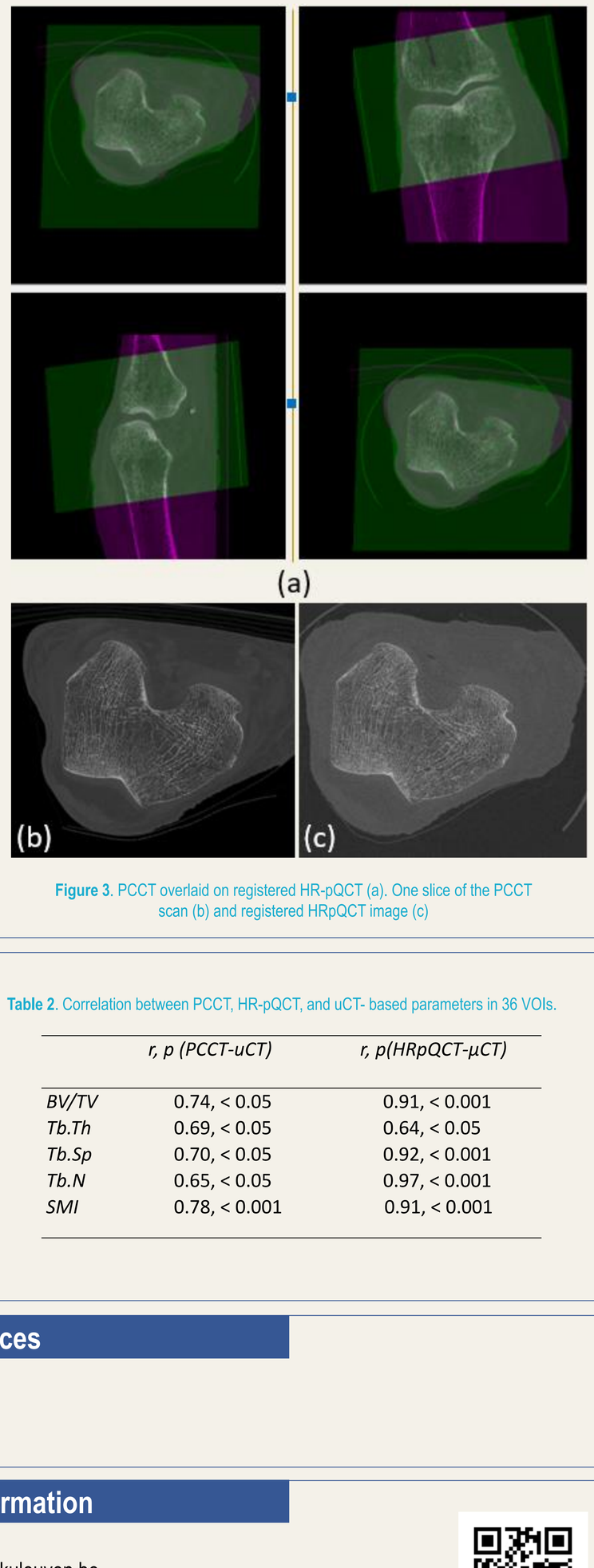


Figure 3. PCCT overlaid on registered HR-pQCT (a). One slice of the PCCT scan (b) and registered HRpQCT image (c)

Results and Discussion

One knee, 36 VOIs were evaluated to quantify bone microstructure using three different image modalities of uCT, HRpQCT, and PCCT. BV/TV as measured with HRpQCT and PCCT correlated well with BV/TV as measured with uCT (Fig 4). The overestimation of trabeculae and the loss of thin trabeculae in PCCT resulted in larger values of BV/TV compared to uCT. The association between uCT and HRpQCT was strong for all bone parameters except Tb.Th; correlations between uCT and PCCT were lower (Table 2).

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

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

	r, p (PCCT-uCT)	*r, p(HRpQCT-µCT)*
BV/TV	0.74, < 0.05	0.91, < 0.001
Tb.Th	0.69, < 0.05	0.64, < 0.05
Tb.Sp	0.70, < 0.05	0.92, < 0.001
Tb.N	0.65, < 0.05	0.97, < 0.001
SMI	0.78, < 0.001	0.91, < 0.001

Conclusion

The good agreement observed between uCT and HRpQCT, considered as the gold standard for in vivo scanning, as well as between PCCT and uCT, the gold standard for ex vivo scanning, supports 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. 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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