CLINICAL APPLICABILITY OF ADVANCED TRABECULAR MICROARCHITECTURE ASSESSMENT USING MULTI-DETECTOR COMPUTED TOMOGRAPHY

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Purpose

Computational trabecular microarchitecture assessment was recently proposed that cluster voxels in high-resolution peripheral quantitative computed tomography (HR-pQCT) images into one of three trabecular microarchitectural classes (TMACs) using pattern recognition methods applied to textural and orientation features.

Motivated by TMACs, that have shown promise in predicting fracture risk in osteoporotic women, we extend and evaluate the method to multi-detector CT (MDCT) images in order to validate their reproducibility at lower, anisotropic resolutions, which can be acquired during clinical routine.

Patients and Imaging

12 intact right forearms were obtained from human cadavers of males (n=4) and females (n=8). The specimens were initially frozen, during which time the imaging was performed. HR-pQCT scans were performed using the standard in vivo protocol of scanner. The clinical CT images were acquired using a 64-slice scanner with two optimized protocols, differing only in tube current-time product (UHklin: 150mAs; UHmax: 300mAs).

Parameters	Units	UHklin	UHmax
tube potential	[kV]	140	140
tube current	[mAs]	150	300
rotation time	[s]	1.5	1.5
slice collimation	[mm]	2×0.5	2×0.5
slice width	[mm]	0.5	0.5
resolution matrix	[mm]	768^2	768^2
resolution mode	[pixel]	ultra high	ultra high
kernel		D	D
FOV	[cm]	< 24	< 24
scan mode		axial	axial
scan type		head	head
CTDI$_{vol}$	[mGy]	77.5	155

Fig 1: (A) Axial ultra high resolution radius protocols for MDCT scanners (Philips Brilliance 64, The Netherlands), with two exposures (UH1 and UH2); (B) Scan region of the radius in HR-pQCT and MDCT scans.

Methods

1. Texture Feature extraction of bone microarchitecture

Trabecular Microarchitecture Class (TMAC)

"Bone Quality Maps" [1]:

TMAC 1 (red) - thick trabeculae with low intertrabecular spacing
TMAC 2 (green) - represents intermediate morphometric quality
TMAC 3 (blue) - inhomogenous & thin trabeculae, poorly connected

Registration of HR-pQCT and MDCT

The registration process was divided into two steps due to different coverage of the scanning region of the radius (Fig 1):

$$\mathcal{T}_x(x) = Rx + t$$

1. Coarse alignment of the overlapping region with coherent point drift (CPD) [2]
2. Microarchitectural refinement of the aligned common region with rigid registration based on sum of squared differences (SSD) [3]

Results

Fig. 2: Comparison of cluster volume fraction (CL.V/TV) for HR-pQCT and MDCT with two different scan protocol UHmax and UHklin. Error bars show standard error in measurement. The star (*) indicates statistical significance between HR-pQCT and the UHklin protocol.

Fig. 3: Classification distribution of each trabecular microarchitecture class (TMAC) by comparing the TMAC classification performance for both scanning protocols (UHklin and UHmax) using MDCT against the validated TMAC method, performed on HR-pQCT images.

HR-pQCT	UHklin			
	TMAC 1 (%)	TMAC 2 (%)	TMAC 3 (%)	Total
TMAC 1	23.87	10.22	0.35	34.43
TMAC 2	9.05	27.36	6.24	42.65
TMAC 3	0.23	4.10	18.60	22.92
Total	33.14	41.67	25.19	100

HR-pQCT	UHmax			
	TMAC 1 (%)	TMAC 2 (%)	TMAC 3 (%)	Total
TMAC 1	23.97	10.01	0.23	34.21
TMAC 2	8.61	28.60	5.28	42.49
TMAC 3	0.18	4.12	19.01	23.30
Total	32.76	42.73	24.51	100

Table 1: Contingency table with relative frequencies based on the total number of cases for both scan protocols

Visualization

Fig. 4: Representative of differences in the trabecular microarchitecture and the TMAC distribution, between the MDCT image using both protocols (UHklin and UHmax) protocol and HR-pQCT

Conclusion

HR-pQCT is a powerful research tool for advanced bone analysis, but its limitations prevent widespread clinical use. Extension of HR-pQCT based algorithms to widely available clinical imaging could have a significant impact on the adoption of quantitative imaging in fracture risk assessment.

We have demonstrated that TMAC mapping, first validated in HR-pQCT imaging, can be adapted to clinical CT images. Example results (Fig. 4) show good qualitative agreement between HR-pQCT and MDCT. TMACs show good agreement despite MDCT having poorer spatial resolution, lower contrast and diminished sharpness. When considering radiation dose, we note that MDCT protocol UHmax outperformed UHklin in terms of overall Dice score by < 2%, but effective dose (ED) was 81.8 µSv for UHklin and 163.5 µSv for UH2. This result suggests that TMAC-based maps can be reliably generated at lower doses.

Future work should focus on further validation of TMACs in MDCT, particularly in high fracture risk anatomies which are not accessible to HR-pQCT imaging (i.e., spine and hip). In addition, further trials should be done to deter- mine if lower-dose scanning protocols can be used to satisfactorily quantify bone microarchitecture in clinical CT.

References

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